SOIL EROSION, DIFFUSE SOURCE POLLUTION AND SEDIMENT PROBLEMS ASSOCIATED WITH MAIZE CULTIVATION IN ENGLAND

by

MOKHTAR BIN JAAFAR

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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(MOKHTAR BIN JAAFAR)

Abstract

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This thesis reports an investigation of soil erosion problems associated with maize cultivation in England. To place the investigation into a broader context, the study commences with a review of soil erosion problems more generally, before focusing on the specific on-site and off-site problems associated with maize cultivation. Agricultural statistics are used to quantify the recent expansion of maize cultivation in England and attention is directed to both the temporal trends and spatial patterns involved. A major expansion of maize cultivation occurred in England between 1990 and 2000. Particular attention is then directed to the expansion of maize cultivation in Southwest England, since this is a very important area for cultivation of forage maize.

Against this general background, a more detailed investigation of soil erosion associated with maize fields and its impact on the local streams and rivers was undertaken. This focused on two river catchments, namely the River Culm above Cullompton, Devon, and the River Tone above Taunton, Somerset. These two basins were selected as having a high density of maize fields within their catchments. A detailed field survey was undertaken to identify all the fields used for maize cultivation in the two catchments during 2004 and the previous two years and to provide a map of their location. More detailed work, aimed at quantifying both gross and net rates of soil loss, was undertaken on six fields selected to be representative of maize fields in the two catchments. Beryllium-7 measurements were used to estimate the erosion associated with a period of heavy rainfall in late December 2004 and early January 2005, when the harvest fields were left in a bare compacted conditions, with little or no vegetation cover and field observations indicated that significant erosion occurred. The results obtained from the beryllium-7 measurements which related only to the short period in late 2004 and early 2005 were complemented by caesium-137 measurements in the same fields which were used to obtain an estimate of the longer-term (i.e. *ca*. 45 years) mean annual erosion rates associated with the more traditional land use that had characterized these fields prior to the introduction of forage maize cultivation. These results indicated that the introduction of maize cultivation increased gross and net rates of soil loss by ca. 4 and 8 times, respectively and significantly increased sediment delivery ratios, resulting in more efficient delivery of sediment from the eroding fields to the streams.

An assessment of the likely impact of sediment mobilised from the maize fields within the catchments of the River Culm and River Tone during winter 2004-5 was made by establishing a sediment monitoring and sampling programme at the downstream gauging stations on these two rivers over the period November 2004 to March 2005. Estimates of the suspended sediment loads of both rivers were obtained for this period and these were compared with an estimate of the total amount of sediment delivered to the water courses in the two catchments from maize fields based on an upscaling of the results obtained from the beryllium-7 measurements undertaken on the six representative fields. Uncertainties regarding both field to channel and within channel

and floodplain conveyance losses precluded definitive comparison of the estimates of the amounts of sediment delivered to the water courses from maize fields with the measured sediment loads. However, the results obtained demonstrated the likely importance of the contribution from eroding maize fields to the suspended sediment loads of the Rivers Culm and Tone during winter 2004-5. The geochemical properties of suspended sediment collected from the two rivers were also compared with the equivalent properties of soil collected from the surface of maize fields within the two study catchments, in order to provide further evidence of the impact of maize cultivation on their suspended loads. The available geochemical data confirmed that much of the sediment transported by the Rivers Culm and Tone could have been mobilized from maize fields, but the lack of detailed geochemical data, precluded a definitive conclusion regarding its source.

The results obtained from the field-based component of the study have been combined with the information on the regional and national patterns of maize cultivation and synthesized to provide a general assessment of the likely environmental impact of maize cultivation in England. This information has in turn been used to consider the potential for developing improved land management practises to reduce the environmental impact of maize cultivation within the context of the EU Common Agricultural Policy (CAP) and the Water Framework Directive (WFD). Finally, recommendations for the further development and extension of the study are provided.

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ABBREVIATIONS

AAPS	Arable Area Payment Scheme
AAS	Atomic Absorption Spectrophotometry
ACL	Agricultural Land Classification
AES	Agri-Environment Scheme
Bq	Becquerel
CAP	Common Agricultural Policy
CEH	Centre for Ecological Hydrology
CIA	Central Intelligence Agency
COGAP	Code of Good Agricultural Practise
CSF	Catchment Sensitive Farming
CSS	Countryside Stewardship Scheme
DC	The number of dairy cows
CS	Countryside Stewardship
DEFRA	Department of Environment, Food and Rural Affairs
DM	Dry matter (maize silage)
DWPA	Diffuse Water Pollution from Agriculture
EA	Environment Agency
EAS	Environmentally Sensitive Areas
ECSFDI	England Catchment Sensitive Farming Delivery Initiative
EL	Edinburgh Library
ELS	Entry Level Stewardship
ESA	Environmentally Sensitive Area
ESS	Environmental Stewardship Scheme
ETDA	Ethylene diamine-tetra acid
EU	European Union
EUWFD	European Union Water Framework Directive
FAO	Food and Agriculture Organization
FEP	Full energy peak
FER	Farm Environment Record
FMD	Foot and Mouth Disease
FRP	Filterable reactive P
GAEC	Good Agricultural and Environmental Condition
GER	Gross erosion rate
GIS	Geographical Information Systems
HLS	Higher Level Stewardship
HPGe	High-purity germanium
IACR	Institute of Arable Crops Research
IGER	Institute of Grassland and Environmental Research
LCM	Land Cover Map
LFA	Less Favoured Area
MAFF	Ministry of Agriculture, Fisheries and Food
MC	Area under maize cultivation
NER	Net erosion rate
NVZ	Nitrate Vulnerable Zones
OELS	Organic Entry Level Stewardship
POS	Protection of Soil

POW	Protection of Water
RBMP	River Basin Management Plan
RBPG	River Basin Planning Guidance
RPA	Rural Payment Agency
RQO	River Quality Objective
SDA	Severely Disadvantage Areas
SDR	Sediment delivery ratio
SFPS (SFP)	Single Farm Payment Scheme
SMP	Soil Management Plan
SMR	Statutory Management Requirements
SOAEFD	The Scottish Office Agriculture, Environment and Fisheries Department
SPS	Single Payment Scheme
SSC	Suspended sediment concentration
FTU	Formazin Turbidity Unit
SSL	Suspended sediment load
SY	Sediment yield
TPO	Tree Preservation Orders
TSE	Transmissible Spongiform Encephalopathies
USLE	Universal Soil Loss Equation
WFD	Water Framework Directive

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CHAPTER 1: INTRODUCTION

1.1 Overview

Globally, land degradation is studied by scientists, such as geomorphologists, engineers and ecologists in order to understand physical processes. In particular, soil erosion is one of the physical processes of land degradation that can cause serious environmental problems.

Pimentel and Kounang (1998) estimated that about 75 billion tonne of soils are eroded from the world's terrestrial ecosystems each year. In most cases, agricultural land is the most at risk of being eroded, losing soil at rates ranging from 13 t/ha/yr to 40 t/ha/yr. The authors also state that worldwide, erosion rates range from a low of 0.001-2 t/ha/yr on relatively flat land with grass and/or forest cover to rates ranging from 1-5 t/ha/yr on mountainous regions with normal vegetation cover. Many scientists also agree that the rate of soil erosion, either by wind or water, frequently exceeds the rate of soil formation. For example, over a period of 100 years at an erosion rate of 2 t/ha/yr on 10 ha, erosion deposits soil equivalent to about 1 ha of land with a soil depth of 15 cm (Pimentel and Kounang, 1998).

Agricultural land is probably the greatest contributor to soil loss in the world. According to the FAO (2003), about one-third of agricultural land is planted for crops, and cropland is more highly susceptible to erosion as a result of tillage practises, which expose the soil to wind and water erosion. Serious on-farm soil erosion reduces overall crop productivity. This is associated with loss of organic matter and plant nutrients in the erosion process, together with a reduction of soil depth. In addition, soil erosion by water on slopes will decrease the infiltration capacity and this will result in increased runoff and decreased water-storage. Wiebe (2003) estimated that the global crop production loss caused by erosion is highest for potatoes at 0.6% per year, followed by millet (0.48%), and maize (0.42%). It has also been estimated that the total anual cost of erosion from agricultural land in the USA is about US$44 billion per year, which is equivalent to US$247 per ha of cropland and pasture (Eswaran et al. (various years) in Wiebe, 2003).

Off-farm impacts of soil erosion from agricultural land are varied, but serious environmental problems on agricultural terrain commonly start when runoff transporting soil particles reaches water bodies or streams. This will affect the biological status of water systems, degrading water quality and threatening aquatic life, and can cause flooding when overflow occurs because of sedimentation. The cost of the damage associated with the off-farm impacts of soil erosion is difficult to quantify precisely but it is generally high and of a similar magnitude to the on-site costs, and perhaps higher.

1.2 Soil Erosion on Agricultural Land in England

Archaeological studies have suggested that soil erosion has probably taken place in England since the clearance of land for agriculture in the Bronze Age (Bell and Boardman, 1992). However, soil erosion has really only been recognized as a serious environmental problem in England since the 1970s, and is often associated with negative impacts resulting from inappropriate land management. Robinson (1999) listed a number of studies of soil erosion in the United Kingdom that demonstrate the seriousness of soil erosion on agricultural land in the region. This include Reed (1979), Boardman (1984), and Robinson and Blackman (1990). Prior to the 1970s, most soil erosion problems in the United Kingdom were associated with the upland areas and were caused by overgrazing. This included upland peat moors where sheep undercut the turf and damaged and exposed the bare surface to wind erosion, especially during dry periods. However since then, soil erosion by water has increased in England and more arable land is at more risk of erosion by water than by wind, especially on sandy and sandy loam soils (Evans, 1990; 1992). Morgan (1985) noted that most of these soils used for arable farming in the Midland and Eastern counties of England are readily susceptable to soil erosion after sudden storms. In addition, rilling of arable land is more widespread on sandy soils, and is also common on light loams and loamy soils with a high silt content (Evans, 1992).

The serious impact of soil erosion in England has generally been blamed on adverse changes associated with agricultural activities, such as mismanagement and environmentally unfriendly attitudes among farmers and harvest contractors. According to Unwin's (2001) classification of agricultural land in England, it is the areas below an altitude of 150 m and rainfall of over 1000 mm, with intensive cropping, which are most at risk of soil erosion. Solomon (1997) reported that the total area of arable crops considered as being at very high risk of water erosion in England is 17,990 ha with 62,170 ha of crops at high risk, and 74,590 ha of crops at locally high risk.

Twenty years ago most agricultural land was used for the growing of spring-sown barley and winter wheat and the production of grass for cattle and sheep. However, in the 1980s and 1990s, and in more recent years, the arable land has been autumn-drilled for winter cereals, in response to the better yields. The crop cover provided by winter cereals is low throughout the winter period and exposes the soil surface to heavy rainfall, which can create rills and gullies within the fields and cause floods downstream. Currently, maize growing is becoming a major environmental issue in England, due to its association with bare soil during the late autumn of winter period, which frequently coincides with periods of heavy rain. A more detailed discussion on this with particular issue will be provided in the next section (1.3).

The causes of soil erosion on agriculture land are mainly related to on-farm activities, and are the result of factors such as the failure of agricultural policy and socio-economic pressure. Inman (2006) discussed some of the causes of soil erosion on agriculture land in England and Wales. He suggests that one of the key on-farm activities that encourages soil erosion is the growing crops on inappropriate land. This is closely related to unsuitable soil types which are too fragile to resist the erosive energy of rainfall and snow melt. Crops have also been grown on more marginal land, particularly on steep slopes. Rills may develop during periods of heavy rainfall.

Another significant cause of soil erosion is inappropriate timing of agricultural practises. This relates to ploughing and harvesting land during winter periods or under wet conditions. Ploughing and harvesting using heavy machinery can cause soil compaction and destroy soil structure. These conditions will increase surface runoff and soil erosion that cause the depletion of soil nutrients.

Late sowing in the autumn and delayed harvesting in the late autumn of winter periods will increase the risks of soil erosion. Both situations will leave the land with a lack of ground cover to protect the soil surface from rainfall impact. Exposure of bare soil surfaces to winter rainfall is likely to result in the development of rills and gullies, and these will increase the rate of on-site soil erosion.

Most of the measurements of water erosion in England have recorded relatively low rates of soil loss. For example, Walling and Quine (1991) reported a net erosion rate from a sugar beet field at Rufford Forest Farm in Nottinghamshire of 10.5 t/ha/yr. The average soil erosion rate from bare loamy sands of the Bridgnorth series in Shropshire has been reported as 11.3 t/ha/yr (Fullen, 1992). Brazier (2004) listed the results of soil erosion studies undertaken at various places in the UK, involving various soil types, and his data indicated that average soil erosion rates range from 0.22 to 4.89 t/ha/yr. However, studies based on ^{137}Cs surveys reported by Walling & Quine (1995) indicated that soil erosion rates at various places in the UK ranged from 0.6 to 10.5 t/ha/yr. Brazier (2004) showed that based on several field survey in the UK, the erosion rates ranged from 0.001 to 6.3 t/ha/yr in various soil types. In addition, Morgan (1985) reported that the erosion rates in the UK from cultivated land ranged from 0.01 to 0.30 kg/m^2/yr, and 1.00 to 4.50 kg/m^2/yr from bare soil. These findings show that the erosion rates in the UK are relatively low compared with other countries in the world. As an example, the erosion rates from cultivated land and bare soil in Belgium ranged from 0.30 to 3.00 and 0.70 to 8.20 kg/m^2/yr respectively, it ranged from 0.50 to 17.00 and 0.40 to 9.00 kg/m^2/yr in the USA, and in China, it ranged from 15.00 to 20.00 and 28.00 to 36.00 kg/m^2/yr (Morgan, 1985). All of these findings support Morgan's (1985) conclusions that very low annual soil erosion rates were caused by water erosion. Relatively, the soil erosion rates is also low compared with the soil erosion rates in Asia, Africa, and South America, averaging 30 to 40 t/ha/yr (Pimentel *et al*., 1995).

Generally, most soil erosion events have been reported in areas of arable cultivation during the autumn and winter periods, associated with greater rainfall. This is also associated with late sowing in autumn with harvesting in winter, which leaves bare soil surfaces without very little or no ground cover. The impact of soil erosion, especially on agricultural land has major implications for physical landscapes and society at large. It also has both on-farm and off-farm impacts.

The main on-farm effect of soil erosion from agricultural land can be related to the loss of production associated with the loss of topsoil which is rich in organic matter. Off-farm effects include loss of biodiversity, damage to roads and footpaths, contamination of drinking water, and nutrient over-enrichment of freshwater bodies. For example, soil erosion on the South Downs of Southern England has occurred regularly since the early 1980s, especially during the wetter autumn and winter periods, providing average annual rates of erosion of 0.5 to 5.0 m^3/ha/yr for the decade 1982-1991 (Boardman *et al*., 2003). Although the overall rates seem low, the rates for individual fields can be very high, reaching over 200 m^3/ha/yr, and the costs of damage resulting from muddy floods has proved to be very high. For example, damage in Mile Oak and Hangleton, Brighton in 1987 caused by muddy floods totalled more than £259,000 (Robinson and Blackman, 1990), while the total damage cost in Rottingdean was in excess of £400,000 (Boardrman, 1995). In the bigger picture, the total annual external environmental and health cost of the UK agriculture was estimated at £2.343 billion in 1996, comprised of air pollution (£1,113 m), human health costs (£776 m), water pollution (£231 m), damage to biodiversity and landscape (£126 m), and soil damage (£96 m). In specific to water pollution regarding to drinking water, the highest damage comes from pesticides

(£120 m), phosphate and soil (£55 m), zoonoses (£23 m), nitrate (£16 m), monitoring and advice on pesticides and nutrients (£11 m), and eutrophication and pollution incidents such as fertilizers and animal wastes (£6 m) (Pretty *et al*., 2000).

In order to combat both on-farm and off-farm soil erosion effects, including diffuse agricultural pollution, the Ministry of Agriculture Fisheries and Food, and the Environment Agency are working closely together with farmers' organizations to reduce soil erosion and water erosion effects. Some of the initiatives to tackle this issue are The Code of Good Agricultural Practice for the Protection of Soil, and the Provision of Advisory Services. More spesific, DEFRA (Department for Environment, Food and Rural Affairs) also introduced a Catchment-Sensitive Farming Programme to tackle DWPA (Diffuse Water Pollution from Agriculture). More details on these policies as they are associated with maize cultivation will be discussed in Chapter 9.

1.3 Maize Cultivation and Environmental Problems in England

Besides potatoes and winter wheat, one of the major crops that causes serious environmental problems associated with both the on-farm and off-farm impact of soil erosion is maize cultivation. Growing maize has become more common in England since the early 1970s to produce feed for cattle, and particularly to support dairy farming, where maize is mainly used for silage. Forage maize has become a major alternative to grass silage for ruminant livestock in England because of its better end-product quality, which is related to improved forage intake, and improved animal productivity, and it can also reduce production costs (Fitzgerald *et al*., 1998; Anil *et a*l., 2000).

According to the DEFRA database, land cultivated with maize in England in the 1970s occupied an area of less than 10,000 ha. However, this increased to 108,400 ha in 2003. A more detailed discussion of the growth of maize cultivation in England will be presented in Chapter 4.

As discussed above, in Sections 1.1 and 1.2, it is already well known that soil erosion associated with agricultural activity, especially crop farming, has a serious environmental impact, and this is particularly the case for maize cultivation in England. Maize is usually drilled during spring (April/May) and harvested in the autumn (mid-September/mid-October), but in some cases it is also harvested in late autumn, due to restrictions on the availability of contractors for harvesting. Once the maize has been harvested, fields are left bare and this exposes the fields to autumn and winter rainfall. Both factors (bare soil and heavy rainfall) increase the likelihood of water erosion by creating rills and/or gullies on slope surfaces, and promoting surface runoff, which flows downhill into water courses. Maize harvesting also frequently takes place under wet conditions with heavy harvest machinery, leading to compaction of the soil and damage to soil structure, and this increses runoff still further. Most maize growers harvest their crops by moving the harvesting equipment up and down the slope, rather than across it. This also increases the runoff in accordance with the steepness of the slope.

Maize is often grown continuously on the same field, and the fields are frequently left fallow over winter prior to cultivation and pre-drilling the following spring. It is common for farmers to take the opportunity to spread slurry onto bare harvested maize fields over the winter period as an organic fertilizer to support the crop during the next season. However, this is likely to reduce the infiltration rates, espescially if the slurry dries up, thereby increasing runoff, and transporting slurry and sediment to watercourses during periods of heavy rainfall.

Clements and Lavender (2004) have reported a plot study involving measurement of surface water runoff from fine sandy loam soils with a slope steepness 3.7^{o} in maize stubble fields in the Parrett Catchment area of Somerset during the winter period of 2003/04. The results, based on ten rainfall events from 10 November 2003 to 29 March 2004, show that the mean surface runoff from late harvest plots can be as high at 762 m^3/h, and from bare stubble plots at 283 m^3/h. However, more suspended solids were measured from bare stubble plots with mean as high at 1975 mg/l, and at 1842 mg/l from late harvest plots. In the case of phosphorus, it was reported that more phosphorus was measured from late harvest plots with mean as high at 7202 µg/l, and at 5052 µg/l from bare stubble plots. The results also show that more nitrate nitrogen was measured from bare stubble plots compared with late harvest plots, at 1.87 mg/l and only 0.76 mg/l, respectively. The results of surface runoff show the seriousness of on-farm effects of soil erosion from bare maize plots and late harvest plots, associated with the mobilization of top soil and low infiltration rates, which increase the runoff on the slope with a probable resulting increase in soil erosion rates. In addition, off-farm effects from high surface runoff from both treatment plots can be seen from the mean value of suspended solids and phosphorus and nitrate contents.

An investigation of soil erosion in a 6.7 ha bare maize field at Higher Walton Farm near Crediton, undertaken by Blake (2000) using ^{7}Be measurements indicate that the mean erosion rates for the field was 5.3 kg/m^2 with a net soil loss of 2.5 kg/m^2 and the sediment delivery ratio (SDR) is calculated as 0.80. The erosion rates and the net soil loss must be seen as quite high for the local area and the SDR value indicates that a significant proportion of the mobilized soil was delivered beyond the field towards the local stream (Blake, 2000). By comparing the short-term results with medium-term tracer of ^{137}Cs, Blake (2000) reported that the mean erosion rate, a net soil loss and the SDR value derived from ^{7}Be are significantly higher (1.1 kg/m^2/yr, 0.48 kg/m^2/yr, 0.83 respectively, for ^{137}Cs). The ^{7}Be measurements results can be explained by the intensive nature of rainfall during the soil sampling programme in the January 1998, which can be considered to be quite rare. In the case of ^{137}Cs measurements results, it can be related to the high yield of such rarer rainfall that would be lost in the averaging effect over the 30-40 years period (Blake, 2000). Serious off-farm effects from the field resulted from the SDR for both tracers indicate that a significant proportion of the soil was transported out of the field as eroded sediment to nearby water courses.

The references discussed above indicate that harvested maize fields in autumn tend to be exposed to soil erosion during winter periods under heavy rainfall when they are characterized by compacted bare soil. The effects of on-farm erosion and the resulting off-farm pollution clearly demonstrate the seriousness of soil loss and damage to water courses because sediments and nutrients degrade water quality and thus aquatic ecosystems.

1.4 Research Needs

The above discussion has demonstrate the potential seriousness of both the off-farm and on-farm impact of soil erosion associated with maize cultivation. Apart from those discussed above, there have been very few studies in investigating soil erosion rates from bare maize fields in England. Previously, most studies of soil erosion from cropland in England have concentrated on cereals, sugar beet, potatoes, and vegetable crops.

Considering the serious environmental problems that can occur as a result of maize cultivation, and especially the considerable expansion of the area under maize in England in recent years, it is important that there should be more studies of the soil erosion that is likely to occur as a result. Further studies are required of both gross and net rate of soil loss as well as the magnitude of soil losses from individual fields and the role of the sediment mobilized from bare maize fields in polluting river systems.

Documentation of soil erosion associated with maize cultivation including both on-farm and off-farm impacts at both field and catchment scales will serve to improve management policy and to encourage more environmentally friendly attitudes among farmers and harvest contractors with regard to the management of soil, farming systems, harvesting practises, and bare soil conservation on maize fields. Currently, it would be fair to say that management policy regarding the control of soil erosion from agricultural land, including maize cultivation for silage, is still facing problems in reducing soil erosion impact. Guidelines for improved agricultural land management, such as ‘The Code of Good Agricultural Practice for the Protection of Soil’, and ‘The Catchment Sensitive Farming Programme’, may help in solving any practical problems in tackling the impact of soil erosion from maize cultivation areas. However, many farmers leave maize fields bare after harvesting, without any effective protection from rainfall, and the very turbid rivers that are often observed during the winter period, are possibly linked to sediment mobilization from bare soil in the maize fields that have experienced soil erosion. Overall there is a need for a better review and understanding of current management policy regarding soil erosion control and soil conservation, and also of pollution prevention, and management practises associated with maize cultivation that can reduce on-farm and off-farm impact, especially with regard to water courses.

1.5 Research Aims

The overall aim of the research reported in this thesis is to investigate the problem of soil erosion by water associated with maize cultivation. To achieve the research aim, this research has been divided into three parts. The first considers the distribution of maize growing in England and its recent expansion. The second develops an understanding of the on-farm and off-farm impacts of maize cultivation, and the third considers the implications of the results of the research for improving management practices to reduce the impact of soil erosion from maize fields. The work should help to provide better documentation of on-farm and off-farm impacts of soil erosion, and could be used to review some of the farming management systems applied by policy makers, farmers and harvest contractors.

1.6 Thesis Structure

The thesis is divided into 10 chapters. Chapter 1 establishes the background to soil erosion associated with maize cultivation in England and outlines the aims of the research undertaken. Chapter 2 explains the objectives of the research, and a description of the research strategy. This includes a discussion of how the study area was selected at national, regional, local and site scales. Chapter 3 describes the methodology used in this research to investigate on-farm and off-farm impacts associated with maize cultvation. The description is divided into two sections: the first concerns techniques for soil sampling and water-sediment monitoring, including sample preparation; the second concerns laboratory analysis involving ^{7}Be and ^{137}Cs measurements, and also analysis of the chemical properties of soils and sediment.

Chapter 4 presents a review of maize cultivation in England and its expansion from national to regional perspectives. Chapter 5 builds on Chapter 4 and provides a discussion of maize cultivation at the local and site scales. Chapter 6 describes the soil erosion investigation undertaken at selected study sites, and this in turn is divided into two sections. The first section is a discussion of the information on soil erosion rates and patterns provided by ^{7}Be measurements which provide a short-term perspective, and the second presents equivalent information obtained from ^{137}Cs measurements which provide a longer-term perspective. Chapter 7 reports the results of an investigation on suspended sediment transported by the Rivers Culm and Tone and this includes information on the analysis of several chemical properties of the sediment such as heavy metal, organic carbon, and total phosphorus content. Chapter 8 discusses the environmental impact of maize cultivation in England based on a review of the national distribution of maize growing areas and the river networks of England, and presents an assessment of the possibility of off-farm impact from maize cultivation areas on river catchments, based on the project results. Chapter 9 reviews current farming management systems and a discussion of potential improvements to the system of combating soil erosion impacts associated with maize cultivation. The final chapter, Chapter 10, summarizes the thesis and the results presented and provides recommendations for future research.

CHAPTER 2: RESEARCH STRATEGY

2.1 Overview

This chapter describes the research strategy designed to achieve research aims outlined in Chapter 1. Specific objectives based on the research needs are outlined in Section 2.2. The chapter will also describe the process of choosing the study area in this project to fulfill the research aims and individual objectives which are based on four perspectives, at national, regional, local and site scales.

2.2 Research Objectives

As indicated in the previous chapter, the aims of the project are divided into two aspects. The first is to provide an understanding of the off-farm impacts of maize cultivation on a local or catchment scale, and the second is to consider the implication of the results of the project for improving management practices in order to reduce the impact of soil erosion associated with maize cultivation. Based on both aims, the objectives of this project are listed below;

1. To review the background to maize cultivation in England.
2. To analyse the spatial and temporal patterns of maize cultivation.
3. To investigate rates and patterns of soil erosion from maize fields.
4. To investigate sediment transfer from maize fields to rivers.
5. To evaluate the environmental impact of maize cultivation in England.
6. To consider the potential of improved management practises in reducing the environmental impact of maize cultivation.

In addition, the first and second objectives are to discuss the causes of the expansion of maize cultivation area in the country, and to report and describe spatial and temporal patterns of maize cultivation at national, regional and local scales. The results obtained from these discussions will be dealt with in Chapter 4, for the national and regional scales; and in Chapter 5 for local scales. In the case of the third objective, the investigation of rates and patterns of soil erosion will be based on shorter and longer terms of radionuclide tracer at a site scale. The results will be reported in Chapter 6. Investigation of sediment transfer from maize fields to rivers will be made at a local or catchment scale, and the result will be discussed in Chapter 7. The fifth objective of evaluation of the environmental impact of maize cultivation will be made at local and national scales, based on the results from Chapter 4, Chapter 5, Chapter 6 and Chapter 7; and the discussion will be made in Chapter 8. Consideration of the potential of improved management practises in order to reduce the environmental impact of maize cultivation will be discussed at a national scale, considering several policies associated with agriculture in general as well as the cultivation of maize.

In accordance with the above description, the next section will focus on a discussion of the selection of study areas at national, regional, local and site scales. Figure 2.1 summarizes the above description and the further discussion of the strategy that will be taken in this project.

2.3 Selection of the Study Area

As mentioned above, the process of the selection of the study areas is based on four scales, national, regional, local and site scales. As is well known, the United Kingdom consists of four countries or political entities, namely England, Wales, Scotland and

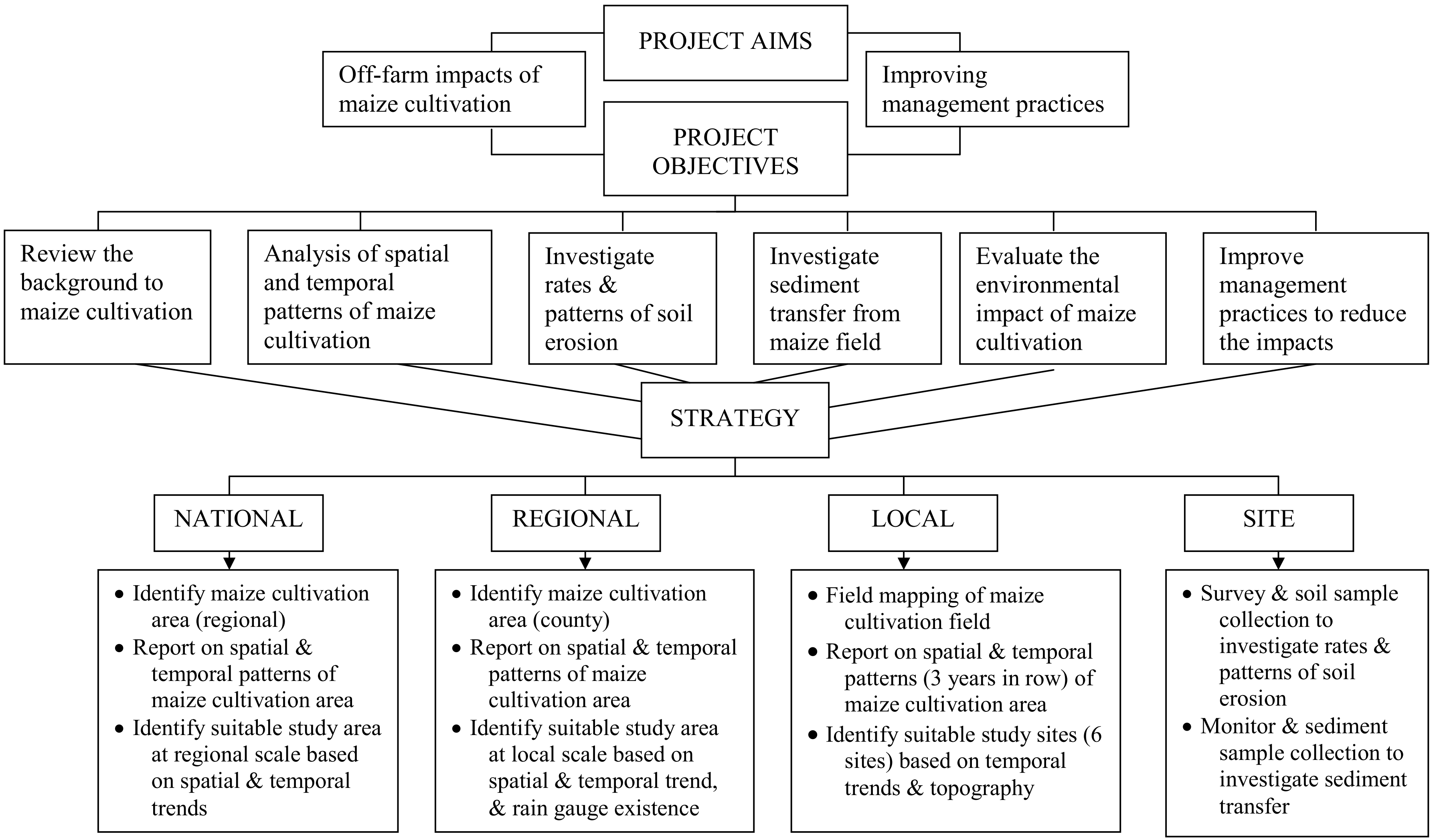

Figure 2.1 : Flow chart of the project

Northern Ireland. However, considering the time-period of the project and limitations that could occur during the process of collecting field and secondary data, this project has tried to minimize any uncertainty and limitations in carrying out the project from the beginning to try and avoid future problems.

2.3.1 National scale

As indicated in Figure 2.1, achieving the aims and the objectives of the project ought ideally to be done on a national scale in order to understand the spatial and temporal patterns of maize cultivation in the United Kingdom. However, under the project time-period limitation, the author has had to select only one of the countries for this project, and England has been choosen. The reason for this is because England is the largest country of the four, at 130,395 km^2. In addition, most of the land in England is arable and cultivated with variety of crops, which thus better suits the project aims and objectives. A detailed description of cropland in England will be made in Chapter 4.

In order to review the background to maize cultivation in England, data on maize cultivation for certain years are needed to show the spatial and temporal patterns of maize growing. Data in map format has been supplied by the Library of Edinburgh University for the years 1979, 1981, 1985, 1988, 1993, 1995, 1997, 1999 and 2000. The data are in raster format, and all data are in size of 2 km^2 per pixel, except for 1985 which is in 5 km^2 per pixel size. The data have been analysed using Geographical Information Systems (GIS) of ArcMap, version 8.3. In the case of temporal patterns, the data were collected from the DEFRA website (Department for Environment, Food and Rural Affairs), for the years of 1970, 1972, 1974, 1980, 1982, 1984, 1990, 2000 and 2002. These data were transferred to Excel for trend analysis.

The main analysis process at this scale is to identify maize cultivation area in England for each region, for the years mentioned above. The results from this analysis were intended for use in identifying a suitable study area at a regional scale after a study of spatial and temporal patterns in each region.

The project will also discuss the factors that cause the expansion of maize cultivation areas in England. In addition, it will also review and discuss management practises with the aim of making some recommendations so as to reduce the environmental impact of maize cultivation. This could be done by reviewing present agricultural policies, especially those dealing directly with maize cultivation. The results will be discussed in Chapter 9.

2.3.2 Regional scale

One of the most important considerations in selecting a suitable study area at a regional scale is to choose an area relatively densely cultivated with maize. As a result of studies of maize cultivation at a national scale, the Southwest region was selected as the most suitable study area for this project. Starting from this point, a similar analysis of spatial and temporal patterns of maize cultivation in the Southwest region was also carried out, based on the similar data from both the Edinburgh Library and from DEFRA.

The study of the spatial and temporal patterns of maize cultivation at this scale will cover all six counties of the Southwest region, i.e. Cornwall and the Isles of Scilly, Devon, Dorset, Gloucestershire, Somerset, and Wiltshire. The spatial distribution of maize cultivation in the Southwest region will be presented in map format while the temporal patterns will be reported using figures to show the trends of maize cultivation scale within the counties. The report will also be discussed in Chapter 4, together with the results at a national scale.

2.3.3 Local scale

The studies of spatial and temporal patterns of maize cultivation in the Southwest region have in turn been used to identify two catchments as a study area at local scale. The reason for the choice of the two catchments as study areas in this project was based on the reasons below:

- investigation of any differences of soil erosion rates and patterns from two different catchment background of soil types;
- investigation of any differences of off-farm impact in the river, associated with diffuse pollution, from different physical characteristics, such as topography, geological aspects, soil types, the size of catchment and river network length;
- representation of the country of England associated with the environmental impact of maize cultivation with regard to catchment size and the location of maize fields to the river network.

In addition, the existence and availability of rain gauge stations and river flow data such as turbidity and water discharge has also been considered in selecting suitable catchments in this project.

Finally, after taking into consideration the reasons mentioned above, two catchments were selected as study areas in this project: the Culm Catchment, which is in the Exe River basin and located in Devon, and the Tone Catchment, which is one of the main Parrett River tributaries and is located in Somerset.

At this scale, two main actions were taken. The first was to identify maize fields within both catchments for the years 2002, 2003 and 2004. This involved field mapping work to gather information from farmers and land owners using direct interviews and based on observation during the field work. Farmers and land owners were asked to identify maize fields that had been cultivated for those three years. More than 300 farms and farmers were visited and interviewed to fulfill this purpose.

Secondly, it was necessary to identify the existence of rain gauge stations and the availability of river flow data for the purpose of investigation of off-farm impact from maize cultivation area. This involved field checking of existing river gauging stations at down-stream points from both catchments, and the suitability and possibility of the stations for sediment concentration and river turbidity measurements. In addition, the availability of secondary data based on daily measurements of river flow and turbidity from the Environment Agency (EA) were also checked to support field measurement data. Another requirement that was considered was accessibility to the river gauging stations for river monitoring. This included the distance of the river gauging station from Exeter University and permission from the Environment Agency to access and set-up river monitoring instruments. Taking account all those factors, two river gauging stations were finally selected for this project, with one for each catchment, to act as river monitoring points down-stream. The river gauging station selected to represent the Culm Catchment is known as the Woodmill station, while that for the Tone catchment is the Bishop Hull station.

The Woodmill station is run by the School of Geography, University of Exeter, monitoring river flow and river turbidity. This is an advantage for this project because of the accessibility of the secondary data regarding the history of river flow and river turbidity history. However, in the case of the Bishop Hull station, the station is operated by the Environment Agency alone, and in order to gain access to the premises to set-up the monitoring instruments and for field work monitoring during the winter period of 2004/2005, permission had to be given by the management of the EA. The EA have their own river flow and turbidity instruments at this station, which was a help for this project because it enabled comparisons to be made for data from different monitoring instruments.

2.3.4 Site scale

Furthermore, in investigating soil erosion rates and patterns, the project needs a suitable number of study sites for soil sampling collections to represent the local study area. Some considerations that have to be taken an account before deciding the number of study sites in this project are listed below:

1. The size of maize field. This relates to the number of sampling points for each field. If the size of the field slope is longer from the top to the bottom of the field, the number of sampling points will be more.

2. The half-life of ^{7}Be that needs to be measured soon after its dry and sieved. This is associated with limited number of detectors in the School of Geography Laboratory, which are also being used by other researchers.

3. The distance between each field, which will effect how far it might be to carry out soil sampling within the same day, or at least on consecutive days after the first day of sampling. This is important, in the case of ^{7}Be to avoid any uncertainty of soil samples regarding a second rainfall event.

Taking these considerations into account, the author decided to choose six bare maize fields, three in each catchment, to be study sites. According to this decision, the next process was to identify six suitable maize fields as study sites. The process of selecting six suitable maize fields was carried out by referring to field mapping results on a local scale. This process involved three important aspects. The first was to identify maize fields grown with maize for three years in a row from 2002 to 2004. The second was the importance of avoiding undulating or flat fields. Undulating fields would have a tendency to spread runoff on the surface in too many directions, while flat fields could be flooded and thus rendered unsuitable as case studies. It is also important to avoid undulating fields because of the necessity of using a transect approach in soil sampling programmes. The third was to select a different background of soil type for each field so as to represent a variety of soil types within the catchments. The geographical and physical characteristics of the six study sites will be described in Chapter 6.

In addition, soil sampling programmes for both ^{7}Be and ^{137}Cs have been made in the same fields and at the same as sampling points for the purpose of comparison of soil erosion rates at shorter and longer terms of life for both radionuclide tracers.

2.4 Summary

This chapter has described the research strategy at various scales in achieving the aims and objectives of the project. England was chosen as a study area at the national scale, and the Southwest region was selected to represent the England at a regional scale. For both scales, the spatial and temporal patterns of maize cultivation is described based on data supplied by the library of Edinburgh University and DEFRA. Furthermore, two catchments (the Culm and Tone catchments) were selected for investigation of off-farm impacts of soil erosion, and six maize fields were chosen to represent both catchments associated with soil erosion rates at shorter and longer terms.

The next chapter will describe the methodology that has been used in this project. It will cover aspects of field work for field mapping, the soil sampling programme and river turbidity monitoring approaches that were applied in this project. In addition, the methodology chapter will also describe the laboratory work associated with radionuclide measurements and chemical property analyses.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter will describe various methods employed in the field and laboratory components of the study, and more specifically the measurements of fallout radionuclides and analysis of the chemical properties of soil and suspended sediment samples. The fallout radionuclide measurements focused on ^{7}Be, ^{137}Cs and ^{210}Pb fallout, whilst the analysis of chemical characteristics included heavy metals, base cations, phosphorus, carbon and nitrogen. The detailed procedures employed to determine the ^{7}Be and the ^{137}Cs content of soil and sediment samples will, however, be presented in Chapter 6. The present chapter also describes some of the techniques employed for data manipulation and analysis.

3.2 Field Sampling and Sample Preparation

This section will describe the soil sampling techniques that were employed in the field to obtain samples for ^{7}Be, ^{137}Cs and ^{210}Pb fallout measurements. The collection of water samples for determination of suspended sediment concentration and recovery of sediment for analysis will also be included in this section. In addition, the processing and preparation of soil and suspended sediment samples prior to laboratory analysis will also be explained in this section.

Soil sampling for ^{7}Be and ^{137}Cs measurements was undertaken at a number of study sites (fields) in the Culm and Tone catchments. A transect approach was employed, and this involved two parallel transects in each field. The same sampling points were used for both ^{137}Cs and ^{7}Be. The main sampling was undertaken in maize fields, but it was also necessary to collect reference samples from adjacent flat areas in pasture fields. The soil sampling was undertaken after the maize had been harvested.

3.2.1 Soil sampling and sample preparation for ^{7}Be measurement

Bulk soil samples for ^{7}Be measurement were collected from the study sites within the catchments of the River Tone and Culm in order to determine the ^{7}Be inventory. Soil cores were collected using a 150mm diameter plastic core tube (Plate 3.1). The tube was driven into the soil surface to a depth of 30mm and the shallow core was carefully removed and transferred to a strong plastic bag. The plastic bag containing the soil sample was tied and labeled to record the sampling point. In order to make a comparison with the inventories recorded in the study fields, bulk reference cores were also collected in the same way from pasture sites adjacent to each study field.

All soil samples were fully dried prior to measurement of their ^{7}Be contents. In view of the need to dry the soil samples rapidly, because of the short half-life of ^{7}Be, all soil samples were freeze-dried. The soil samples were fully frozen (Plate 3.2) prior to being placed in the vacuum chamber of the ThermoSavant ModulyoD freezed drier (Plate 3.3). After drying the soil samples were weighed and disaggregated. Disaggregation was undertaken using a rotary sieve (Plate 3.4), which pulverized and sieved the soil samples to < 2mm fractions. Grinding times for each sample were 10–15 minutes. Only the sieve size of < 2mm fractions was used for ^{7}Be measurement. The fine fraction samples were packed into medium-sized Marinelli beakers (Plate 3.5) and weighed, prior to assay of their ^{7}Be contents using a high-purity germanium coaxial γ-detector (HPGe).

Plate 3.1: Plastic core tube used in ^{7}Be soil sampling

Plate 3.2: Soil samples in a freezer

Plate 3.3: Soil samples in the freezer drier

Plate 3.4: The rotary sieve used for disaggregating and sieving the soil samples

Plate 3.5: The fine fraction of a soil sample contained in a medium-sized Marinelli beaker

3.2.2 Soil sampling and sample preparation for ^{137}Cs measurement

Bulk soil cores were collected from the study sites to determine the ^{137}Cs inventory. Soil cores were collected using a 70mm internal diameter metal corer (Plate 3.6). The corer was driven into the soil using a motorized percussion hammer (Plate 3.6) to various depths, depending on the location of the sampling points along the slope, and the soil depth and composition. If a sampling point was stony, the depth of soil core could be only 30–45cm. Most of the stony sampling points were found at the top of the slopes. In contrast, many sampling points in the middle of the slopes were 45–55cm deep, whilst for some of the sampling points at the bottom of the slope, the soil cores could be > 55cm long. The soil cores were carefully removed and transferred to strong plastic bags, tied and labelled to record the point. Bulk reference cores were taken in the same way from an adjacent flat pasture site for each study field.

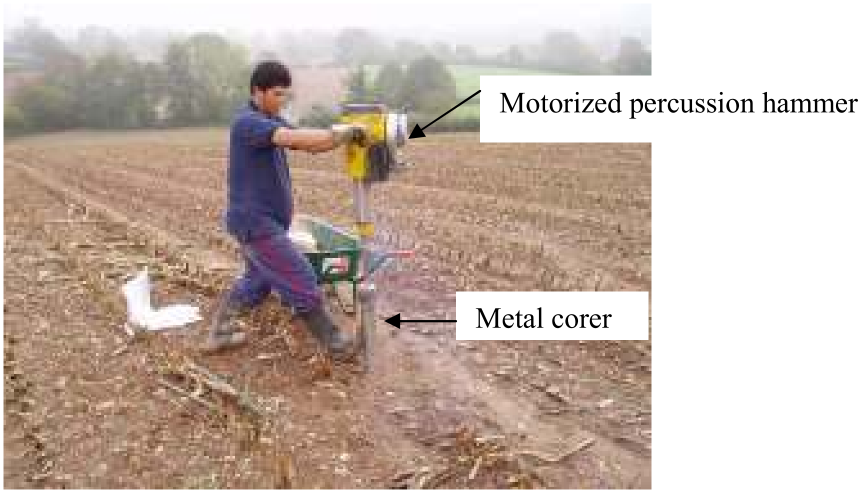

Plate 3.6: Metal corer and motorized percussion hammer used in ^{137}Cs soil sampling

All soil samples were oven dried at 50^{o}C, and after being fully dried, the samples were ready for weighing. Dried soil samples were disaggregated using a similar approach to that used for preparing samples for ^{7}Be analysis, as described in section 3.2.1. However, the sieving times for the ^{137}Cs soil samples were longer, taking up to 20–30 minutes, because the soil samples collected for a ^{137}Cs analysis were considerately larger than those collected for ^{7}Be analysis. The fine fraction at < 2mm of the soil samples was packed into a medium-sized Marinelli beaker, and after being weighed, the samples were ready for ^{137}Cs assay using the same detector as used for ^{7}Be measurements.

3.2.3 Soil sampling and sample preparation for ^{210}Pb and chemical analysis

In order to analyse the excess ^{210}Pb activity and the chemical properties of surface soil from maize fields, additional soil sampling was undertaken in 24 maize fields within the Culm and Tone catchments. Those 24 maize fields included 12 maize fields in the Culm Catchment and another 12 maize fields in the Tone Catchment. The maize fields were chosen randomly within these catchments, but it was a requirement that the field had to be free from any farming activity during the soil sampling time.

The soil samples were collected using a small scoop from the soil surface adjacent to the slope rills which provided evidence that the slope surface had been eroded during preceding heavy rain. The sampling points were located randomly in each field. The mass of the soil samples collected from each of the fields typically amounted to 500–600g. All soil samples were transported and stored in strong plastic bags, tied and clearly labeled.

The soil samples were oven dried at 50^{o}C before being weighed. Subsequently, the samples were disaggregated gently using a pestle and mortar (Plate 3.7), and dry sieved to recover the 20µm fraction using a 20µm sieve. The sieved soil samples were packed into strong plastic bags, in readiness for ^{210}Pb activity measurement and chemical analysis.

Plate 3.7: Soil samples for chemical analysis were disaggregated using a pestle and mortar

3.2.4 River water sampling and sample preparation for suspended sediment analysis

River water sampling for recovery of suspended sediment and measurement of suspended sediment concentrations was undertaken at two hydrological monitoring stations, located at the outlet of the Culm and Tone catchments. The Woodmill station, located closed to Cullompton, was at the outlet of the Culm Catchment outlet, while the Bishop's Hull station, located closed to Taunton, was located at the Tone Catchment outlet.

River water sampling was undertaken during peak river flows after heavy rain had occurred. For the purpose of recovering suspended sediment, sampling involved use of a submersible pump powered by a portable generator, to pump river water through a 30mm reinforced plastic hose into five 20l polyethylene cans. However, for the purpose of determining suspended sediment concentrations, the river water sample was collected in 500ml bottles using the same apparatus.

The 100l bulk river water samples collected at the both outlets of both catchments were taken back to the laboratory, and left for four days to allow the suspended sediment in the water samples to settle to the bottom of the can. After the suspended sediment had completely settled, the overlying clear water was syphoneed out using a small hose, leaving the suspended sediment at the bottom of the can along with a small volume of water. This residual sample of suspended sediment contained in a small volume of water was transferred to a centrifuge bottle, ready for recovery using a Multifuge 4 KR Heraeus centrifuge (Plate 3.8). The centrifuging process took about one hour, and after this process had been completed, the suspended sediment was transferred using distilled water and a spatula into a plastic pot. The sediment contained in these plastic pots was then freeze dried, and stored in plastic bags, prior to chemical analysis.

Plate 3.8: The Heraeus Multifuge 4 KR Centrifuge

3.3 Laboratory Analysis

This section will cover two areas. The first describing the measurement of ^{7}Be, ^{137}Cs and ^{210}Pb activity, and the second the techniques used for analyses of the chemical properties of soil and suspended sediment samples.

3.3.1 Radionuclide measurement

In this study, a high resolution of low-level gamma spectrometer incorporating a high-purity germanium (HPGe) detector (Plate 3.9) was used to determine gamma-emitted radioactivity in soil and sediment samples. More specifically, the detector type used in this study is a hyperpure germanium coaxial γ-detector (EG&G ORTEC HPGe) with associated lead-shielding and liquid nitrogen cooling, linked to a multi-channel analyser. A detailed explanation of gamma spectrometry measurements is provided by Wallbrink *et al*. (2002).

Plate 3.9: A hyperpure germanium coaxial γ-detector

The detector, which contains a germanium crystal, generates free electrons in response to absorbing energy from ionizing radioactivity, and the magnitude of the charge in the crystal is directly related to the energy of the incident gamma ray (Wallbrink *et al*., 2002). In this case, the sample in the detector releases γ-ray emissions and some of them will be absorbed. At this stage, the γ-ray emissions lose part or all of their energy by producing electron pulses. These electron pulses are amplified by the pre-amplifier as voltage pulses and sent to the multichannel analyser. The pulses are sorted by height and output from the different channels into the counting system, where the counts are processed and displayed (Blake, 2000).

The counting system is based on the full energy peak (FEP), where the area under the FEP is known as the net count rate, which can be used to calculate the radionuclide activity in the sample. In order to calculate the radionuclide activity in the sample from the net count rate value, it is important to know the detector efficiency. The efficiency of the detector is a function of the energy of the γ-rays, the characteristics of the crystal, the geometry of the sample and the self absorption of γ-rays by the sample itself (Blake, 2000). All these must be taken into account when defining the efficiency of a detector using standards.

3.3.1.1 Measurement of ^{7}Be and ^{137}Cs activity in soil samples

As indicated above, soil samples for ^{7}Be and ^{137}Cs, analysis were packed into medium-sized Marinelli beakers. The Marinelli beaker surrounds the detector head to provide more efficient detection.

In order to convert the net full energy peak (FEP) into a measurement of radionuclide activity, the efficiency of the detector must be known. This is defined as the ratio of the net FEP count rate of γ-ray recorded by the detector to the emission rate of γ-ray from the sample. The activity in the sample can be calculated as:

$$A_x = (n_x / \eta_x) \tag{3.1}$$

where n_x is the net FEP count rate of γ-ray recorded by the detector, and η_x is the efficiency for a γ-ray emitted from radionuclide x in a sample.

The detector efficiency calibration can be defined as:

$$f\,(M_0) = (C_0 / T_0 - C_b / T_b) \text{ x } (1 / M_0 \text{ x } (A_0 e^{-\lambda(t-t_0)}) \tag{3.2}$$

where f is the activity efficiency of the detector, which is defined as the efficiency τ (emission rate) multiplied by the r (emission probability of the gamma ray), M_0 is the standard mass in kg, C_0 is the total counts, C_b is the background counts of an unspiked sample, T_0 is the count time, T_b is the corresponding background count time, and λ is the decay constant of the radionuclide, which can be defined as:

$$\lambda = 1n2 / T_{0.5} \tag{3.3}$$

where $T_{0.5}$ is the half-life of the radionuclide.

In analysis for ^{7}Be and ^{137}Cs, soil samples were counted on the detector for at least 6 hours. Walling and Quine (1993) have suggested that counting times to detect the fallout activity are commonly in the range 29000 to 55000s. However, considering the large number of soil samples (more than 300 samples), the limitations of detector availability, and the time limitation for analysis of ^{7}Be soil samples linked to the short half-life of this radionuclide, count-times were kept as short as possible, whilst still providing reliable results.

In this study, the areal activity (Bq m^{-2}) of ^{7}Be and ^{137}Cs is used to characterize the fallout activity in the soil sample. The areal activity (A_a) for bulk cores can be calculated as:

$$A_a = AM_T / S \tag{3.4}$$

where A is the activity of the sub-sample of the bulk core analysed (Bq kg^{-1}), M_T is the total mass of the bulk core (kg), and S is the corer area. The activity of ^{7}Be in the samples was obtained from the counts at the 475 keV, and 660 keV for ^{137}Cs.

Since radionuclides are subject to continuous decay, it is important to relate all measurements to a standard point in time. It is therefore necessary to correct the derived activity to the date on which the sample was collected (ic A(0)), and this can be calculated as;

$$A(t) = A(0)e^{-\lambda t} \tag{3.5}$$

where $A(t)$ is the activity of a radionuclide in a radioactive source at the time of measurement, and λt is the decay constant of the radionuclide, which was defined in Equation 3.2. The $T_{0.5}$ for ^{7}Be is 53.3 days, and 11,059.5 days or 30.3 years for ^{137}Cs.

The results from the ^{7}Be and ^{137}Cs fallout activity measurement, which are expressed in Bq m^{-2} will be used in this study to estimate soil erosion rates for each study site. Detailed explanation of the use of ^{137}Cs and ^{7}Be to estimate soil erosion will be provided in Chapter 6.

3.3.1.2 Measurement of excess ^{210}Pb in soil and suspended sediment samples

The < 20µm fraction of the soil and suspended sediment samples for excess ^{210}Pb was packed into a plastic pot. The pot was sealed and left for 21 days before measurement to allow ^{226}Ra to come to equilibrium with ^{214}Pb.

The detector efficiency calibration for excess ^{210}Pb measurement, based on the mass in the pot and pot height, can be calculated as:

$$\eta\ (h) = [n(h)\ /\ A_0(h)\text{ך} \qquad (3.6)$$

where $\eta(h)$ is the γ-ray count rate recorded by the detector, and $A_0(h)$ and ך are the known activity of the pot with mass and height and the abundance of γ-ray, respectively. The pot inner diameter is 7cm and the height is 8cm.

The plastic pot containing the sample was placed on top of the detector head and counted for over 50,000s. This provided a precision of *ca.* ± 10% at the 90% level of confidence for the γ-ray spectrometry measurements. The activity of ^{137}Cs in the samples was obtained from the counts at the 660 keV peak. The total activity of the sample was measured at 46.5 keV for ^{210}Pb, and 350 keV for ^{226}Ra. The excess of unsupported ^{210}Pb concentrations of the sample was calculated by subtracting the ^{226}Ra-supported ^{210}Pb concentrations from the total ^{210}Pb concentrations. The ^{226}Ra is measured via the short-lived daughter ^{214Pb}.

The activity calculation for ^{210}Pb can be represented as:

$$A_{Pb\text{-}210ex} = A_{Pb\text{-}210} - A_{Pb\text{-}214} \tag{3.7}$$

where $A_{Pb\text{-}210ex}$ is the unsupported ^{210}Pb activity (mBq g^{-1}), $A_{Pb\text{-}210}$ is the total ^{210}Pb activity (mBq g^{-1}), and $A_{Pb\text{-}214}$ is the ^{214}Pb activity (mBq g^{-1}).

However, since ^{214}Pb is a daughter of ^{222}Rn, which is an inert gas, the use of ^{214}Pb activity to estimate the ^{226}Ra-suppprted ^{210}Pb activity can result in over-estimation of its value due to escape of a proportion of the ^{222}Rn from the soil sample. This effect can be corrected using a proportion factor α:

$$A_{Pb\text{-}210ex} = A_{Pb\text{-}210} - \alpha A_{Pb\text{-}214} \tag{3.8}$$

and α can be calculated as:

$$\alpha = (A_{Pb\text{-}210.deep}) / (A_{Pb\text{-}214.deep}) \tag{3.9}$$

where $A_{Pb\text{-}210.deep}$ is the total ^{210}Pb activity for a sample from below the penetration depth of fallout ^{210}Pb (mBq g^{-1}), and $A_{Pb\text{-}214.deep}$ is the ^{214}Pb activity for a sample from below the penetration depth of atmospheric ^{210}Pb (mBq g^{-1}). In this case, the value of α is normally in the range 0.80–1.0.

3.3.2 Total organic carbon (C) and nitrogen (N) analysis

The concentration of carbon and nitrogen in the soil and suspended sediment samples were determined by pyrolysis using a CE Instruments NA 2500 elemental analyzer (Plate 3.10). The samples were packed into small tin capsules, and were sealed by pressing the tin capsules with samples into pellets.

Plate 3.10: The CE Instruments NA 2500 elemental analyzer used for C and N analyses

Blake (2000) explained the process occurring within the tin capsule samples and the elemental analyzer reaction in detail. The elemental analyzer is set up at 1000^{o}C, which allows the sample and tin capsule to melt. At this stage, the exothermic reaction with the capsule produces a dynamic flash combustion at 1800^{o}C, and the resulting gas is then transported by a constant flow of helium and oxygen through chromium oxide oxidation catalysts where oxidation is completed (Blake, 2000). The combustion products are then transported in another reactor at 780^{o}C and converted into elemental carbon and nitrogen. The measurement of carbon and nitrogen is made when the sample is eluted through a gas chromatographic column where it passes across a thermal conductivity detector (Blake, 2000).

Quantifying the carbon and nitrogen content of the soil and suspended sediment samples is carried out by determining the carbon and nitrogen calibration curves. This can be done using an ethylene diamine-tetra acid (ETDA) as a standard. This standard sample is also processed in the same way as the soil and suspended sediment samples. The results from the measurements will be reported in Chapter 7.

3.3.3 Heavy metal analysis

The heavy metal content of soil and suspended sediment samples were determined using Atomic Absorption Spectrophotometry (AAS) (Plate 3.11). The technique used in this study was documented by Allen (1989), and involves the extraction of the heavy metals from the direct digestion using nitric and hydrochloric acid. According to Alloway and Ayres (1997), the term *heavy metal* is applied to the group of metals and metalloids with an atomic density greater than 6 g/cm^3.

In this study, heavy metal elements associated with agricultural sources were selected for analysis. This involved three sources of heavy metals which are heavy metals from impurities in fertilizers, from pesticides, and from composts and manures. The heavy metal elements associated with these three sources are As, Cd, Cn, Cr, Cu, Hg, Mn, Mo, Ni, Pb, U, V, and Zn.

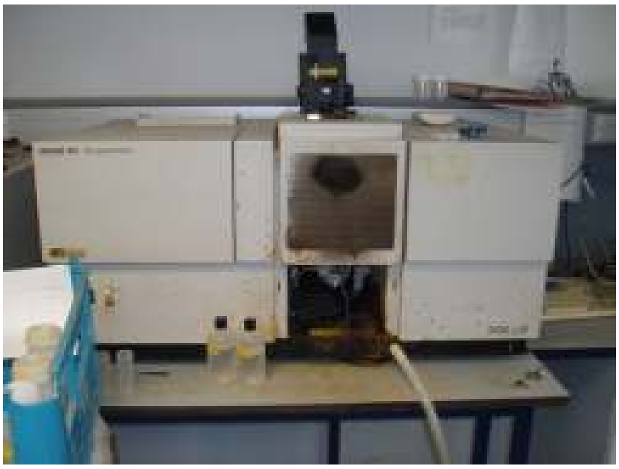

Plate 3.11: The Atomic Absorption Spectrophotometer
used for heavy metal analysis

3.3.4 Base cations analysis

A method proposed by Qui and Zhu (1993) was used to extract base cations from soil and sediment samples for subsequent analysis by AAS. The base cations used in this study were Ca and Na, and ammonium acetate was used as a reagent to extract the base cations.

3.3.5 Total phosphorus analysis

The total phosphorus was extracted from soil and suspended sediment samples using the method proposed by Olsen and Dean (1965). The digestion process uses perchloric acid, sulphuric acid, ascorbic acid, ammonium molybdate and potassium antimony tartrate as reagents.

3.4 Data Manipulation and Analysis

One of the primary study objectives is to review the spatial and temporal background of maize cultivation at national, regional and local scales. This requires the manipulation and analysis of data from many different sources. In this study, data were supplied by the Department for Environment, Food and Rural Affairs (DEFRA), the Edinburgh Library (EL), and the Centre for Ecology and Hydrology (CEH). To complement these secondary data, field mapping and data verification have also been undertaken. Each data source has a different background and this section will focus on an explanation of the data sources.

To process and support these primary and secondary data, the system known as GIS (Geographical Information Systems) was used as a tool. The GIS software of ArcGIS v8.3, which consists of ArcCatalog and ArcMap, were used in data manipulation and analysis.

3.4.1 DEFRA data

In this study, the data used from DEFRA sources relates to the annual census conducted by DEFRA, and the results are released every year in June through the Agricultural and Horticultural Census. The released result is based on census form returns each year by registered farmers. Each farmer is obliged to give information about the size of each field occupied by every type of agricultural activity. The accuracy of such information is of course highly dependent on the reliability and availability of the farmers' information returns. DEFRA also produces an agricultural map for Agricultural Land Classification (ALC) at a 1:250,000 scale. However, such a scale is not really suitable for the purpose of this research, as more detailed information is needed. The census data available to use in this research are from the following years: 1950, 1954, 1955, 1960 to 1965, 1970 to 1975, 1980 to 1985, 1990, 1995 and 2000 to 2003.

3.4.2 Edinburgh Library data

The Edinburgh Library has data in digital map format for various years and in different resolutions. The information in the digital maps is derived from agricultural census data summarized by MAFF (Ministry of Agriculture, Fisheries and Food) and SOAEFD (The Scottish Office Agriculture, Environment and Fisheries Department) and is related to groups of farm holdings. The process of data transformation is based on parish data in a square grid of 1km^2. The Parish Framework is used in conjunction with a 7-fold classification of land use with the same 1 km^2 grid as in the Land Use Framework. The digital maps used in this research represent the following years: 1979, 1981, 1985, 1988, 1993, 1995, 1997, 1999 and 2000. These maps are based on a 2 km^2 grids, except for that of 1985, which is based on a 5 km^2 grid.

3.4.3 CEH data

The CEH dataset used in this study is the Land Cover Map (LCM) of 2000. The LCM2000 is a thematic classification map based on spectral data recorded by satellite images. The dataset is based on a raster format derived from a vector database and stored as pixels in a 1km grid. It can be divided into two major classes, namely Target Classes as the top hierarchy, and Subclasses. The Target Classes or Level 1 was considered the nearest match which could be achieved consistently and with a high level of accuracy. It was divided into 16 groups, such as arable and horticultural, suburban and urban, and littoral rock and sediment.

The Subclasses are divided at two levels, known as Level 2 and Level 3. Level 2 is the standard level of detail which provides 26 subclasses such as arable cereals, arable horticulture and non-rotational horticulture. Level 3 known as Variants, provides details down to 72 categories. In this research, the Variants level was used to identify the area of maize.

Since it was based on interpretation of satellite imagery, an attempt was made to validate the CEH data. Eighteen fields in the Culm Catchment and 24 fields in the Tone Catchment shown as being used for maize in the CEH database were selected and their land use in 2000 was checked by interviewing the relevant farm owner. The result showed that 22 of the 24 maize fields in the Tone Catchment were used for maize in 2000. However, the other two fields identified by CEH data as a maize field in 2000 were not used for maize, both fields being covered with rough grassland mixed with coppice and scrub. The validation process in the Culm Catchment shows that 100 percent of the selected maize fields were used for growing maize in 2000. For both areas combined, the validation applied showed that 95.2 percent of maize fields identified by CEH were used for growing maize in 2000. This result confirms the reliability of the CEH data, which has therefore been used in this study.

3.4.4 Field mapping data

The secondary data supplied by DEFRA, EL and CEH do not provide spatial information after 2000. From a local perspective, it was very important to show the current spatial distribution of the maize-growing area within the Culm and the Tone catchments for soil sampling purposes. In order to support the secondary data, field mapping was undertaken to identify all maize fields within the study catchments for the years 2002, 2003 and 2004. The field mapping carried out was based on interviews with farm owners within the catchments. Each farm owner was asked to identify their maize fields in those years, and topography maps were used as basic maps.

3.5 Summary

This chapter has explained various methods employed in this study to achieve the study objectives. The methods have involved both fieldwork, which involved soil and suspended sediment sampling, and also laboratory work which included sample processing and preparation and analysis of the radionuclide and chemical contents of soil and suspended sediment samples. In addition, data manipulation and analysis, based on field-mapping work and secondary data from DEFRA and CEH have also been described. The results of the sampling and analysis programmes will be presented and discussed in Chapters 6 and 7. Results from the data manipulation and analysis employed GIS will be presented and reported in Chapters 4 and 5.

CHAPTER 4: MAIZE CULTIVATION IN ENGLAND AND THE SOUTHWEST REGION

4.1 Introduction

Most of the land in England is under agriculture. In 1950, about 10.33 million ha of England were under arable land, grassland and rough grazing, but the area decreased to 8.15 million ha by 2003. This represented 44.3% of the agricultural land in the United Kingdom in 2003. Arable land occupied about 50.4% of the agricultural land in England in 1950, with permanent grassland accounting for 35.4%, and rough grazing land for 4.2%. However, by 2003, the proportion associated with arable land had decreased to 47.1%, with grassland accounting for 44.9%, and rough grazing for 8.0%.

Crops still constitute the largest area of agricultural land in England, and in 2003, the area of arable land extended to 3.81 million ha. Most cropland is used for the growing of cereals (66.7%) such as wheat, barley and oats. Other crops (those not used for feeding of stock) accounted for 18.8% of cropland, and included crops such as sugar beat, potatoes and rape. Fodder or compounding crops and horticultural crops occupied a smaller area and together accounting for 14.5% of the cropland in England.

One crop that has expanded rapidly in England in recent years is maize. In 1990, the area under maize cultivation was 33,265 ha, but by 2004, the area under maize had increased to 107,494 ha. In England, maize is grown as a fodder crop. A detailed review of the increase and spatial distribution of maize cultivation in both England and the Southwest Region will be presented in section 4.4.

4.2 Maize Cultivation: An Overview

Maize (*Zea mays* L.) is the world's third most important crops after rice and wheat. According to FAO data, the world total maize production in 2005 was 692 million metric tonnes, and the three top maize producers are the United States (280 million metric tonnes), China (131 million metric tonnes) and Brazil (35 million metric tonnes). However, this information relates to the production of grain maize, and information on maize cultivation for animal feeding is not available from the FAO database. According to the data produced by *Maisadour Semences*, the area of maize cultivation for silage production totalled 3,857,000 ha in 1999, and this accounted for 61.3% of the cultivation of silage maize in Europe. Table 4.1 provides a ranked list of countries in Europe with respect to the area devoted to silage maize in 1999, with the equivalent figures for grain maize cultivation given for comparison. From Table 4.1, it is clear that growing maize for animal feeding or silage maize is more important in northern countries, whilst cultivation of maize for grain is of greater importance in the countries of southern Europe.

The most important countries for silage maize cultivation in Europe in 1999 were France, Romania and Germany, with these three countries accounts for 64.3% of the silage maize production in Europe. The United Kingdom, occupies position 11, and accounted for 2.7% of the area of silage maize cultivation in Europe in 1999. However, in terms of the proportion of arable land occupied by silage maize, Romania tops the ranking, with silage maize occupy 2.136% of its arable land in 1999, and Ireland is at the bottom of the ranking with silage maize occupy only 0.012% of its arable land. Silage maize cultivation in the United Kingdom accounts for 0.099% of its arable land, and placing it at rank 17 within the countries of Europe. In the case of the United Kingdom, more than 90.0 % of the area under maize cultivation is found in England.

Table 4.1: A ranked list silage maize and grain maize production within European countries in 1999

Rank	Country	Silage maize (ha x 10^3)	Silage maize area as a proportion of the total arable land[1]	Grain maize (ha x 10^3)
1	France	1,550	0.810 (7)	1.650
2	Romania	1,300	2.136 (1)	2,000
3	Germany	1,200	1.138 (6)	300
4	Bosnia-Herzegovina	520	1.994 (2)	-
5	Czech Rep.	240	1.206 (5)	40
6	Italy	235	0.211 (11)	920
7	Netherlands	233	1.510 (4)	9
8	Belgium	185	1.675 (3)	20
9	Poland	120	0.158 (14)	120
10	Slovakia	120	0.719 (8)	110
11	United Kingdom	103	0.099 (17)	-
12	Hungary	100	0.537 (10)	950
13	Austria	95	0.191 (12)	140
14	Portugal	55	0.103 (15)	96
15	Croatia	40	0.183 (13)	40
16	Denmark	45	0.558 (9)	-
17	Turkey	40	0.015 (20)	460
18	Switzerland	40	0.100 (16)	25
19	Bulgaria	30	0.081 (18)	370
20	Spain	30	0.016 (19)	330
21	Greece	10	0.015 (21)	115
22	Ireland	5	0.012 (22)	-

Source: Maisadour semences
[1]CIA

In general, there has been a significant increase in the area under silage maize cultivation in Europe since the mid-1980s, in response to changes in both agricultural policy and agricultural technology. Most European countries suffered from WWII, and each country introduced a comprehensive package of agricultural reforms to encourage increased production of food, crops and livestock. More land was put under the plough, and the governments in individual countries continued to support farming activity by subsidising arable cultivation via both area and yield. These subsidies encouraged farmers to plough more land for crop cultivation and to devote more land to cattle. More grass was also cultivated in order to support dairy farming. However, with technological changes in farming, especially in animal feeding, silage maize cultivation became increasing popular in European countries to support dairy farming. This occurred in parallel with a change in animal feeding rations from hay or grass silage (considered less valuable fodder in terms of nutrition), to maize silage, which is rich in nutrients. In addition, and especially in the 1990s, the Common Agricultural Policy (CAP) provided a major impetus to the growing of silage maize through subsidies and other additional benefits associated with dairy farming.

In the case of the United Kingdom, and also England, agricultural policy still plays an important role in defining farming activities. The CAP offers market price support and aid or income support in many ways to support farming activities. In this situation, farmers are highly dependent on income support. This support offers farmers direct income for their arable crops in the form of area payments under the Arable Area Payments Scheme (AAPS). Brassley (2000) stated that, by the mid-1990s, maize qualified for AAPS of up to £320 per hectare. However, in 2001, payment rates declined to £225.64 per hectare but increased to £238.94 per hectare in 2002 and 2003. In 2005, all arable land in England was put under a new scheme called the Single Payment Scheme (SPS), following the CAP reform in 2003. Instead of subsidising arable land based on production as in AAPS, the SPS makes payments based on the 'environmentally friendly' concept. Broadly, the SPS divided land into three classes; moorland with uplands, regarded as Severely Disadvantage Areas (SDA), land in the upland SDA but outside the moorland line, and all land outside the upland SDA. The calculation of the arable area payment rates in these three zones is based on three factors, namely, the historic area, a flat rate, and a combination of the two.

In general, farmers have more freedom to farm to the demands of the market, as subsidies are being decoupled from production. On top of this, environmental friendly farming practices under the standard of Good Agricultural and Environmental Conditions (GAEC) are becoming better acknowledged and rewarded. This will probably have some influence on farmers in making decisions as to whether to grow maize in future. When considering whether farming practises qualify as 'environmentally friendly', soil erosion occurring during the winter after harvesting will need to be taken into account.

As indicated above, maize cultivation in the United Kingdom is undertaken to support dairy farming, and the growing of maize commenced in the 1950s, as forage for cattle. Before that, hay and silage were two main sources of dairy fodder in the UK. Among the factors that make silage maize cultivation important and occupy large area of cropland in the UK, is the importance of dairy farming itself. The major animal fodder in the UK is grass, beans, peas and maize. Maize silage is used to feed dairy cows during the winter prior to their returning from the fields during the summer. As reported later in this chapter, the area of maize cultivation expanded very strongly in the 1990s. Since the war, the pattern and productivity of the UK dairy farming has changed substantially, with better feeding systems, improved genetics and more skilful management of farms (Brigstocke, 2004). Under these conditions, more farmers became involved in dairy farming in England. According to DEFRA data, the number of dairy holders in 1990 totalled 28,756 farms in England and involved more than 1.997 million dairy cows. In 2000 and 2003, the number of dairy holders had decreased to 20,094 and 16,027 farms with the number of cows at 1.575 million and 1.434 million, respectively, for each of these years. Although the number of dairy holders and the number of cows had declined, maize still retains its importance as a fodder crop in England. To some extent, new technologies in making silage suggest that a combination of maize silage with high quality grass silage is a good alternative for winter rations in dairy farming. This situation will probably remain, with farmers continuing to grow maize in the future.

In addition, maize silage has also been shown to provide a better diet in dairy farming and to produce better quality milk. Maize silage at 30-32 percent of dry matter (DM) has been proved to be high in starch and fibre and ferments more slowly in the rumen. For example, milk yield is higher for maize silage (30% DM) at 33.0 kg/day compared with grass silage at only 28.0 kg/day (Advanta).

In general, growing maize for forage needs dry conditions to produce good quality silage. The weather in the UK offers almost ideal conditions for growing fodder maize, especially in England and Wales. Maize cultivation in England usually commences in April, starting with sowing the crop, and ending with harvesting in mid-September or early October. Maize grows well in areas with an annual rainfall below 760 mm and with good soil conditions. In areas with an annual rainfall greater than 760 mm, maize can still be grown (Huntseeds). However, in such cases, farmers are advised to use only early varieties to avoid the need to harvest in late autumn. With warm temperatures and sufficient solar radiation in summer in England, and especially in the Southwest region, maize can be grown in ideal conditions to produce viable yields (ECN).

Other factors motivating farmers to change from grass silage to maize are the overall costs of growing maize, which are relatively cheaper than grass silage. Although maize seed is relatively expensive (around £40 to £50 per acre or 0.4046 ha), compared to grass seed (£6 per 0.4046 ha), the overall costs are cheaper for maize. For example, the establishment and growing costs[1] for grass silage is cheaper than for maize at £76 and £90 per 0.4046 ha, respectively. However, the total fixed costs per 0.4046 ha[2] and the total fixed costs per tonne are relatively cheaper for maize at £6.60 against £7.90 for grass silage. A more detailed calculation involving yield of fresh matter, yield of dry matter, dry matter content and metabolizable energy for maize gives a cost of £196 per 0.4046 ha, compared to grass silage, which is more expensive at £202.50 per 0.4046 ha (Huntseeds).

Although silage maize cultivation is considered as an important crop in Europe and England, it also produces problems for the environment. This already been discussed in Chapter 1. In general, the environmental problems associated with maize cultivation can be related to soil erosion and diffuse water pollution from the area of maize cultivation. Soil erosion problems in maize fields can frequently be related to harvesting in late autumn, which leaves surfaces bare and unprotected from rainfall impact in winter. This could promote surface runoff and sediment mobilization and the transport of sediment to nearby watercourses, which can pollute the water with both nutrients and pesticides. The off-site impact associated with maize cultivation will be discussed in Chapter 7. This chapter will focus on temporal and spatial patterns of maize cultivation in England

[1] Establishment costs involved the cost of seed, agrochemicals and fertilizer before seeding, while the growing costs include fertilizer and agrochemical costs during the growing period.
[2] The total fixed costs per 0.4046 ha include the costs of cultivation, drilling, spraying, fertilizer or slurry spreading, and ensiling costs.

and the Southwest Region, and the factors that have influenced changes in these patterns.

4.3 The Data Used in this Analysis

This investigation of spatial and temporal patterns of maize cultivation in England and the Southwest region is based on data from two sources. The sources comprise, firstly, the Department for Environment, Food and Rural Affairs (DEFRA), and secondly, the Edinburgh Library (EL). Each source has a different background which was explained in the previous chapter.

The DEFRA data are based on the annual census through the Agricultural and Horticultural Census, which are released annually in June. These data are based on farmers' information returns, field-by-field, and the results are presented in acreage format. In the case of the EL data, the data are in digital map format, based on a spatial resolution of a 1 km^2 grid. It was necessary to manipulate the scale of the data from unsupervised format to a supervised format of five categories, based on the density of maize cultivation area in ha km^{-2}. The five categories are (i) less than 2 ha km^{-2}, (ii) 3-6 ha km^{-2}, (iii) 7-12 ha km^{-2}, (iv) 13-20 ha km^{-2}, and (v) more than 20 ha km^{-2}. The (i) and (ii) values are considered as a low density, (iii) as a moderate density, and (iv) and (v) as a high density. Although the manipulation of the EL data was applied to all available data, as mentioned in the previous chapter, for the purpose of this chapter, only relevant data will be used in order to review the spatial and temporal patterns of maize cultivation in England. This involves the data available for four years, namely, 1979, 1988, 1995 and 2000.

4.4 Maize Cultivation in England

As indicated in the introduction to this chapter, crops still constitute the largest area of agricultural land in England with most of cropland having used for the growing of cereals. Cereals have becomes the most important crops in England since 1950, and the area has probably never fallen below 2.4 million ha. The second most important crop in England is stock crops (not for stock feeding) such as potato and sugar beat. This crop increased in area by 25.9% between 1950 and 2003, increasing from 570,200 ha in 1950 to 717,700 ha in 2003. Fodder crops[3] occupied the third place for cropland in England. The area under fodder crops in 1950 extended 386,000 ha but this had decreased by 5.3% to 365,500 ha in 2003. Beans and peas have becomes important fodder crops in England and accounted for 62.9% or 229,900 ha of the fodder crop area in 2003. They are followed by maize in third place and the area cultivated for maize has expanded rapidly since the 1970s.

According to DEFRA data, maize has been grown as a fodder crops in England since 1970, but the area was small in the early years. Figure 4.1 shows the temporal trend in the area devoted to maize in England in the period from 1970 to 2004. In the early 1970s, the area of maize cultivation in England was relatively small, occupying an area of less than 10,000 ha, and representing less than 5.0% of the total area under fodder crops. The area of maize cultivation expanded to 20,800 ha in 1980, and increased by a further 60.1% to 33,300 ha in 1990. However, since 1990, the area expanded to 100,000 ha in 1995 and to 107,494 ha in 2004, an increased of 7.5%. The greatest area cultivated for maize in England was reported in 2001, when the crop occupied an area of 119,557

[3] This includes turnips, swedes, fodder beet, mangolds, kale, cabbage, savoy, kohl rabi, beans, peas and maize.

ha. Table 4.2 presents more detailed data for the trend in the maize cultivation area in England between 1970 and 2004.

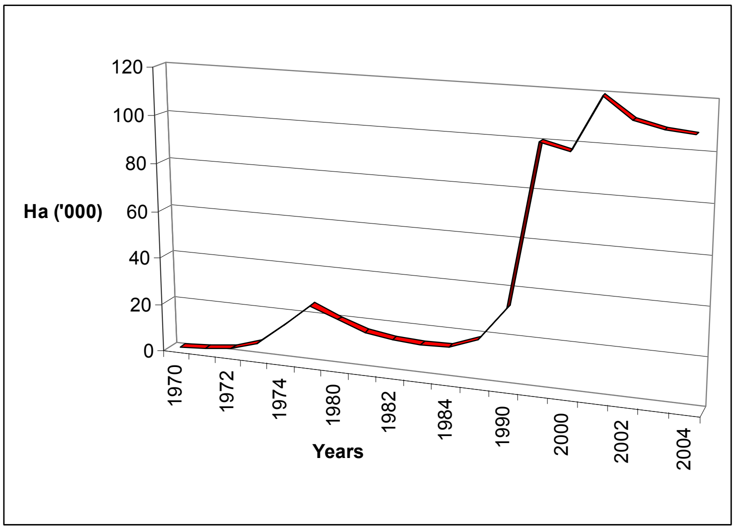

Figure 4.1: Trends in maize cultivation in England between 1970 and 2004

Table 4.2: Changes in the maize cultivation area in England between 1970 and 2004

Year	Area (ha x 10^3)	Change (%)	Year	Area (ha x 10^3)	Change (%)
1970	1.0	-	1984	14.7	1983-1984 (+2.1)
1971	2.0	1970-1971 (+100.0)	1985	19.0	1984-1985 (+16.2)
1972	3.5	1971-1972 (+75.0)	1990	33.3	1985-1990 (+75.3)
1973	6.6	1972-1973 (+88.6)	1995	100.4	1990-1995 (+67.0)
1974	15.7	1973-1974 (+137.9)	2000	97.6	1995-2000 (-2.8)
1975	25.5	1974-1975 (+62.4)	2001	119.5	2000-2001 (+22.4)
1980	20.8	1975-1980 (-18.4)	2002	111.3	2001-2002 (-6.9)
1981	17.0	1980-1981 (-18.3)	2003	108.4	2002-2003 (-2.6)
1982	15.0	1981-1982 (-11.8)	2004	107.4	2003-2004 (-0.9)
1983	14.4	1982-1983 (-4.0)	-	-	-

Source: DEFRA (various years)

Most of the area of maize cultivation during the 1970s was in the Eastern, Southeast and Southwest regions, as shown in Figure 4.2. In the Eastern region, the area of maize cultivation was greatest in the north-western and south-eastern parts. In the Southeast, the maize cultivation area spread to the south-eastern, south-western and north-western parts of the region but the greatest concentration was in the north-west of this region. The area of maize cultivation in the Southwest was greatest in the eastern part of the region.

Figure 4.3 shows the spatial distribution of maize cultivation area in England in 1988. After nine years, the main areas of maize cultivation in England had a similar location to that in 1979. However, in terms of the density, more areas of maize cultivation evidenced increased, especially in the Southeast and the Southwest regions. In the Southeast, more areas in the south-western and the north-western part of the region became moderate in density, whilst in the Southwest, some area in the eastern part of the region became high in density, and this area probably represented the greatest concentration of maize growing in England in the late 1980s.

Although the maps of the maize cultivation areas in England in 1979 and 1988, presented in Figure 4.2 and Figure 4.3, show some changes in density, in general many areas remained low. Growing maize in the United Kingdom has always been related to dairy farming, and more specifically to milk prices. Some small changes in the density of maize cultivation in the 1970s to 1980s could reflect decreases in the milk price. According to the Milk Marketing Board (DEFRA), the milk price in 1974-1983 (26.92 p/l) decreased by 9.1% when compared to that in 1964-1973 (24.48 p/l).

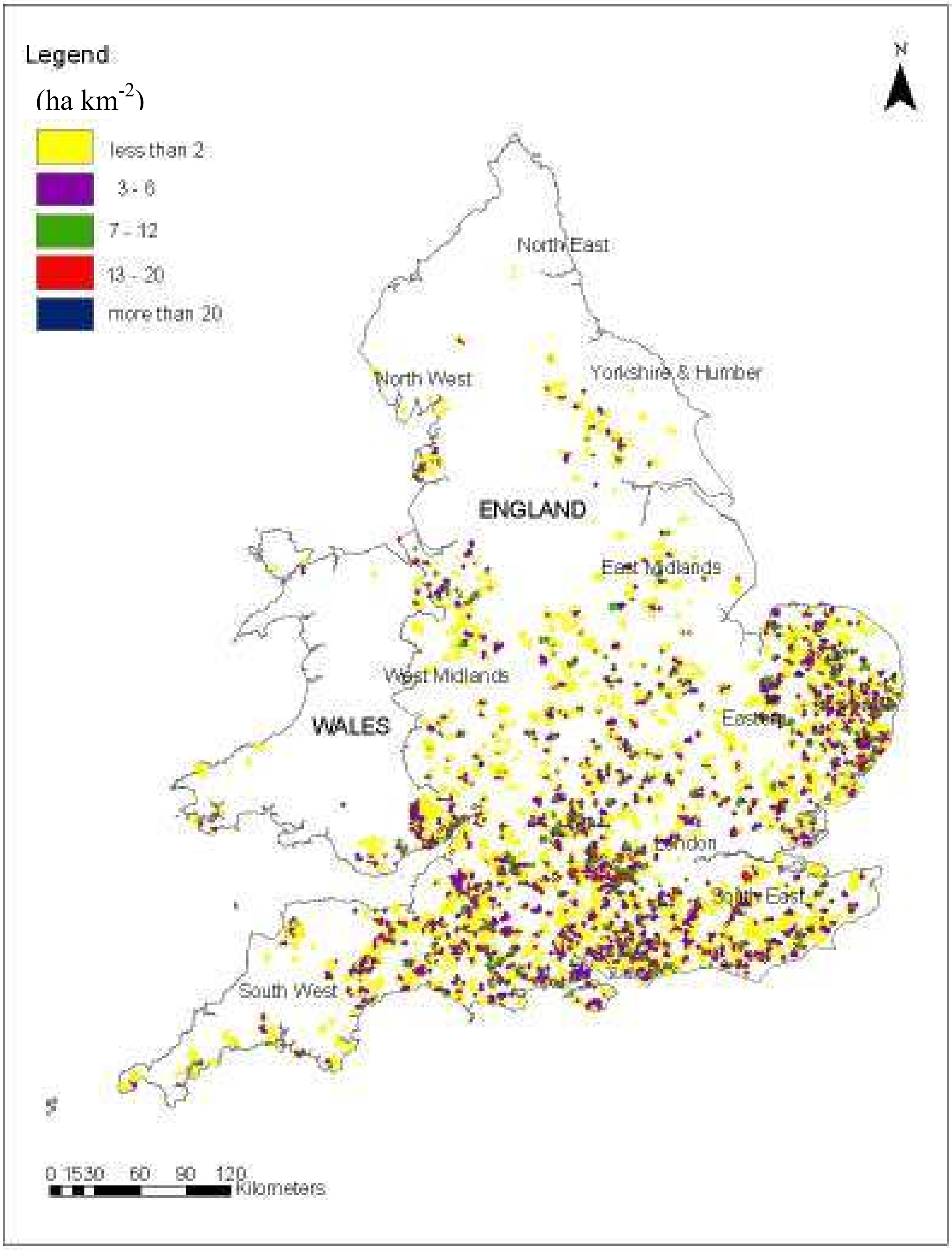

Figure 4.2: The distribution of maize cultivation in England in 1979

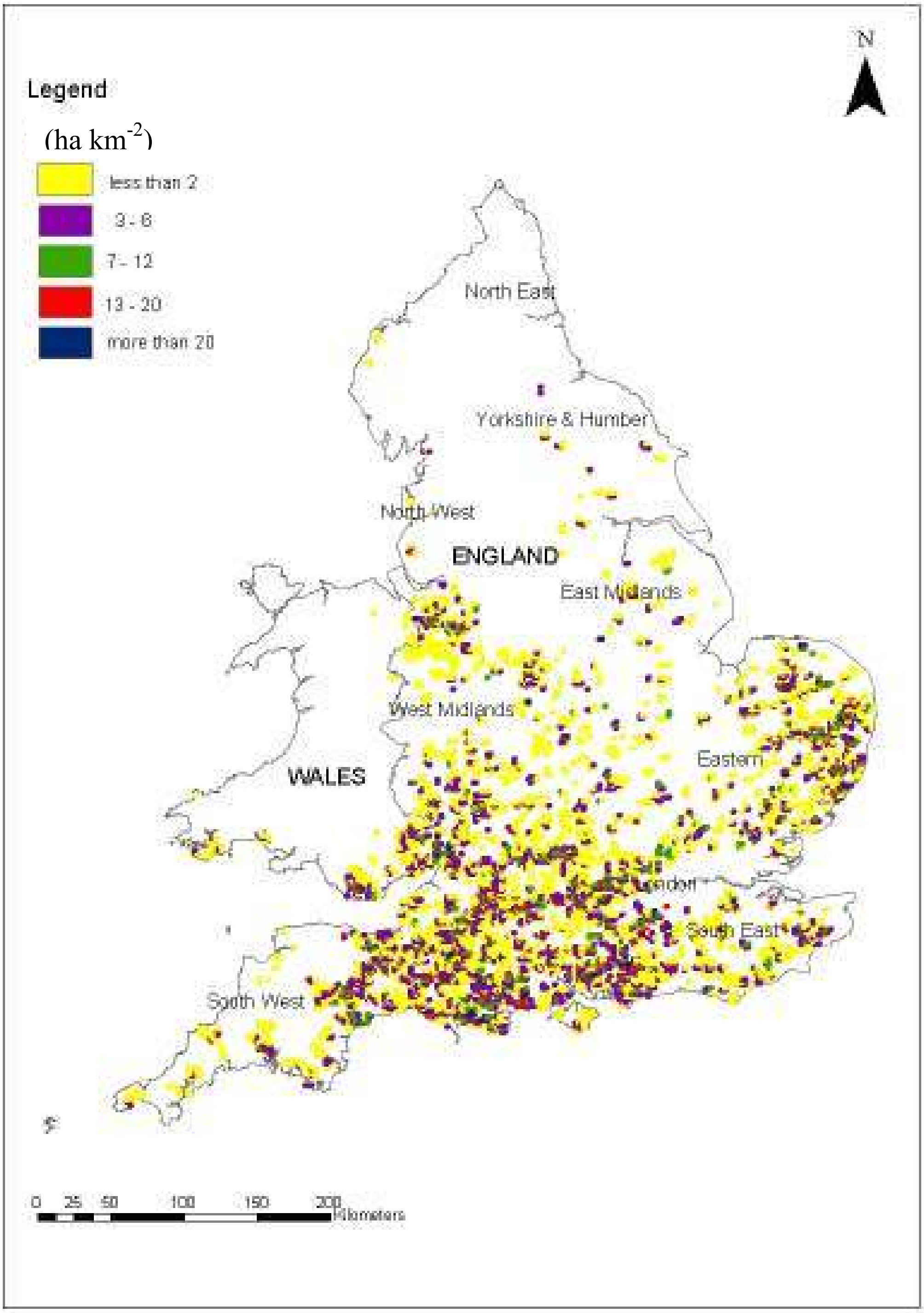

Figure 4.3: The distribution of maize cultivation in England in 1988

By 1995, there was very rapid expansion of the area of maize cultivation in England compared to 1990. The area cultivated with maize increased by 201.5% to 100,432 ha. With the exceptional of the Eastern region, all regions in England showed more than a 100.0% increase in their maize cultivation area, as shown in Table 4.3. The area cultivated for maize in the Eastern region increased by only 50.0%. The largest area cultivated with maize in 1995 was found in the Southwest region, occupying an area of 49,600 ha, followed by the Southeast region (18,900 ha), the West Midlands (12,700 ha), and the Eastern region (6,000 ha). According to Figure 4.4, the greatest concentration of maize growing in 1995 was in the Southwest and West Midlands regions, especially in the eastern part of the Southwest, and in the northern and southern parts of the West Midlands. Meanwhile, in the Southeast region, maize cultivation was greatest in the south-western part. Compared with 1988, more areas in England were characterized by a higher density of maize production.

This major change in area and density of maize cultivation can be related to incentives from the AAPS. As indicated in Section 4.2, by the mid-1990s, maize qualified for the highest payment of £320 per 0.4046 ha. Supporting this was an increase in the standard milk price from 19.35 p/l in 1985-1980 to 21.28 p/l in 1991-1998, which also caused growth in the dairy farming sector. The 1990s also saw changes in technology for maize growers. Improvement in mechanization allowed the use of larger machines that in turn led to an increase in field and farm sizes. New tractors for cultivation such as sprayers for weed pest and disease control, and the use of larger harvesting machines helped farmers to reduce overall costs, and encouraged farmers to grow maize on a large scale. In addition, genetic improvements, which focused on herbicide tolerance, and also

Table 4.3: The maize cultivation area for all regions in England

Region	Area in 1990 (ha x 10^3)	Area in 1995 (ha x 10^3)	Change 1991-1995 (%)	Area in 2000 (ha x 10^3)	Change 1995-2000 (%)	Area in 2001 (ha x 10^3)	Change 2000-2001 (%)	Area in 2002 (ha x 10^3)	Change 2001-2002 (%)	Area in 2003 (ha x 10^3)	Change 2002-2003 (%)
South West	15.0	49.6	+230.6	42.8	-13.7	51.6	+20.6	48.2	-6.6	47.8	-0.8
South East	9.0	18.9	+110.0	18.1	-4.2	22.1	+22.1	20.2	-8.6	18.7	-7.4
Eastern	4.0	6.0	+50.0	6.3	+5.0	7.7	+22.2	7.0	-9.1	6.2	-11.4
West Midlands	2.0	12.7	+535.0	13.0	+2.4	16.1	+23.8	15.3	-5.0	15.3	0.0
Northwest	1.2	5.8	+383.3	8.2	+41.4	10.1	+23.2	9.5	-6.0	9.6	+1.0
East Midlands	1.1	5.4	+390.9	6.8	+25.9	8.7	+27.9	8.0	-8.0	7.8	-2.5
Yorkshire and Humber	0.3	1.5	+400.0	2.0	+33.3	2.6	+30.0	2.7	+3.8	2.6	-3.7
Northeast	0.02	0.2	+900.0	0.2	0.0	0.2	0.0	0.2	0.0	0.2	0.0
London	0.06	0.2	+233.3	0.2	0.0	0.3	+50.0	0.1	-30.0	0.1	0.0

Source: DEFRA (various years)

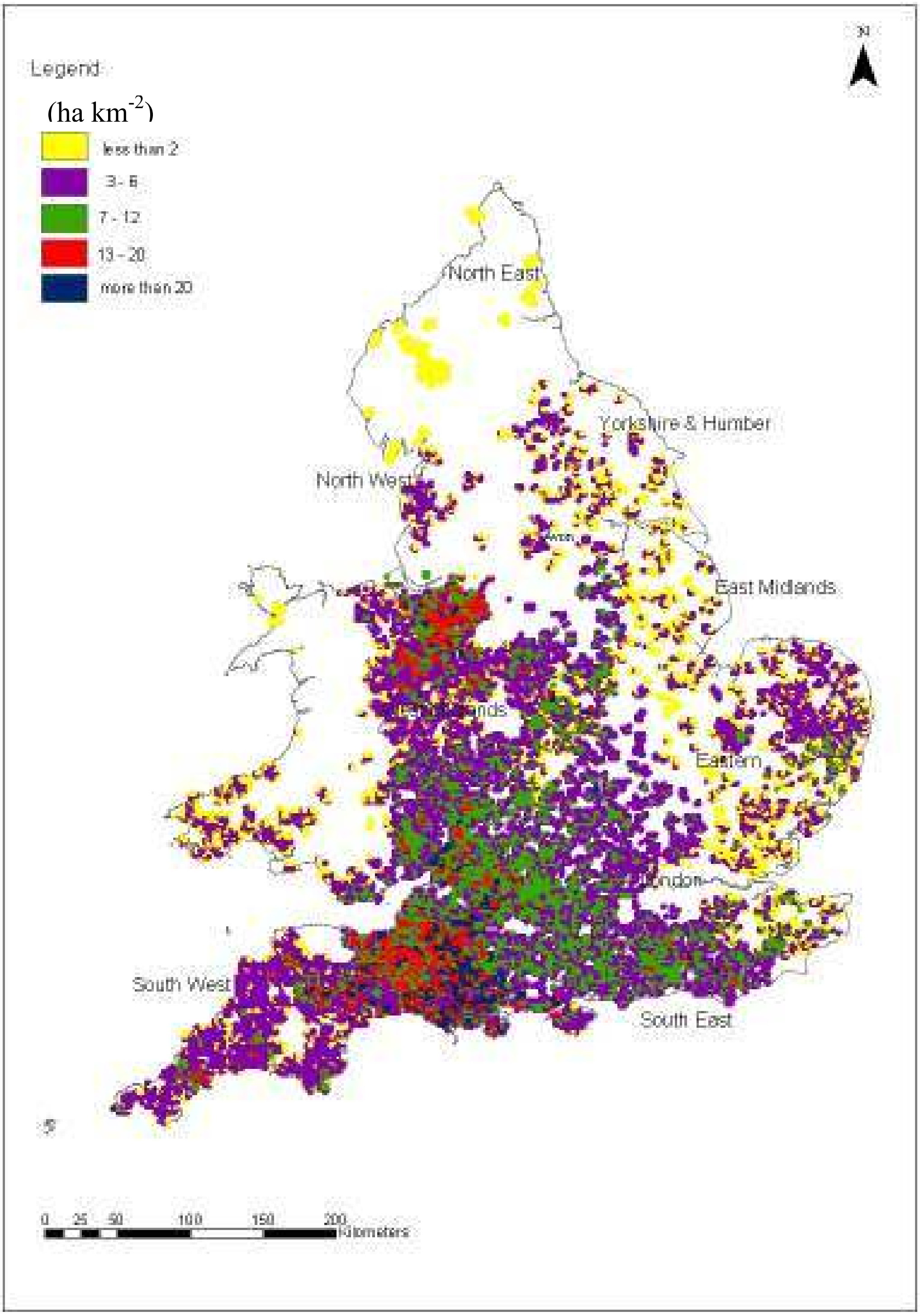

Figure 4.4: The distribution of maize cultivation in England in 1995

provided maize growers with various varieties of high yield seeds, increased maize yields and maize growers' incomes, on top of the AAPS.

By 2000, the area under maize cultivation in England slightly decreased by 2.8%, down to 97,623 ha, compared with area in 1995, but increased again in 2004 by 10.1% up to 107,494 ha. As in the 1980s and 1990s, the Southwest region and the Southeast still remained as the most important maize cultivation areas in England in 2000. However, the area under maize expanded more in the Southwest than in the Southeast, as shown in Figure 4.5. Most of the area under maize in the Eastern region and the West Midlands remained more or less static. The densest area cultivated with maize could thus be found in the Southwest, especially in the eastern part of Devon, Somerset and Dorset. The area cultivated with maize in the Southeast still remained densest in the western and southern parts of the region, whilst in the West Midlands, the densest area for maize cultivation could be observed in northern part, spreading out from there to the southern part of the region.

Small changes in the area of maize cultivation between 1995 and 2004 can be related to changes in the dairy farming sector. The number of dairy farming holders and the number of dairy cows in 2004 decreased by 37.0% (15,554 holders) and 24.0% (1,374,456 cows), respectively, compared with 1995, when there were 24,678 holders and 1,809,282 cows. This decrease can also be related to a decline in milk price, where the milk price in 2002-2003 was 18.33 p/l, a decrease of 13.9% from the price in 1997-1998 (21.28 p/l). The expansion of the area under maize in England, also has implications for environmental problems, especially the off-site impact of the silage maize area after harvesting during winter, in regard to soil erosion from bare maize fields. This is one of the DEFRA concerns in the CAP reform in 2000, which

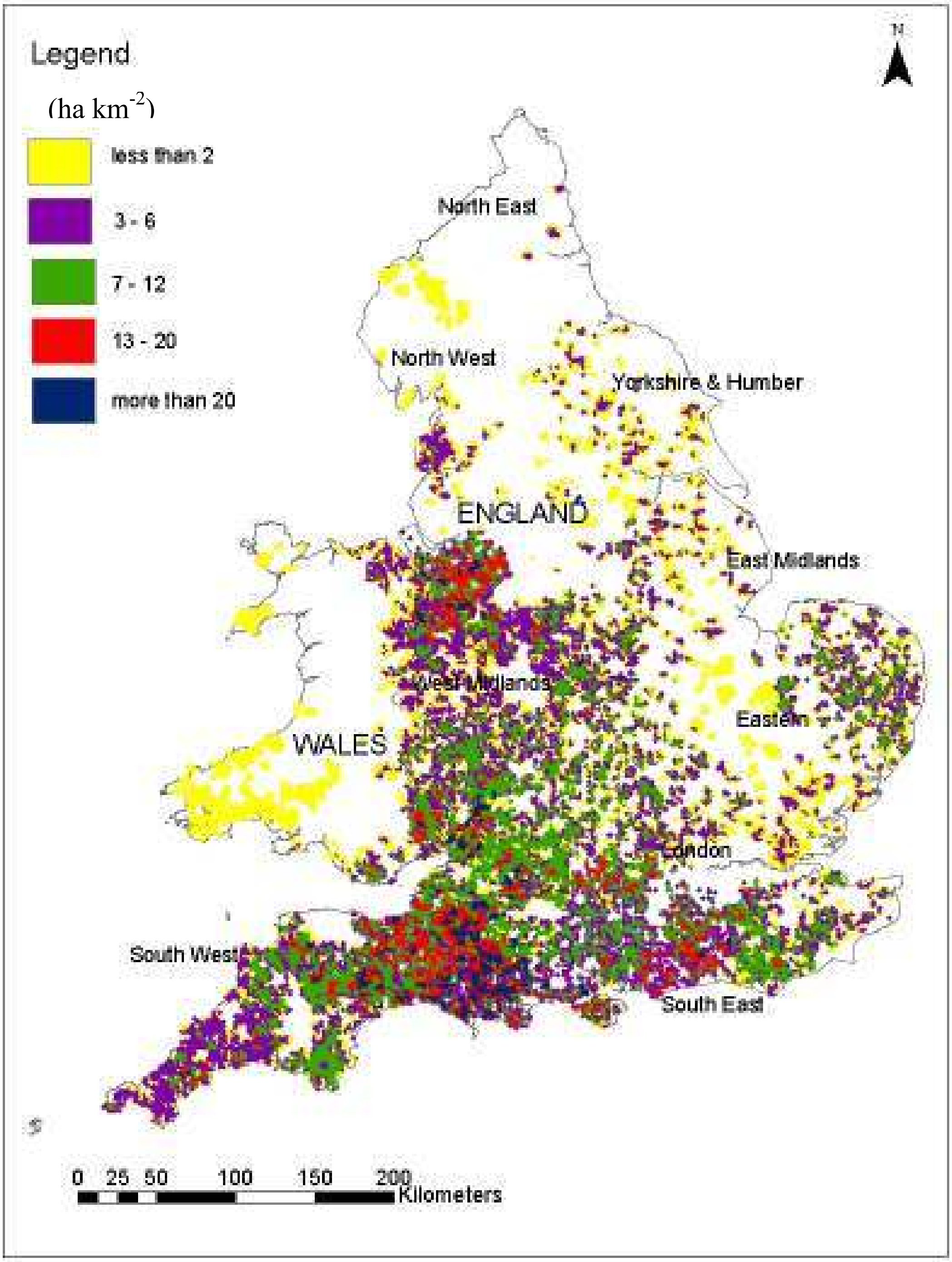

Figure 4.5: The distribution of maize cultivation in England in 2000

recognized that the degraded standard of water quality during winter could be caused by soil erosion from bare maize fields. One of the key changes associated with the CAP reform in 2000, aimed at reducing soil erosion, and avoiding diffuse pollution from maize area and other crop lands, was the AAPS, which declined by 29.5% in 2001 to £225.64 per hectare, compared with payment rates in the mid-1990s of £320.00 per hectare. Although DEFRA promoted environmentally friendly practises in cropping through the agri-environmental scheme, most farmers, including maize growers, were probably still not ready to change the management systems at that time, especially small holding farmers.

Although the area of maize cultivation shows a decline between 1990 and 2004, the author also believes that the area of maize cultivation will continue to show a small decrease in coming years, at least until 2010. This is based on the projection by the Milk Development Council, that milk price would be around 15.00 p/l from 2007 onwards. Compared with milk price in 2002-2003, this is a decrease by 18.2%. Under the CAP reform in 2003, farmers have to follow many environmentally friendly approaches recommended by DEFRA in order to sustain the environment. However, it seems that many farmers are still not ready to fulfil most of the environmentally friendly requirements, as for example mentioned in the Single Payment Scheme and the Environmental Stewardship Scheme, which required them to prepare Soil Management Plans and Soil Protection Reviews. All these could influence the area of maize cultivation in England in the future.

4.5 Maize Cultivation in the Southwest Region

In terms of cropland area, the Southwest is the fifth region in England after the Eastern region, the East Midlands, the Southeast, and Yorkshire and the Humber region. In

2003, the Southwest region accounted for 7.1% of the cropland in England. Cereals have become the most important crop in the Southwest region, and in 2003 occupied an area of more than 312,600 ha. Fodder crops were in second place with a cultivated area of greater than 80,800 ha. Somerset, Devon and Dorset had been the largest areas cultivated with cereals and fodder crops in 2003. Figure 4.6 shows the trends for cropland areas in the Southwest, whilst Figure 4.7 shows the trend for cropland areas for each county in the Southwest from 1950 to 2003.

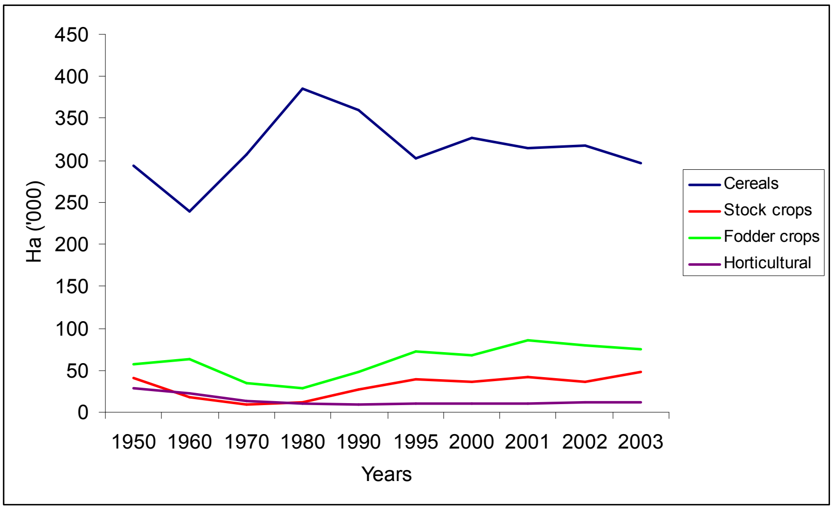

Figure 4.6: Trends in cropland area in the Southwest between 1950 to 2003

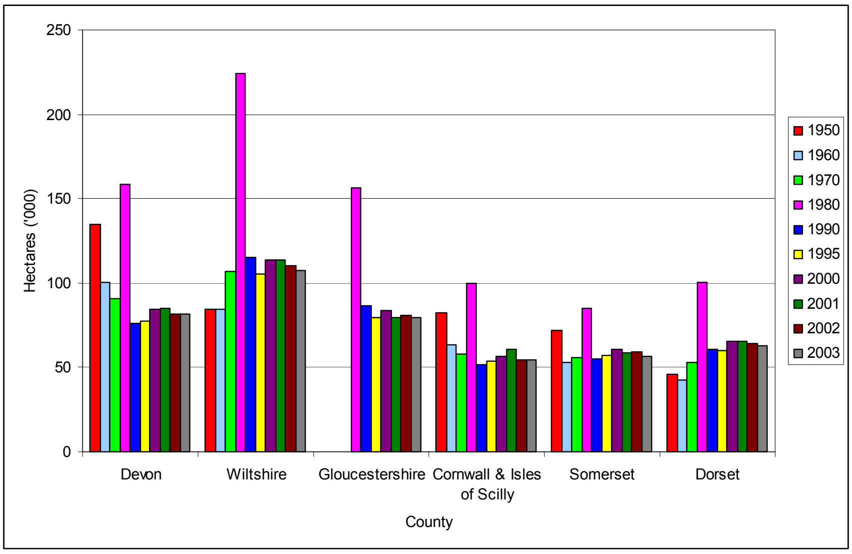

Figure 4.7: Trends in cropland area for each county in the Southwest between 1950 to 2003

As indicated in section 4.4, maize has probably been grown as a fodder crop since the late 1960s, and the area cultivated with maize also expanded very rapidly in the Southwest, especially in the 1990s and early 2000s. In 1990, the area under maize in the Southwest occupied 14,200 ha, and increased by 228.2% up to 46,600 ha in 1995. However, this figure declined by 14.2% in 2000 to 40,000 ha, but increased again in 2004 by 11.7% to 44,700 ha. According to Figure 4.8, Dorset and Somerset became the most important areas of maize cultivation in 1990, accounting for 3,400 ha and 3,300 ha, respectively. However, by 1995, Somerset had become the most important area of maize cultivation, with an area of 11,200 ha. Somerset was followed by Dorset and Devon in second and third places, with areas of 9,500 ha and 9,200 ha, respectively. Until 2003, Somerset and Devon were the most important maize growing areas in the Southwest, with a combined area of 20,500 ha.

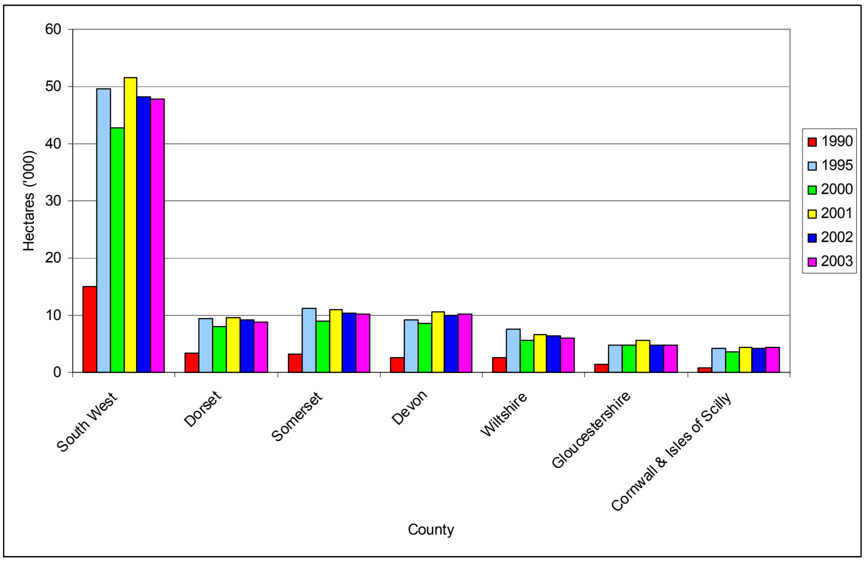

Figure 4.8: Trend in maize cultivation for each county in the Southwest between 1990 to 2003

As shown in Figure 4.9, Somerset, Dorset and Wiltshire were the most important areas for maize cultivation in 1979. In Somerset, maize cultivation was densest in the eastern and southern parts of the county. In Dorset, maize cultivation can be seen to be important in the eastern and south-eastern parts of the county, whilst in Wiltshire, most of the maize cultivation area can be found in the western and northern parts of the county. At this time, maize cultivation was relatively limited in Devon, Gloucestershire, Avon and Cornwall.

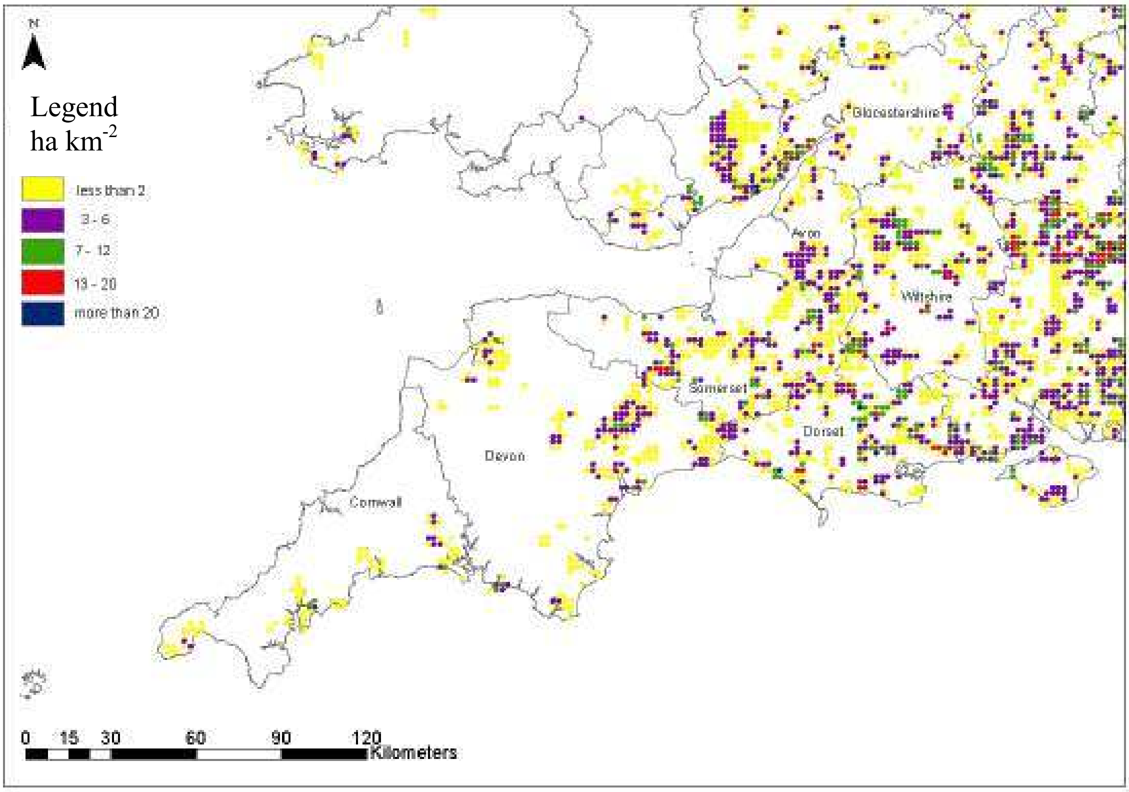

Figure 4.9: The distribution of maize cultivation in the Southwest Region (1979)

When compared with 1979, maize cultivation in the Southwest in 1988 expanded rapidly in Devon, as shown in Figure 4.10. The area of maize cultivation became moderately dense in the eastern and south-eastern parts of the county. Meanwhile, in Somerset, maize cultivation was widely distributed, whilst in Dorset, only limited changes were seen in terms of the area of maize cultivation, because it was largely grown within the same areas. These changes reflected similar trends to those found at the national scale, which can be related to increases in the number of dairy cows.

Overall, the number of dairy cows in the South declined by 7.7% between 1981 and 1988 from 778,880 cows in 1981 to 718,767 cows in 1988.

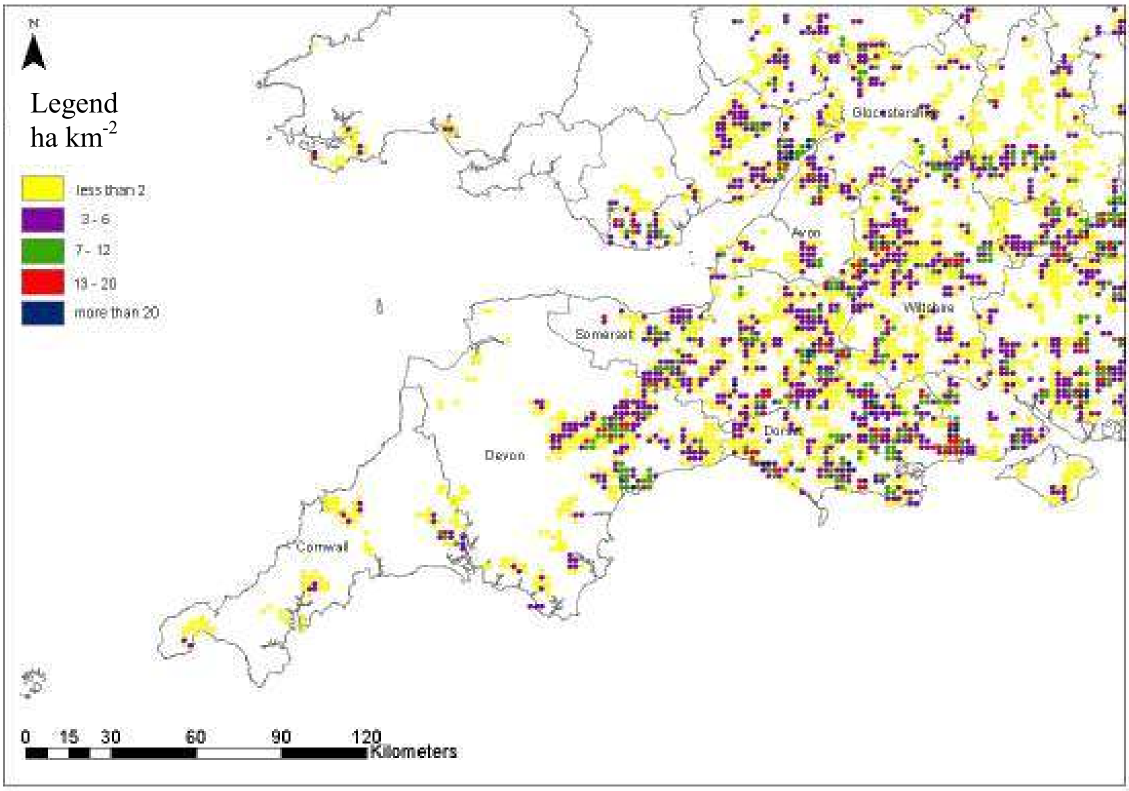

Figure 4.10: The distribution of maize cultivation in the
Southwest Region (1988)

According to Figure 4.11, the density of maize cultivation in the Southwest in 1995 was denser than in 1988. By 1995, the densest area was in eastern part of Somerset and northern part of Dorset. In fact, the area under maize in Somerset expanded in every corner of the county except the north-western part. Other counties also show an expansion of the area of maize cultivation, and more new areas of maize cultivation can be found in southern, western and south-eastern parts of Devon and Cornwall. In 2000, the densest area of maize cultivation occurred in almost the same locations as in 1995, and there were not many changes can be found in terms of the absolute density (Figure 4.12). In some areas in Wiltshire that were cultivated with maize previously, the density of maize cultivation increased, especially in the northern and eastern parts of the county. However, in other counties, most of the areas previously under maize have remained so. In addition, the highest increases in the area under maize in the Southwest between 1995 and 2000 occurred in Devon, by 15% up to 10,599 ha.

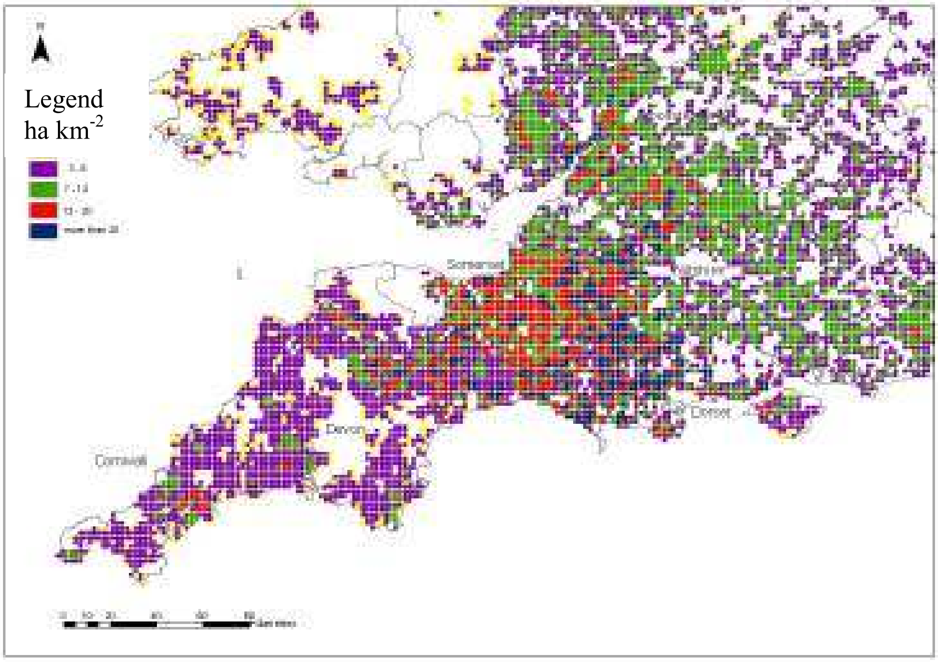

Figure 4.11: The distribution of maize cultivation in the Southwest Region (1995)

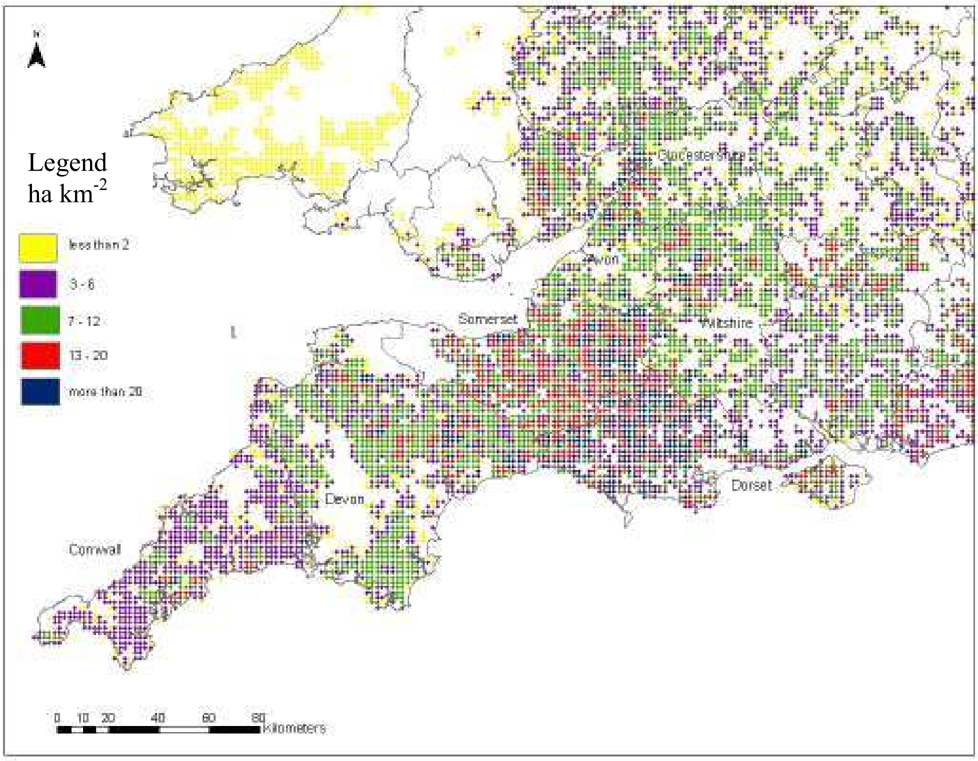

Figure 4.12: The distribution of maize cultivation in the Southwest Region (2000)

Some changes in the density of the area under maize in the Southwest between 1995 and 2000 show similar trends to the national level. In addition to the decline in milk price and incentive payment under the AAPS, the number of dairy cows in all counties in the Southwest also decreased. For example, the number of dairy cows in Devon in 2000 decreased by 11.5% (155,229 cows), compared with the number of dairy cows in 1995 (175,505 cows). Table 4.4 shows the decreases in number of dairy cows in the Southwest that could account for the changes in the area under maize in the region.

4.6 Conclusion

Agriculture is one of the important activities in England, especially in the Southwest region. Most of the agricultural land in England and the Southwest is cultivated with crops, especially for cereal and stock feeding. Fodder crops have become the third most important crops in England and the Southwest. Maize too has become an important fodder crop, and its cultivation expanded very rapidly between 1990 and 2000 in England and notably the Southwest region.

This chapter has discussed the temporal and spatial patterns of maize cultivation in England at the national level but with particular emphasis on the Southwest region. At the national level, growing maize as a fodder crop has become very important since the 1990s to support dairy farming. The rapid expansion of the maize area has occurred in almost every region in England, especially in the Eastern, Southeast and Southwest regions. From the 1970s to the 1980s, most of the maize cultivation area could be found in the Eastern and Southeast regions. However, since then, maize cultivation area has spread rapidly and has become denser in the Southwest region from the 1990s to the present. In the Southwest, the spatial distribution of maize cultivation area in the 1970s and 1980s became denser in Somerset, Dorset and Wiltshire. However, the situation has

SOIL EROSION, DIFFUSE SOURCE POLLUTION AND SEDIMENT PROBLEMS ASSOCIATED WITH MAIZE CULTIVATION IN ENGLAND

by

MOKHTAR BIN JAAFAR

Thesis submitted in partial fulfillment of the requirement for the Degree of Doctor of Philosophy of the University of Exeter

May 2010

SOIL EROSION, DIFFUSE SOURCE POLLUTION AND SEDIMENT PROBLEMS ASSOCIATED WITH MAIZE CULTIVATION IN ENGLAND

Submitted by MOKHTAR BIN JAAFAR to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Geography, May 2010.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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(MOKHTAR BIN JAAFAR)

Abstract

SOIL EROSION, DIFFUSE SOURCE POLLUTION AND SEDIMENT PROBLEMS ASSOCIATED WITH MAIZE CULTIVATION IN ENGLAND

This thesis reports an investigation of soil erosion problems associated with maize cultivation in England. To place the investigation into a broader context, the study commences with a review of soil erosion problems more generally, before focusing on the specific on-site and off-site problems associated with maize cultivation. Agricultural statistics are used to quantify the recent expansion of maize cultivation in England and attention is directed to both the temporal trends and spatial patterns involved. A major expansion of maize cultivation occurred in England between 1990 and 2000. Particular attention is then directed to the expansion of maize cultivation in Southwest England, since this is a very important area for cultivation of forage maize.

Against this general background, a more detailed investigation of soil erosion associated with maize fields and its impact on the local streams and rivers was undertaken. This focused on two river catchments, namely the River Culm above Cullompton, Devon, and the River Tone above Taunton, Somerset. These two basins were selected as having a high density of maize fields within their catchments. A detailed field survey was undertaken to identify all the fields used for maize cultivation in the two catchments during 2004 and the previous two years and to provide a map of their location. More detailed work, aimed at quantifying both gross and net rates of soil loss, was undertaken on six fields selected to be representative of maize fields in the two catchments. Beryllium-7 measurements were used to estimate the erosion associated with a period of heavy rainfall in late December 2004 and early January 2005, when the harvest fields were left in a bare compacted conditions, with little or no vegetation cover and field observations indicated that significant erosion occurred. The results obtained from the beryllium-7 measurements which related only to the short period in late 2004 and early 2005 were complemented by caesium-137 measurements in the same fields which were used to obtain an estimate of the longer-term (i.e. *ca*. 45 years) mean annual erosion rates associated with the more traditional land use that had characterized these fields prior to the introduction of forage maize cultivation. These results indicated that the introduction of maize cultivation increased gross and net rates of soil loss by ca. 4 and 8 times, respectively and significantly increased sediment delivery ratios, resulting in more efficient delivery of sediment from the eroding fields to the streams.

An assessment of the likely impact of sediment mobilised from the maize fields within the catchments of the River Culm and River Tone during winter 2004-5 was made by establishing a sediment monitoring and sampling programme at the downstream gauging stations on these two rivers over the period November 2004 to March 2005. Estimates of the suspended sediment loads of both rivers were obtained for this period and these were compared with an estimate of the total amount of sediment delivered to the water courses in the two catchments from maize fields based on an upscaling of the results obtained from the beryllium-7 measurements undertaken on the six representative fields. Uncertainties regarding both field to channel and within channel

and floodplain conveyance losses precluded definitive comparison of the estimates of the amounts of sediment delivered to the water courses from maize fields with the measured sediment loads. However, the results obtained demonstrated the likely importance of the contribution from eroding maize fields to the suspended sediment loads of the Rivers Culm and Tone during winter 2004-5. The geochemical properties of suspended sediment collected from the two rivers were also compared with the equivalent properties of soil collected from the surface of maize fields within the two study catchments, in order to provide further evidence of the impact of maize cultivation on their suspended loads. The available geochemical data confirmed that much of the sediment transported by the Rivers Culm and Tone could have been mobilized from maize fields, but the lack of detailed geochemical data, precluded a definitive conclusion regarding its source.

The results obtained from the field-based component of the study have been combined with the information on the regional and national patterns of maize cultivation and synthesized to provide a general assessment of the likely environmental impact of maize cultivation in England. This information has in turn been used to consider the potential for developing improved land management practises to reduce the environmental impact of maize cultivation within the context of the EU Common Agricultural Policy (CAP) and the Water Framework Directive (WFD). Finally, recommendations for the further development and extension of the study are provided.

CONTENTS

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ABBREVIATIONS

AAPS	Arable Area Payment Scheme
AAS	Atomic Absorption Spectrophotometry
ACL	Agricultural Land Classification
AES	Agri-Environment Scheme
Bq	Becquerel
CAP	Common Agricultural Policy
CEH	Centre for Ecological Hydrology
CIA	Central Intelligence Agency
COGAP	Code of Good Agricultural Practise
CSF	Catchment Sensitive Farming
CSS	Countryside Stewardship Scheme
DC	The number of dairy cows
CS	Countryside Stewardship
DEFRA	Department of Environment, Food and Rural Affairs
DM	Dry matter (maize silage)
DWPA	Diffuse Water Pollution from Agriculture
EA	Environment Agency
EAS	Environmentally Sensitive Areas
ECSFDI	England Catchment Sensitive Farming Delivery Initiative
EL	Edinburgh Library
ELS	Entry Level Stewardship
ESA	Environmentally Sensitive Area
ESS	Environmental Stewardship Scheme
ETDA	Ethylene diamine-tetra acid
EU	European Union
EUWFD	European Union Water Framework Directive
FAO	Food and Agriculture Organization
FEP	Full energy peak
FER	Farm Environment Record
FMD	Foot and Mouth Disease
FRP	Filterable reactive P
GAEC	Good Agricultural and Environmental Condition
GER	Gross erosion rate
GIS	Geographical Information Systems
HLS	Higher Level Stewardship
HPGe	High-purity germanium
IACR	Institute of Arable Crops Research
IGER	Institute of Grassland and Environmental Research
LCM	Land Cover Map
LFA	Less Favoured Area
MAFF	Ministry of Agriculture, Fisheries and Food
MC	Area under maize cultivation
NER	Net erosion rate
NVZ	Nitrate Vulnerable Zones
OELS	Organic Entry Level Stewardship
POS	Protection of Soil

POW	Protection of Water
RBMP	River Basin Management Plan
RBPG	River Basin Planning Guidance
RPA	Rural Payment Agency
RQO	River Quality Objective
SDA	Severely Disadvantage Areas
SDR	Sediment delivery ratio
SFPS (SFP)	Single Farm Payment Scheme
SMP	Soil Management Plan
SMR	Statutory Management Requirements
SOAEFD	The Scottish Office Agriculture, Environment and Fisheries Department
SPS	Single Payment Scheme
SSC	Suspended sediment concentration
FTU	Formazin Turbidity Unit
SSL	Suspended sediment load
SY	Sediment yield
TPO	Tree Preservation Orders
TSE	Transmissible Spongiform Encephalopathies
USLE	Universal Soil Loss Equation
WFD	Water Framework Directive

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CHAPTER 1: INTRODUCTION

1.1 Overview

Globally, land degradation is studied by scientists, such as geomorphologists, engineers and ecologists in order to understand physical processes. In particular, soil erosion is one of the physical processes of land degradation that can cause serious environmental problems.

Pimentel and Kounang (1998) estimated that about 75 billion tonne of soils are eroded from the world's terrestrial ecosystems each year. In most cases, agricultural land is the most at risk of being eroded, losing soil at rates ranging from 13 t/ha/yr to 40 t/ha/yr. The authors also state that worldwide, erosion rates range from a low of 0.001-2 t/ha/yr on relatively flat land with grass and/or forest cover to rates ranging from 1-5 t/ha/yr on mountainous regions with normal vegetation cover. Many scientists also agree that the rate of soil erosion, either by wind or water, frequently exceeds the rate of soil formation. For example, over a period of 100 years at an erosion rate of 2 t/ha/yr on 10 ha, erosion deposits soil equivalent to about 1 ha of land with a soil depth of 15 cm (Pimentel and Kounang, 1998).

Agricultural land is probably the greatest contributor to soil loss in the world. According to the FAO (2003), about one-third of agricultural land is planted for crops, and cropland is more highly susceptible to erosion as a result of tillage practises, which expose the soil to wind and water erosion. Serious on-farm soil erosion reduces overall crop productivity. This is associated with loss of organic matter and plant nutrients in the erosion process, together with a reduction of soil depth. In addition, soil erosion by water on slopes will decrease the infiltration capacity and this will result in increased runoff and decreased water-storage. Wiebe (2003) estimated that the global crop production loss caused by erosion is highest for potatoes at 0.6% per year, followed by millet (0.48%), and maize (0.42%). It has also been estimated that the total anual cost of erosion from agricultural land in the USA is about US$44 billion per year, which is equivalent to US$247 per ha of cropland and pasture (Eswaran et al. (various years) in Wiebe, 2003).

Off-farm impacts of soil erosion from agricultural land are varied, but serious environmental problems on agricultural terrain commonly start when runoff transporting soil particles reaches water bodies or streams. This will affect the biological status of water systems, degrading water quality and threatening aquatic life, and can cause flooding when overflow occurs because of sedimentation. The cost of the damage associated with the off-farm impacts of soil erosion is difficult to quantify precisely but it is generally high and of a similar magnitude to the on-site costs, and perhaps higher.

1.2 Soil Erosion on Agricultural Land in England

Archaeological studies have suggested that soil erosion has probably taken place in England since the clearance of land for agriculture in the Bronze Age (Bell and Boardman, 1992). However, soil erosion has really only been recognized as a serious environmental problem in England since the 1970s, and is often associated with negative impacts resulting from inappropriate land management. Robinson (1999) listed a number of studies of soil erosion in the United Kingdom that demonstrate the seriousness of soil erosion on agricultural land in the region. This include Reed (1979), Boardman (1984), and Robinson and Blackman (1990). Prior to the 1970s, most soil erosion problems in the United Kingdom were associated with the upland areas and were caused by overgrazing. This included upland peat moors where sheep undercut the turf and damaged and exposed the bare surface to wind erosion, especially during dry periods. However since then, soil erosion by water has increased in England and more arable land is at more risk of erosion by water than by wind, especially on sandy and sandy loam soils (Evans, 1990; 1992). Morgan (1985) noted that most of these soils used for arable farming in the Midland and Eastern counties of England are readily susceptable to soil erosion after sudden storms. In addition, rilling of arable land is more widespread on sandy soils, and is also common on light loams and loamy soils with a high silt content (Evans, 1992).

The serious impact of soil erosion in England has generally been blamed on adverse changes associated with agricultural activities, such as mismanagement and environmentally unfriendly attitudes among farmers and harvest contractors. According to Unwin's (2001) classification of agricultural land in England, it is the areas below an altitude of 150 m and rainfall of over 1000 mm, with intensive cropping, which are most at risk of soil erosion. Solomon (1997) reported that the total area of arable crops considered as being at very high risk of water erosion in England is 17,990 ha with 62,170 ha of crops at high risk, and 74,590 ha of crops at locally high risk.

Twenty years ago most agricultural land was used for the growing of spring-sown barley and winter wheat and the production of grass for cattle and sheep. However, in the 1980s and 1990s, and in more recent years, the arable land has been autumn-drilled for winter cereals, in response to the better yields. The crop cover provided by winter cereals is low throughout the winter period and exposes the soil surface to heavy rainfall, which can create rills and gullies within the fields and cause floods downstream. Currently, maize growing is becoming a major environmental issue in England, due to its association with bare soil during the late autumn of winter period, which frequently coincides with periods of heavy rain. A more detailed discussion on this with particular issue will be provided in the next section (1.3).

The causes of soil erosion on agriculture land are mainly related to on-farm activities, and are the result of factors such as the failure of agricultural policy and socio-economic pressure. Inman (2006) discussed some of the causes of soil erosion on agriculture land in England and Wales. He suggests that one of the key on-farm activities that encourages soil erosion is the growing crops on inappropriate land. This is closely related to unsuitable soil types which are too fragile to resist the erosive energy of rainfall and snow melt. Crops have also been grown on more marginal land, particularly on steep slopes. Rills may develop during periods of heavy rainfall.

Another significant cause of soil erosion is inappropriate timing of agricultural practises. This relates to ploughing and harvesting land during winter periods or under wet conditions. Ploughing and harvesting using heavy machinery can cause soil compaction and destroy soil structure. These conditions will increase surface runoff and soil erosion that cause the depletion of soil nutrients.

Late sowing in the autumn and delayed harvesting in the late autumn of winter periods will increase the risks of soil erosion. Both situations will leave the land with a lack of ground cover to protect the soil surface from rainfall impact. Exposure of bare soil surfaces to winter rainfall is likely to result in the development of rills and gullies, and these will increase the rate of on-site soil erosion.

Most of the measurements of water erosion in England have recorded relatively low rates of soil loss. For example, Walling and Quine (1991) reported a net erosion rate from a sugar beet field at Rufford Forest Farm in Nottinghamshire of 10.5 t/ha/yr. The average soil erosion rate from bare loamy sands of the Bridgnorth series in Shropshire has been reported as 11.3 t/ha/yr (Fullen, 1992). Brazier (2004) listed the results of soil erosion studies undertaken at various places in the UK, involving various soil types, and his data indicated that average soil erosion rates range from 0.22 to 4.89 t/ha/yr. However, studies based on ^{137}Cs surveys reported by Walling & Quine (1995) indicated that soil erosion rates at various places in the UK ranged from 0.6 to 10.5 t/ha/yr. Brazier (2004) showed that based on several field survey in the UK, the erosion rates ranged from 0.001 to 6.3 t/ha/yr in various soil types. In addition, Morgan (1985) reported that the erosion rates in the UK from cultivated land ranged from 0.01 to 0.30 kg/m^2/yr, and 1.00 to 4.50 kg/m^2/yr from bare soil. These findings show that the erosion rates in the UK are relatively low compared with other countries in the world. As an example, the erosion rates from cultivated land and bare soil in Belgium ranged from 0.30 to 3.00 and 0.70 to 8.20 kg/m^2/yr respectively, it ranged from 0.50 to 17.00 and 0.40 to 9.00 kg/m^2/yr in the USA, and in China, it ranged from 15.00 to 20.00 and 28.00 to 36.00 kg/m^2/yr (Morgan, 1985). All of these findings support Morgan's (1985) conclusions that very low annual soil erosion rates were caused by water erosion. Relatively, the soil erosion rates is also low compared with the soil erosion rates in Asia, Africa, and South America, averaging 30 to 40 t/ha/yr (Pimentel *et al*., 1995).

Generally, most soil erosion events have been reported in areas of arable cultivation during the autumn and winter periods, associated with greater rainfall. This is also associated with late sowing in autumn with harvesting in winter, which leaves bare soil surfaces without very little or no ground cover. The impact of soil erosion, especially on agricultural land has major implications for physical landscapes and society at large. It also has both on-farm and off-farm impacts.

The main on-farm effect of soil erosion from agricultural land can be related to the loss of production associated with the loss of topsoil which is rich in organic matter. Off-farm effects include loss of biodiversity, damage to roads and footpaths, contamination of drinking water, and nutrient over-enrichment of freshwater bodies. For example, soil erosion on the South Downs of Southern England has occurred regularly since the early 1980s, especially during the wetter autumn and winter periods, providing average annual rates of erosion of 0.5 to 5.0 m^3/ha/yr for the decade 1982-1991 (Boardman *et al*., 2003). Although the overall rates seem low, the rates for individual fields can be very high, reaching over 200 m^3/ha/yr, and the costs of damage resulting from muddy floods has proved to be very high. For example, damage in Mile Oak and Hangleton, Brighton in 1987 caused by muddy floods totalled more than £259,000 (Robinson and Blackman, 1990), while the total damage cost in Rottingdean was in excess of £400,000 (Boardrman, 1995). In the bigger picture, the total annual external environmental and health cost of the UK agriculture was estimated at £2.343 billion in 1996, comprised of air pollution (£1,113 m), human health costs (£776 m), water pollution (£231 m), damage to biodiversity and landscape (£126 m), and soil damage (£96 m). In specific to water pollution regarding to drinking water, the highest damage comes from pesticides

(£120 m), phosphate and soil (£55 m), zoonoses (£23 m), nitrate (£16 m), monitoring and advice on pesticides and nutrients (£11 m), and eutrophication and pollution incidents such as fertilizers and animal wastes (£6 m) (Pretty *et al*., 2000).

In order to combat both on-farm and off-farm soil erosion effects, including diffuse agricultural pollution, the Ministry of Agriculture Fisheries and Food, and the Environment Agency are working closely together with farmers' organizations to reduce soil erosion and water erosion effects. Some of the initiatives to tackle this issue are The Code of Good Agricultural Practice for the Protection of Soil, and the Provision of Advisory Services. More spesific, DEFRA (Department for Environment, Food and Rural Affairs) also introduced a Catchment-Sensitive Farming Programme to tackle DWPA (Diffuse Water Pollution from Agriculture). More details on these policies as they are associated with maize cultivation will be discussed in Chapter 9.

1.3 Maize Cultivation and Environmental Problems in England

Besides potatoes and winter wheat, one of the major crops that causes serious environmental problems associated with both the on-farm and off-farm impact of soil erosion is maize cultivation. Growing maize has become more common in England since the early 1970s to produce feed for cattle, and particularly to support dairy farming, where maize is mainly used for silage. Forage maize has become a major alternative to grass silage for ruminant livestock in England because of its better end-product quality, which is related to improved forage intake, and improved animal productivity, and it can also reduce production costs (Fitzgerald *et al*., 1998; Anil *et a*l., 2000).

According to the DEFRA database, land cultivated with maize in England in the 1970s occupied an area of less than 10,000 ha. However, this increased to 108,400 ha in 2003. A more detailed discussion of the growth of maize cultivation in England will be presented in Chapter 4.

As discussed above, in Sections 1.1 and 1.2, it is already well known that soil erosion associated with agricultural activity, especially crop farming, has a serious environmental impact, and this is particularly the case for maize cultivation in England. Maize is usually drilled during spring (April/May) and harvested in the autumn (mid-September/mid-October), but in some cases it is also harvested in late autumn, due to restrictions on the availability of contractors for harvesting. Once the maize has been harvested, fields are left bare and this exposes the fields to autumn and winter rainfall. Both factors (bare soil and heavy rainfall) increase the likelihood of water erosion by creating rills and/or gullies on slope surfaces, and promoting surface runoff, which flows downhill into water courses. Maize harvesting also frequently takes place under wet conditions with heavy harvest machinery, leading to compaction of the soil and damage to soil structure, and this increses runoff still further. Most maize growers harvest their crops by moving the harvesting equipment up and down the slope, rather than across it. This also increases the runoff in accordance with the steepness of the slope.

Maize is often grown continuously on the same field, and the fields are frequently left fallow over winter prior to cultivation and pre-drilling the following spring. It is common for farmers to take the opportunity to spread slurry onto bare harvested maize fields over the winter period as an organic fertilizer to support the crop during the next season. However, this is likely to reduce the infiltration rates, espescially if the slurry dries up, thereby increasing runoff, and transporting slurry and sediment to watercourses during periods of heavy rainfall.

Clements and Lavender (2004) have reported a plot study involving measurement of surface water runoff from fine sandy loam soils with a slope steepness 3.7^o in maize stubble fields in the Parrett Catchment area of Somerset during the winter period of 2003/04. The results, based on ten rainfall events from 10 November 2003 to 29 March 2004, show that the mean surface runoff from late harvest plots can be as high at 762 m^3/h, and from bare stubble plots at 283 m^3/h. However, more suspended solids were measured from bare stubble plots with mean as high at 1975 mg/l, and at 1842 mg/l from late harvest plots. In the case of phosphorus, it was reported that more phosphorus was measured from late harvest plots with mean as high at 7202 µg/l, and at 5052 µg/l from bare stubble plots. The results also show that more nitrate nitrogen was measured from bare stubble plots compared with late harvest plots, at 1.87 mg/l and only 0.76 mg/l, respectively. The results of surface runoff show the seriousness of on-farm effects of soil erosion from bare maize plots and late harvest plots, associated with the mobilization of top soil and low infiltration rates, which increase the runoff on the slope with a probable resulting increase in soil erosion rates. In addition, off-farm effects from high surface runoff from both treatment plots can be seen from the mean value of suspended solids and phosphorus and nitrate contents.

An investigation of soil erosion in a 6.7 ha bare maize field at Higher Walton Farm near Crediton, undertaken by Blake (2000) using ^7Be measurements indicate that the mean erosion rates for the field was 5.3 kg/m^2 with a net soil loss of 2.5 kg/m^2 and the sediment delivery ratio (SDR) is calculated as 0.80. The erosion rates and the net soil loss must be seen as quite high for the local area and the SDR value indicates that a significant proportion of the mobilized soil was delivered beyond the field towards the local stream (Blake, 2000). By comparing the short-term results with medium-term tracer of ^{137}Cs, Blake (2000) reported that the mean erosion rate, a net soil loss and the SDR value derived from ^{7}Be are significantly higher (1.1 kg/m^2/yr, 0.48 kg/m^2/yr, 0.83 respectively, for ^{137}Cs). The ^{7}Be measurements results can be explained by the intensive nature of rainfall during the soil sampling programme in the January 1998, which can be considered to be quite rare. In the case of ^{137}Cs measurements results, it can be related to the high yield of such rarer rainfall that would be lost in the averaging effect over the 30-40 years period (Blake, 2000). Serious off-farm effects from the field resulted from the SDR for both tracers indicate that a significant proportion of the soil was transported out of the field as eroded sediment to nearby water courses.

The references discussed above indicate that harvested maize fields in autumn tend to be exposed to soil erosion during winter periods under heavy rainfall when they are characterized by compacted bare soil. The effects of on-farm erosion and the resulting off-farm pollution clearly demonstrate the seriousness of soil loss and damage to water courses because sediments and nutrients degrade water quality and thus aquatic ecosystems.

1.4 Research Needs

The above discussion has demonstrate the potential seriousness of both the off-farm and on-farm impact of soil erosion associated with maize cultivation. Apart from those discussed above, there have been very few studies in investigating soil erosion rates from bare maize fields in England. Previously, most studies of soil erosion from cropland in England have concentrated on cereals, sugar beet, potatoes, and vegetable crops.

Considering the serious environmental problems that can occur as a result of maize cultivation, and especially the considerable expansion of the area under maize in England in recent years, it is important that there should be more studies of the soil erosion that is likely to occur as a result. Further studies are required of both gross and net rate of soil loss as well as the magnitude of soil losses from individual fields and the role of the sediment mobilized from bare maize fields in polluting river systems.

Documentation of soil erosion associated with maize cultivation including both on-farm and off-farm impacts at both field and catchment scales will serve to improve management policy and to encourage more environmentally friendly attitudes among farmers and harvest contractors with regard to the management of soil, farming systems, harvesting practises, and bare soil conservation on maize fields. Currently, it would be fair to say that management policy regarding the control of soil erosion from agricultural land, including maize cultivation for silage, is still facing problems in reducing soil erosion impact. Guidelines for improved agricultural land management, such as ‘The Code of Good Agricultural Practice for the Protection of Soil’, and ‘The Catchment Sensitive Farming Programme’, may help in solving any practical problems in tackling the impact of soil erosion from maize cultivation areas. However, many farmers leave maize fields bare after harvesting, without any effective protection from rainfall, and the very turbid rivers that are often observed during the winter period, are possibly linked to sediment mobilization from bare soil in the maize fields that have experienced soil erosion. Overall there is a need for a better review and understanding of current management policy regarding soil erosion control and soil conservation, and also of pollution prevention, and management practises associated with maize cultivation that can reduce on-farm and off-farm impact, especially with regard to water courses.

1.5 Research Aims

The overall aim of the research reported in this thesis is to investigate the problem of soil erosion by water associated with maize cultivation. To achieve the research aim, this research has been divided into three parts. The first considers the distribution of maize growing in England and its recent expansion. The second develops an understanding of the on-farm and off-farm impacts of maize cultivation, and the third considers the implications of the results of the research for improving management practices to reduce the impact of soil erosion from maize fields. The work should help to provide better documentation of on-farm and off-farm impacts of soil erosion, and could be used to review some of the farming management systems applied by policy makers, farmers and harvest contractors.

1.6 Thesis Structure

The thesis is divided into 10 chapters. Chapter 1 establishes the background to soil erosion associated with maize cultivation in England and outlines the aims of the research undertaken. Chapter 2 explains the objectives of the research, and a description of the research strategy. This includes a discussion of how the study area was selected at national, regional, local and site scales. Chapter 3 describes the methodology used in this research to investigate on-farm and off-farm impacts associated with maize cultvation. The description is divided into two sections: the first concerns techniques for soil sampling and water-sediment monitoring, including sample preparation; the second concerns laboratory analysis involving ^{7}Be and ^{137}Cs measurements, and also analysis of the chemical properties of soils and sediment.

Chapter 4 presents a review of maize cultivation in England and its expansion from national to regional perspectives. Chapter 5 builds on Chapter 4 and provides a discussion of maize cultivation at the local and site scales. Chapter 6 describes the soil erosion investigation undertaken at selected study sites, and this in turn is divided into two sections. The first section is a discussion of the information on soil erosion rates and patterns provided by ^{7}Be measurements which provide a short-term perspective, and the second presents equivalent information obtained from ^{137}Cs measurements which provide a longer-term perspective. Chapter 7 reports the results of an investigation on suspended sediment transported by the Rivers Culm and Tone and this includes information on the analysis of several chemical properties of the sediment such as heavy metal, organic carbon, and total phosphorus content. Chapter 8 discusses the environmental impact of maize cultivation in England based on a review of the national distribution of maize growing areas and the river networks of England, and presents an assessment of the possibility of off-farm impact from maize cultivation areas on river catchments, based on the project results. Chapter 9 reviews current farming management systems and a discussion of potential improvements to the system of combating soil erosion impacts associated with maize cultivation. The final chapter, Chapter 10, summarizes the thesis and the results presented and provides recommendations for future research.

CHAPTER 2: RESEARCH STRATEGY

2.1 Overview

This chapter describes the research strategy designed to achieve research aims outlined in Chapter 1. Specific objectives based on the research needs are outlined in Section 2.2. The chapter will also describe the process of choosing the study area in this project to fulfill the research aims and individual objectives which are based on four perspectives, at national, regional, local and site scales.

2.2 Research Objectives

As indicated in the previous chapter, the aims of the project are divided into two aspects. The first is to provide an understanding of the off-farm impacts of maize cultivation on a local or catchment scale, and the second is to consider the implication of the results of the project for improving management practices in order to reduce the impact of soil erosion associated with maize cultivation. Based on both aims, the objectives of this project are listed below;

1. To review the background to maize cultivation in England.
2. To analyse the spatial and temporal patterns of maize cultivation.
3. To investigate rates and patterns of soil erosion from maize fields.
4. To investigate sediment transfer from maize fields to rivers.
5. To evaluate the environmental impact of maize cultivation in England.
6. To consider the potential of improved management practises in reducing the environmental impact of maize cultivation.

In addition, the first and second objectives are to discuss the causes of the expansion of maize cultivation area in the country, and to report and describe spatial and temporal patterns of maize cultivation at national, regional and local scales. The results obtained from these discussions will be dealt with in Chapter 4, for the national and regional scales; and in Chapter 5 for local scales. In the case of the third objective, the investigation of rates and patterns of soil erosion will be based on shorter and longer terms of radionuclide tracer at a site scale. The results will be reported in Chapter 6. Investigation of sediment transfer from maize fields to rivers will be made at a local or catchment scale, and the result will be discussed in Chapter 7. The fifth objective of evaluation of the environmental impact of maize cultivation will be made at local and national scales, based on the results from Chapter 4, Chapter 5, Chapter 6 and Chapter 7; and the discussion will be made in Chapter 8. Consideration of the potential of improved management practises in order to reduce the environmental impact of maize cultivation will be discussed at a national scale, considering several policies associated with agriculture in general as well as the cultivation of maize.

In accordance with the above description, the next section will focus on a discussion of the selection of study areas at national, regional, local and site scales. Figure 2.1 summarizes the above description and the further discussion of the strategy that will be taken in this project.

2.3 Selection of the Study Area

As mentioned above, the process of the selection of the study areas is based on four scales, national, regional, local and site scales. As is well known, the United Kingdom consists of four countries or political entities, namely England, Wales, Scotland and

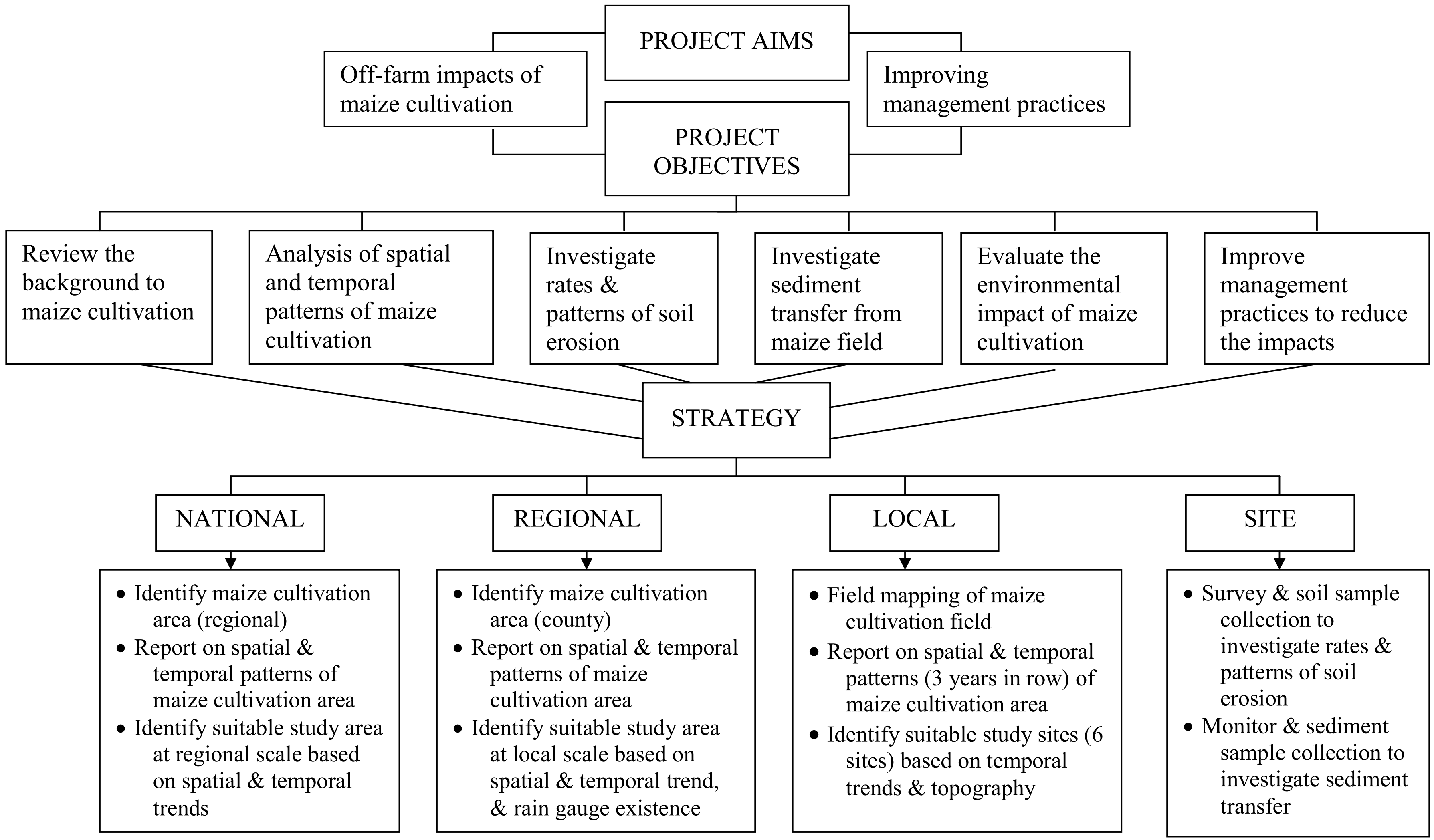


Figure 2.1 : Flow chart of the project

Northern Ireland. However, considering the time-period of the project and limitations that could occur during the process of collecting field and secondary data, this project has tried to minimize any uncertainty and limitations in carrying out the project from the beginning to try and avoid future problems.

2.3.1 National scale

As indicated in Figure 2.1, achieving the aims and the objectives of the project ought ideally to be done on a national scale in order to understand the spatial and temporal patterns of maize cultivation in the United Kingdom. However, under the project time-period limitation, the author has had to select only one of the countries for this project, and England has been choosen. The reason for this is because England is the largest country of the four, at 130,395 km^2. In addition, most of the land in England is arable and cultivated with variety of crops, which thus better suits the project aims and objectives. A detailed description of cropland in England will be made in Chapter 4.

In order to review the background to maize cultivation in England, data on maize cultivation for certain years are needed to show the spatial and temporal patterns of maize growing. Data in map format has been supplied by the Library of Edinburgh University for the years 1979, 1981, 1985, 1988, 1993, 1995, 1997, 1999 and 2000. The data are in raster format, and all data are in size of 2 km^2 per pixel, except for 1985 which is in 5 km^2 per pixel size. The data have been analysed using Geographical Information Systems (GIS) of ArcMap, version 8.3. In the case of temporal patterns, the data were collected from the DEFRA website (Department for Environment, Food and Rural Affairs), for the years of 1970, 1972, 1974, 1980, 1982, 1984, 1990, 2000 and 2002. These data were transferred to Excel for trend analysis.

The main analysis process at this scale is to identify maize cultivation area in England for each region, for the years mentioned above. The results from this analysis were intended for use in identifying a suitable study area at a regional scale after a study of spatial and temporal patterns in each region.

The project will also discuss the factors that cause the expansion of maize cultivation areas in England. In addition, it will also review and discuss management practises with the aim of making some recommendations so as to reduce the environmental impact of maize cultivation. This could be done by reviewing present agricultural policies, especially those dealing directly with maize cultivation. The results will be discussed in Chapter 9.

2.3.2 Regional scale

One of the most important considerations in selecting a suitable study area at a regional scale is to choose an area relatively densely cultivated with maize. As a result of studies of maize cultivation at a national scale, the Southwest region was selected as the most suitable study area for this project. Starting from this point, a similar analysis of spatial and temporal patterns of maize cultivation in the Southwest region was also carried out, based on the similar data from both the Edinburgh Library and from DEFRA.

The study of the spatial and temporal patterns of maize cultivation at this scale will cover all six counties of the Southwest region, i.e. Cornwall and the Isles of Scilly, Devon, Dorset, Gloucestershire, Somerset, and Wiltshire. The spatial distribution of maize cultivation in the Southwest region will be presented in map format while the temporal patterns will be reported using figures to show the trends of maize cultivation scale within the counties. The report will also be discussed in Chapter 4, together with the results at a national scale.

2.3.3 Local scale

The studies of spatial and temporal patterns of maize cultivation in the Southwest region have in turn been used to identify two catchments as a study area at local scale. The reason for the choice of the two catchments as study areas in this project was based on the reasons below:

- investigation of any differences of soil erosion rates and patterns from two different catchment background of soil types;
- investigation of any differences of off-farm impact in the river, associated with diffuse pollution, from different physical characteristics, such as topography, geological aspects, soil types, the size of catchment and river network length;
- representation of the country of England associated with the environmental impact of maize cultivation with regard to catchment size and the location of maize fields to the river network.

In addition, the existence and availability of rain gauge stations and river flow data such as turbidity and water discharge has also been considered in selecting suitable catchments in this project.

Finally, after taking into consideration the reasons mentioned above, two catchments were selected as study areas in this project: the Culm Catchment, which is in the Exe River basin and located in Devon, and the Tone Catchment, which is one of the main Parrett River tributaries and is located in Somerset.

At this scale, two main actions were taken. The first was to identify maize fields within both catchments for the years 2002, 2003 and 2004. This involved field mapping work to gather information from farmers and land owners using direct interviews and based on observation during the field work. Farmers and land owners were asked to identify maize fields that had been cultivated for those three years. More than 300 farms and farmers were visited and interviewed to fulfill this purpose.

Secondly, it was necessary to identify the existence of rain gauge stations and the availability of river flow data for the purpose of investigation of off-farm impact from maize cultivation area. This involved field checking of existing river gauging stations at down-stream points from both catchments, and the suitability and possibility of the stations for sediment concentration and river turbidity measurements. In addition, the availability of secondary data based on daily measurements of river flow and turbidity from the Environment Agency (EA) were also checked to support field measurement data. Another requirement that was considered was accessibility to the river gauging stations for river monitoring. This included the distance of the river gauging station from Exeter University and permission from the Environment Agency to access and set-up river monitoring instruments. Taking account all those factors, two river gauging stations were finally selected for this project, with one for each catchment, to act as river monitoring points down-stream. The river gauging station selected to represent the Culm Catchment is known as the Woodmill station, while that for the Tone catchment is the Bishop Hull station.

The Woodmill station is run by the School of Geography, University of Exeter, monitoring river flow and river turbidity. This is an advantage for this project because of the accessibility of the secondary data regarding the history of river flow and river turbidity history. However, in the case of the Bishop Hull station, the station is operated by the Environment Agency alone, and in order to gain access to the premises to set-up the monitoring instruments and for field work monitoring during the winter period of 2004/2005, permission had to be given by the management of the EA. The EA have their own river flow and turbidity instruments at this station, which was a help for this project because it enabled comparisons to be made for data from different monitoring instruments.

2.3.4 Site scale

Furthermore, in investigating soil erosion rates and patterns, the project needs a suitable number of study sites for soil sampling collections to represent the local study area. Some considerations that have to be taken an account before deciding the number of study sites in this project are listed below:

1. The size of maize field. This relates to the number of sampling points for each field. If the size of the field slope is longer from the top to the bottom of the field, the number of sampling points will be more.

2. The half-life of ^{7}Be that needs to be measured soon after its dry and sieved. This is associated with limited number of detectors in the School of Geography Laboratory, which are also being used by other researchers.

3. The distance between each field, which will effect how far it might be to carry out soil sampling within the same day, or at least on consecutive days after the first day of sampling. This is important, in the case of ^{7}Be to avoid any uncertainty of soil samples regarding a second rainfall event.

Taking these considerations into account, the author decided to choose six bare maize fields, three in each catchment, to be study sites. According to this decision, the next process was to identify six suitable maize fields as study sites. The process of selecting six suitable maize fields was carried out by referring to field mapping results on a local scale. This process involved three important aspects. The first was to identify maize fields grown with maize for three years in a row from 2002 to 2004. The second was the importance of avoiding undulating or flat fields. Undulating fields would have a tendency to spread runoff on the surface in too many directions, while flat fields could be flooded and thus rendered unsuitable as case studies. It is also important to avoid undulating fields because of the necessity of using a transect approach in soil sampling programmes. The third was to select a different background of soil type for each field so as to represent a variety of soil types within the catchments. The geographical and physical characteristics of the six study sites will be described in Chapter 6.

In addition, soil sampling programmes for both ^{7}Be and ^{137}Cs have been made in the same fields and at the same as sampling points for the purpose of comparison of soil erosion rates at shorter and longer terms of life for both radionuclide tracers.

2.4 Summary

This chapter has described the research strategy at various scales in achieving the aims and objectives of the project. England was chosen as a study area at the national scale, and the Southwest region was selected to represent the England at a regional scale. For both scales, the spatial and temporal patterns of maize cultivation is described based on data supplied by the library of Edinburgh University and DEFRA. Furthermore, two catchments (the Culm and Tone catchments) were selected for investigation of off-farm impacts of soil erosion, and six maize fields were chosen to represent both catchments associated with soil erosion rates at shorter and longer terms.

The next chapter will describe the methodology that has been used in this project. It will cover aspects of field work for field mapping, the soil sampling programme and river turbidity monitoring approaches that were applied in this project. In addition, the methodology chapter will also describe the laboratory work associated with radionuclide measurements and chemical property analyses.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter will describe various methods employed in the field and laboratory components of the study, and more specifically the measurements of fallout radionuclides and analysis of the chemical properties of soil and suspended sediment samples. The fallout radionuclide measurements focused on ^{7}Be, ^{137}Cs and ^{210}Pb fallout, whilst the analysis of chemical characteristics included heavy metals, base cations, phosphorus, carbon and nitrogen. The detailed procedures employed to determine the ^{7}Be and the ^{137}Cs content of soil and sediment samples will, however, be presented in Chapter 6. The present chapter also describes some of the techniques employed for data manipulation and analysis.

3.2 Field Sampling and Sample Preparation

This section will describe the soil sampling techniques that were employed in the field to obtain samples for ^{7}Be, ^{137}Cs and ^{210}Pb fallout measurements. The collection of water samples for determination of suspended sediment concentration and recovery of sediment for analysis will also be included in this section. In addition, the processing and preparation of soil and suspended sediment samples prior to laboratory analysis will also be explained in this section.

Soil sampling for ^{7}Be and ^{137}Cs measurements was undertaken at a number of study sites (fields) in the Culm and Tone catchments. A transect approach was employed, and this involved two parallel transects in each field. The same sampling points were used for both ^{137}Cs and ^{7}Be. The main sampling was undertaken in maize fields, but it was also necessary to collect reference samples from adjacent flat areas in pasture fields. The soil sampling was undertaken after the maize had been harvested.

3.2.1 Soil sampling and sample preparation for ^{7}Be measurement

Bulk soil samples for ^{7}Be measurement were collected from the study sites within the catchments of the River Tone and Culm in order to determine the ^{7}Be inventory. Soil cores were collected using a 150mm diameter plastic core tube (Plate 3.1). The tube was driven into the soil surface to a depth of 30mm and the shallow core was carefully removed and transferred to a strong plastic bag. The plastic bag containing the soil sample was tied and labeled to record the sampling point. In order to make a comparison with the inventories recorded in the study fields, bulk reference cores were also collected in the same way from pasture sites adjacent to each study field.

All soil samples were fully dried prior to measurement of their ^{7}Be contents. In view of the need to dry the soil samples rapidly, because of the short half-life of ^{7}Be, all soil samples were freeze-dried. The soil samples were fully frozen (Plate 3.2) prior to being placed in the vacuum chamber of the ThermoSavant ModulyoD freezed drier (Plate 3.3). After drying the soil samples were weighed and disaggregated. Disaggregation was undertaken using a rotary sieve (Plate 3.4), which pulverized and sieved the soil samples to < 2mm fractions. Grinding times for each sample were 10–15 minutes. Only the sieve size of < 2mm fractions was used for ^{7}Be measurement. The fine fraction samples were packed into medium-sized Marinelli beakers (Plate 3.5) and weighed, prior to assay of their ^{7}Be contents using a high-purity germanium coaxial γ-detector (HPGe).

Plate 3.1: Plastic core tube used in ^{7}Be soil sampling

Plate 3.2: Soil samples in a freezer

Plate 3.3: Soil samples in the freezer drier

Plate 3.4: The rotary sieve used for disaggregating and sieving the soil samples

Plate 3.5: The fine fraction of a soil sample contained in a medium-sized Marinelli beaker

3.2.2 Soil sampling and sample preparation for ^{137}Cs measurement

Bulk soil cores were collected from the study sites to determine the ^{137}Cs inventory. Soil cores were collected using a 70mm internal diameter metal corer (Plate 3.6). The corer was driven into the soil using a motorized percussion hammer (Plate 3.6) to various depths, depending on the location of the sampling points along the slope, and the soil depth and composition. If a sampling point was stony, the depth of soil core could be only 30–45cm. Most of the stony sampling points were found at the top of the slopes. In contrast, many sampling points in the middle of the slopes were 45–55cm deep, whilst for some of the sampling points at the bottom of the slope, the soil cores could be > 55cm long. The soil cores were carefully removed and transferred to strong plastic bags, tied and labelled to record the point. Bulk reference cores were taken in the same way from an adjacent flat pasture site for each study field.

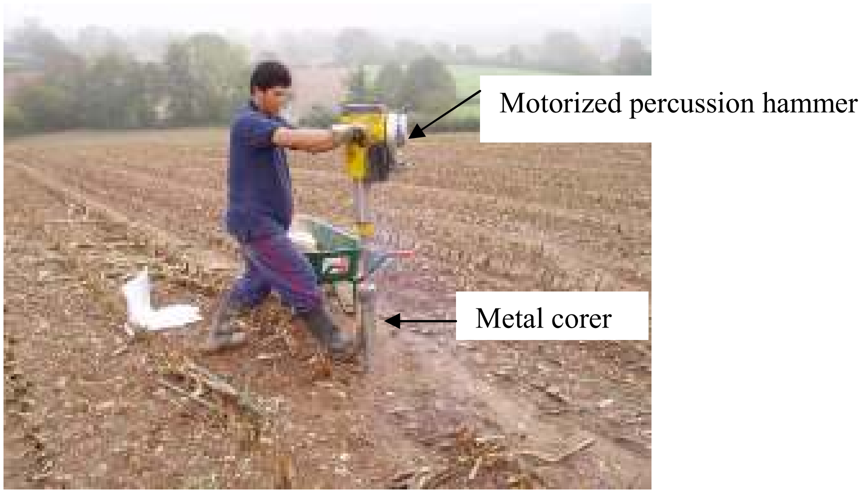


Plate 3.6: Metal corer and motorized percussion hammer used in ^{137}Cs soil sampling

All soil samples were oven dried at 50^{o}C, and after being fully dried, the samples were ready for weighing. Dried soil samples were disaggregated using a similar approach to that used for preparing samples for ^{7}Be analysis, as described in section 3.2.1. However, the sieving times for the ^{137}Cs soil samples were longer, taking up to 20–30 minutes, because the soil samples collected for a ^{137}Cs analysis were considerately larger than those collected for ^{7}Be analysis. The fine fraction at < 2mm of the soil samples was packed into a medium-sized Marinelli beaker, and after being weighed, the samples were ready for ^{137}Cs assay using the same detector as used for ^{7}Be measurements.

3.2.3 Soil sampling and sample preparation for ^{210}Pb and chemical analysis

In order to analyse the excess ^{210}Pb activity and the chemical properties of surface soil from maize fields, additional soil sampling was undertaken in 24 maize fields within the Culm and Tone catchments. Those 24 maize fields included 12 maize fields in the Culm Catchment and another 12 maize fields in the Tone Catchment. The maize fields were chosen randomly within these catchments, but it was a requirement that the field had to be free from any farming activity during the soil sampling time.

The soil samples were collected using a small scoop from the soil surface adjacent to the slope rills which provided evidence that the slope surface had been eroded during preceding heavy rain. The sampling points were located randomly in each field. The mass of the soil samples collected from each of the fields typically amounted to 500–600g. All soil samples were transported and stored in strong plastic bags, tied and clearly labeled.

The soil samples were oven dried at 50^{o}C before being weighed. Subsequently, the samples were disaggregated gently using a pestle and mortar (Plate 3.7), and dry sieved to recover the 20µm fraction using a 20µm sieve. The sieved soil samples were packed into strong plastic bags, in readiness for ^{210}Pb activity measurement and chemical analysis.

Plate 3.7: Soil samples for chemical analysis were disaggregated using a pestle and mortar

3.2.4 River water sampling and sample preparation for suspended sediment analysis

River water sampling for recovery of suspended sediment and measurement of suspended sediment concentrations was undertaken at two hydrological monitoring stations, located at the outlet of the Culm and Tone catchments. The Woodmill station, located closed to Cullompton, was at the outlet of the Culm Catchment outlet, while the Bishop's Hull station, located closed to Taunton, was located at the Tone Catchment outlet.

River water sampling was undertaken during peak river flows after heavy rain had occurred. For the purpose of recovering suspended sediment, sampling involved use of a submersible pump powered by a portable generator, to pump river water through a 30mm reinforced plastic hose into five 20l polyethylene cans. However, for the purpose of determining suspended sediment concentrations, the river water sample was collected in 500ml bottles using the same apparatus.

The 100l bulk river water samples collected at the both outlets of both catchments were taken back to the laboratory, and left for four days to allow the suspended sediment in the water samples to settle to the bottom of the can. After the suspended sediment had completely settled, the overlying clear water was syphoneed out using a small hose, leaving the suspended sediment at the bottom of the can along with a small volume of water. This residual sample of suspended sediment contained in a small volume of water was transferred to a centrifuge bottle, ready for recovery using a Multifuge 4 KR Heraeus centrifuge (Plate 3.8). The centrifuging process took about one hour, and after this process had been completed, the suspended sediment was transferred using distilled water and a spatula into a plastic pot. The sediment contained in these plastic pots was then freeze dried, and stored in plastic bags, prior to chemical analysis.

Plate 3.8: The Heraeus Multifuge 4 KR Centrifuge

3.3 Laboratory Analysis

This section will cover two areas. The first describing the measurement of ^{7}Be, ^{137}Cs and ^{210}Pb activity, and the second the techniques used for analyses of the chemical properties of soil and suspended sediment samples.

3.3.1 Radionuclide measurement

In this study, a high resolution of low-level gamma spectrometer incorporating a high-purity germanium (HPGe) detector (Plate 3.9) was used to determine gamma-emitted radioactivity in soil and sediment samples. More specifically, the detector type used in this study is a hyperpure germanium coaxial γ-detector (EG&G ORTEC HPGe) with associated lead-shielding and liquid nitrogen cooling, linked to a multi-channel analyser. A detailed explanation of gamma spectrometry measurements is provided by Wallbrink *et al*. (2002).

Plate 3.9: A hyperpure germanium coaxial γ-detector

The detector, which contains a germanium crystal, generates free electrons in response to absorbing energy from ionizing radioactivity, and the magnitude of the charge in the crystal is directly related to the energy of the incident gamma ray (Wallbrink *et al*., 2002). In this case, the sample in the detector releases γ-ray emissions and some of them will be absorbed. At this stage, the γ-ray emissions lose part or all of their energy by producing electron pulses. These electron pulses are amplified by the pre-amplifier as voltage pulses and sent to the multichannel analyser. The pulses are sorted by height and output from the different channels into the counting system, where the counts are processed and displayed (Blake, 2000).

The counting system is based on the full energy peak (FEP), where the area under the FEP is known as the net count rate, which can be used to calculate the radionuclide activity in the sample. In order to calculate the radionuclide activity in the sample from the net count rate value, it is important to know the detector efficiency. The efficiency of the detector is a function of the energy of the γ-rays, the characteristics of the crystal, the geometry of the sample and the self absorption of γ-rays by the sample itself (Blake, 2000). All these must be taken into account when defining the efficiency of a detector using standards.

3.3.1.1 Measurement of ^{7}Be and ^{137}Cs activity in soil samples

As indicated above, soil samples for ^{7}Be and ^{137}Cs, analysis were packed into medium-sized Marinelli beakers. The Marinelli beaker surrounds the detector head to provide more efficient detection.

In order to convert the net full energy peak (FEP) into a measurement of radionuclide activity, the efficiency of the detector must be known. This is defined as the ratio of the net FEP count rate of γ-ray recorded by the detector to the emission rate of γ-ray from the sample. The activity in the sample can be calculated as:

$$A_x = (n_x / \eta_x) \qquad (3.1)$$

where n_x is the net FEP count rate of γ-ray recorded by the detector, and η_x is the efficiency for a γ-ray emitted from radionuclide x in a sample.

The detector efficiency calibration can be defined as:

$$f\,(M_0) = (C_0 / T_0 - C_b / T_b) \text{ x } (1 / M_0 \text{ x } (A_0 e^{-\lambda(t-t_0)}) \qquad (3.2)$$

where f is the activity efficiency of the detector, which is defined as the efficiency τ (emission rate) multiplied by the r (emission probability of the gamma ray), M_0 is the standard mass in kg, C_0 is the total counts, C_b is the background counts of an unspiked sample, T_0 is the count time, T_b is the corresponding background count time, and λ is the decay constant of the radionuclide, which can be defined as:

$$\lambda = 1n2 / T_{0.5} \qquad (3.3)$$

where $T_{0.5}$ is the half-life of the radionuclide.

In analysis for ^{7}Be and ^{137}Cs, soil samples were counted on the detector for at least 6 hours. Walling and Quine (1993) have suggested that counting times to detect the fallout activity are commonly in the range 29000 to 55000s. However, considering the large number of soil samples (more than 300 samples), the limitations of detector availability, and the time limitation for analysis of ^{7}Be soil samples linked to the short half-life of this radionuclide, count-times were kept as short as possible, whilst still providing reliable results.

In this study, the areal activity (Bq m^{-2}) of ^{7}Be and ^{137}Cs is used to characterize the fallout activity in the soil sample. The areal activity (A_a) for bulk cores can be calculated as:

$$A_a = AM_T / S \tag{3.4}$$

where A is the activity of the sub-sample of the bulk core analysed (Bq kg^{-1}), M_T is the total mass of the bulk core (kg), and S is the corer area. The activity of ^{7}Be in the samples was obtained from the counts at the 475 keV, and 660 keV for ^{137}Cs.

Since radionuclides are subject to continuous decay, it is important to relate all measurements to a standard point in time. It is therefore necessary to correct the derived activity to the date on which the sample was collected (ic A(0)), and this can be calculated as;

$$A(t) = A(0)e^{-\lambda t} \tag{3.5}$$

where $A(t)$ is the activity of a radionuclide in a radioactive source at the time of measurement, and λt is the decay constant of the radionuclide, which was defined in Equation 3.2. The $T_{0.5}$ for ^{7}Be is 53.3 days, and 11,059.5 days or 30.3 years for ^{137}Cs.

The results from the ^{7}Be and ^{137}Cs fallout activity measurement, which are expressed in Bq m^{-2} will be used in this study to estimate soil erosion rates for each study site. Detailed explanation of the use of ^{137}Cs and ^{7}Be to estimate soil erosion will be provided in Chapter 6.

3.3.1.2 Measurement of excess ^{210}Pb in soil and suspended sediment samples

The < 20μm fraction of the soil and suspended sediment samples for excess ^{210}Pb was packed into a plastic pot. The pot was sealed and left for 21 days before measurement to allow ^{226}Ra to come to equilibrium with ^{214}Pb.

The detector efficiency calibration for excess ^{210}Pb measurement, based on the mass in the pot and pot height, can be calculated as:

$\eta\ (h) = [n(h)\ /\ A_0(h)$ר (3.6)

where $\eta(h)$ is the γ-ray count rate recorded by the detector, and $A_0(h)$ and ר are the known activity of the pot with mass and height and the abundance of γ-ray, respectively. The pot inner diameter is 7cm and the height is 8cm.

The plastic pot containing the sample was placed on top of the detector head and counted for over 50,000s. This provided a precision of *ca.* ± 10% at the 90% level of confidence for the γ-ray spectrometry measurements. The activity of ^{137}Cs in the samples was obtained from the counts at the 660 keV peak. The total activity of the sample was measured at 46.5 keV for ^{210}Pb, and 350 keV for ^{226}Ra. The excess of unsupported ^{210}Pb concentrations of the sample was calculated by subtracting the ^{226}Ra-supported ^{210}Pb concentrations from the total ^{210}Pb concentrations. The ^{226}Ra is measured via the short-lived daughter $^{214\text{Pb}}$.

The activity calculation for ^{210}Pb can be represented as:

$$A_{Pb\text{-}210ex} = A_{Pb\text{-}210} - A_{Pb\text{-}214} \tag{3.7}$$

where $A_{Pb\text{-}210ex}$ is the unsupported ^{210}Pb activity (mBq g^{-1}), $A_{Pb\text{-}210}$ is the total ^{210}Pb activity (mBq g^{-1}), and $A_{Pb\text{-}214}$ is the ^{214}Pb activity (mBq g^{-1}).

However, since ^{214}Pb is a daughter of ^{222}Rn, which is an inert gas, the use of ^{214}Pb activity to estimate the ^{226}Ra-suppprted ^{210}Pb activity can result in over-estimation of its value due to escape of a proportion of the ^{222}Rn from the soil sample. This effect can be corrected using a proportion factor α:

$$A_{Pb\text{-}210ex} = A_{Pb\text{-}210} - \alpha A_{Pb\text{-}214} \tag{3.8}$$

and α can be calculated as:

$$\alpha = (A_{Pb\text{-}210.deep}) / (A_{Pb\text{-}214.deep}) \tag{3.9}$$

where $A_{Pb\text{-}210.deep}$ is the total ^{210}Pb activity for a sample from below the penetration depth of fallout ^{210}Pb (mBq g^{-1}), and $A_{Pb\text{-}214.deep}$ is the ^{214}Pb activity for a sample from below the penetration depth of atmospheric ^{210}Pb (mBq g^{-1}). In this case, the value of α is normally in the range 0.80–1.0.

3.3.2 Total organic carbon (C) and nitrogen (N) analysis

The concentration of carbon and nitrogen in the soil and suspended sediment samples were determined by pyrolysis using a CE Instruments NA 2500 elemental analyzer (Plate 3.10). The samples were packed into small tin capsules, and were sealed by pressing the tin capsules with samples into pellets.

Plate 3.10: The CE Instruments NA 2500 elemental analyzer used for C and N analyses

Blake (2000) explained the process occurring within the tin capsule samples and the elemental analyzer reaction in detail. The elemental analyzer is set up at 1000^{o}C, which allows the sample and tin capsule to melt. At this stage, the exothermic reaction with the capsule produces a dynamic flash combustion at 1800^{o}C, and the resulting gas is then transported by a constant flow of helium and oxygen through chromium oxide oxidation catalysts where oxidation is completed (Blake, 2000). The combustion products are then transported in another reactor at 780^{o}C and converted into elemental carbon and nitrogen. The measurement of carbon and nitrogen is made when the sample is eluted through a gas chromatographic column where it passes across a thermal conductivity detector (Blake, 2000).

Quantifying the carbon and nitrogen content of the soil and suspended sediment samples is carried out by determining the carbon and nitrogen calibration curves. This can be done using an ethylene diamine-tetra acid (ETDA) as a standard. This standard sample is also processed in the same way as the soil and suspended sediment samples. The results from the measurements will be reported in Chapter 7.

3.3.3 Heavy metal analysis

The heavy metal content of soil and suspended sediment samples were determined using Atomic Absorption Spectrophotometry (AAS) (Plate 3.11). The technique used in this study was documented by Allen (1989), and involves the extraction of the heavy metals from the direct digestion using nitric and hydrochloric acid. According to Alloway and Ayres (1997), the term *heavy metal* is applied to the group of metals and metalloids with an atomic density greater than 6 g/cm^3.

In this study, heavy metal elements associated with agricultural sources were selected for analysis. This involved three sources of heavy metals which are heavy metals from impurities in fertilizers, from pesticides, and from composts and manures. The heavy metal elements associated with these three sources are As, Cd, Cn, Cr, Cu, Hg, Mn, Mo, Ni, Pb, U, V, and Zn.

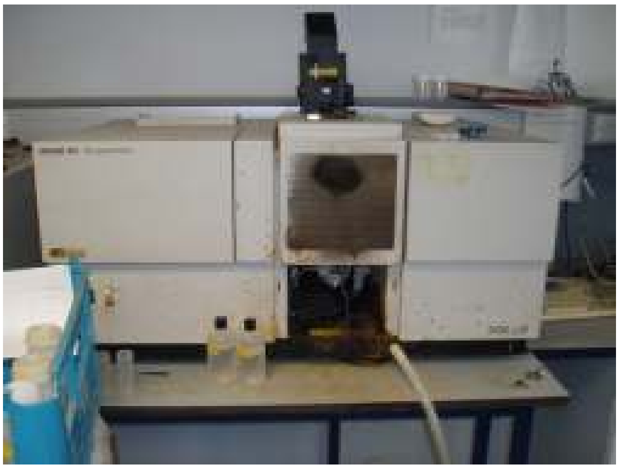


Plate 3.11: The Atomic Absorption Spectrophotometer used for heavy metal analysis

3.3.4 Base cations analysis

A method proposed by Qui and Zhu (1993) was used to extract base cations from soil and sediment samples for subsequent analysis by AAS. The base cations used in this study were Ca and Na, and ammonium acetate was used as a reagent to extract the base cations.

3.3.5 Total phosphorus analysis

The total phosphorus was extracted from soil and suspended sediment samples using the method proposed by Olsen and Dean (1965). The digestion process uses perchloric acid, sulphuric acid, ascorbic acid, ammonium molybdate and potassium antimony tartrate as reagents.

3.4 Data Manipulation and Analysis

One of the primary study objectives is to review the spatial and temporal background of maize cultivation at national, regional and local scales. This requires the manipulation and analysis of data from many different sources. In this study, data were supplied by the Department for Environment, Food and Rural Affairs (DEFRA), the Edinburgh Library (EL), and the Centre for Ecology and Hydrology (CEH). To complement these secondary data, field mapping and data verification have also been undertaken. Each data source has a different background and this section will focus on an explanation of the data sources.

To process and support these primary and secondary data, the system known as GIS (Geographical Information Systems) was used as a tool. The GIS software of ArcGIS v8.3, which consists of ArcCatalog and ArcMap, were used in data manipulation and analysis.

3.4.1 DEFRA data

In this study, the data used from DEFRA sources relates to the annual census conducted by DEFRA, and the results are released every year in June through the Agricultural and Horticultural Census. The released result is based on census form returns each year by registered farmers. Each farmer is obliged to give information about the size of each field occupied by every type of agricultural activity. The accuracy of such information is of course highly dependent on the reliability and availability of the farmers' information returns. DEFRA also produces an agricultural map for Agricultural Land Classification (ALC) at a 1:250,000 scale. However, such a scale is not really suitable for the purpose of this research, as more detailed information is needed. The census data available to use in this research are from the following years: 1950, 1954, 1955, 1960 to 1965, 1970 to 1975, 1980 to 1985, 1990, 1995 and 2000 to 2003.

3.4.2 Edinburgh Library data

The Edinburgh Library has data in digital map format for various years and in different resolutions. The information in the digital maps is derived from agricultural census data summarized by MAFF (Ministry of Agriculture, Fisheries and Food) and SOAEFD (The Scottish Office Agriculture, Environment and Fisheries Department) and is related to groups of farm holdings. The process of data transformation is based on parish data in a square grid of 1km^2. The Parish Framework is used in conjunction with a 7-fold classification of land use with the same 1 km^2 grid as in the Land Use Framework. The digital maps used in this research represent the following years: 1979, 1981, 1985, 1988, 1993, 1995, 1997, 1999 and 2000. These maps are based on a 2 km^2 grids, except for that of 1985, which is based on a 5 km^2 grid.

3.4.3 CEH data

The CEH dataset used in this study is the Land Cover Map (LCM) of 2000. The LCM2000 is a thematic classification map based on spectral data recorded by satellite images. The dataset is based on a raster format derived from a vector database and stored as pixels in a 1km grid. It can be divided into two major classes, namely Target Classes as the top hierarchy, and Subclasses. The Target Classes or Level 1 was considered the nearest match which could be achieved consistently and with a high level of accuracy. It was divided into 16 groups, such as arable and horticultural, suburban and urban, and littoral rock and sediment.

The Subclasses are divided at two levels, known as Level 2 and Level 3. Level 2 is the standard level of detail which provides 26 subclasses such as arable cereals, arable horticulture and non-rotational horticulture. Level 3 known as Variants, provides details down to 72 categories. In this research, the Variants level was used to identify the area of maize.

Since it was based on interpretation of satellite imagery, an attempt was made to validate the CEH data. Eighteen fields in the Culm Catchment and 24 fields in the Tone Catchment shown as being used for maize in the CEH database were selected and their land use in 2000 was checked by interviewing the relevant farm owner. The result showed that 22 of the 24 maize fields in the Tone Catchment were used for maize in 2000. However, the other two fields identified by CEH data as a maize field in 2000 were not used for maize, both fields being covered with rough grassland mixed with coppice and scrub. The validation process in the Culm Catchment shows that 100 percent of the selected maize fields were used for growing maize in 2000. For both areas combined, the validation applied showed that 95.2 percent of maize fields identified by CEH were used for growing maize in 2000. This result confirms the reliability of the CEH data, which has therefore been used in this study.

3.4.4 Field mapping data

The secondary data supplied by DEFRA, EL and CEH do not provide spatial information after 2000. From a local perspective, it was very important to show the current spatial distribution of the maize-growing area within the Culm and the Tone catchments for soil sampling purposes. In order to support the secondary data, field mapping was undertaken to identify all maize fields within the study catchments for the years 2002, 2003 and 2004. The field mapping carried out was based on interviews with farm owners within the catchments. Each farm owner was asked to identify their maize fields in those years, and topography maps were used as basic maps.

3.5 Summary

This chapter has explained various methods employed in this study to achieve the study objectives. The methods have involved both fieldwork, which involved soil and suspended sediment sampling, and also laboratory work which included sample processing and preparation and analysis of the radionuclide and chemical contents of soil and suspended sediment samples. In addition, data manipulation and analysis, based on field-mapping work and secondary data from DEFRA and CEH have also been described. The results of the sampling and analysis programmes will be presented and discussed in Chapters 6 and 7. Results from the data manipulation and analysis employed GIS will be presented and reported in Chapters 4 and 5.

CHAPTER 4: MAIZE CULTIVATION IN ENGLAND AND THE SOUTHWEST REGION

4.1 Introduction

Most of the land in England is under agriculture. In 1950, about 10.33 million ha of England were under arable land, grassland and rough grazing, but the area decreased to 8.15 million ha by 2003. This represented 44.3% of the agricultural land in the United Kingdom in 2003. Arable land occupied about 50.4% of the agricultural land in England in 1950, with permanent grassland accounting for 35.4%, and rough grazing land for 4.2%. However, by 2003, the proportion associated with arable land had decreased to 47.1%, with grassland accounting for 44.9%, and rough grazing for 8.0%.

Crops still constitute the largest area of agricultural land in England, and in 2003, the area of arable land extended to 3.81 million ha. Most cropland is used for the growing of cereals (66.7%) such as wheat, barley and oats. Other crops (those not used for feeding of stock) accounted for 18.8% of cropland, and included crops such as sugar beat, potatoes and rape. Fodder or compounding crops and horticultural crops occupied a smaller area and together accounting for 14.5% of the cropland in England.

One crop that has expanded rapidly in England in recent years is maize. In 1990, the area under maize cultivation was 33,265 ha, but by 2004, the area under maize had increased to 107,494 ha. In England, maize is grown as a fodder crop. A detailed review of the increase and spatial distribution of maize cultivation in both England and the Southwest Region will be presented in section 4.4.

4.2 Maize Cultivation: An Overview

Maize (*Zea mays* L.) is the world's third most important crops after rice and wheat. According to FAO data, the world total maize production in 2005 was 692 million metric tonnes, and the three top maize producers are the United States (280 million metric tonnes), China (131 million metric tonnes) and Brazil (35 million metric tonnes). However, this information relates to the production of grain maize, and information on maize cultivation for animal feeding is not available from the FAO database. According to the data produced by *Maisadour Semences*, the area of maize cultivation for silage production totalled 3,857,000 ha in 1999, and this accounted for 61.3% of the cultivation of silage maize in Europe. Table 4.1 provides a ranked list of countries in Europe with respect to the area devoted to silage maize in 1999, with the equivalent figures for grain maize cultivation given for comparison. From Table 4.1, it is clear that growing maize for animal feeding or silage maize is more important in northern countries, whilst cultivation of maize for grain is of greater importance in the countries of southern Europe.

The most important countries for silage maize cultivation in Europe in 1999 were France, Romania and Germany, with these three countries accounts for 64.3% of the silage maize production in Europe. The United Kingdom, occupies position 11, and accounted for 2.7% of the area of silage maize cultivation in Europe in 1999. However, in terms of the proportion of arable land occupied by silage maize, Romania tops the ranking, with silage maize occupy 2.136% of its arable land in 1999, and Ireland is at the bottom of the ranking with silage maize occupy only 0.012% of its arable land. Silage maize cultivation in the United Kingdom accounts for 0.099% of its arable land, and placing it at rank 17 within the countries of Europe. In the case of the United Kingdom, more than 90.0 % of the area under maize cultivation is found in England.

Table 4.1: A ranked list silage maize and grain maize production within European countries in 1999

Rank	Country	Silage maize (ha x 10^3)	Silage maize area as a proportion of the total arable land[1]	Grain maize (ha x 10^3)
1	France	1,550	0.810 (7)	1.650
2	Romania	1,300	2.136 (1)	2,000
3	Germany	1,200	1.138 (6)	300
4	Bosnia-Herzegovina	520	1.994 (2)	-
5	Czech Rep.	240	1.206 (5)	40
6	Italy	235	0.211 (11)	920
7	Netherlands	233	1.510 (4)	9
8	Belgium	185	1.675 (3)	20
9	Poland	120	0.158 (14)	120
10	Slovakia	120	0.719 (8)	110
11	United Kingdom	103	0.099 (17)	-
12	Hungary	100	0.537 (10)	950
13	Austria	95	0.191 (12)	140
14	Portugal	55	0.103 (15)	96
15	Croatia	40	0.183 (13)	40
16	Denmark	45	0.558 (9)	-
17	Turkey	40	0.015 (20)	460
18	Switzerland	40	0.100 (16)	25
19	Bulgaria	30	0.081 (18)	370
20	Spain	30	0.016 (19)	330
21	Greece	10	0.015 (21)	115
22	Ireland	5	0.012 (22)	-

Source: Maisadour semences
[1]CIA

In general, there has been a significant increase in the area under silage maize cultivation in Europe since the mid-1980s, in response to changes in both agricultural policy and agricultural technology. Most European countries suffered from WWII, and each country introduced a comprehensive package of agricultural reforms to encourage increased production of food, crops and livestock. More land was put under the plough, and the governments in individual countries continued to support farming activity by subsidising arable cultivation via both area and yield. These subsidies encouraged farmers to plough more land for crop cultivation and to devote more land to cattle. More grass was also cultivated in order to support dairy farming. However, with technological changes in farming, especially in animal feeding, silage maize cultivation became increasing popular in European countries to support dairy farming. This occurred in parallel with a change in animal feeding rations from hay or grass silage (considered less valuable fodder in terms of nutrition), to maize silage, which is rich in nutrients. In addition, and especially in the 1990s, the Common Agricultural Policy (CAP) provided a major impetus to the growing of silage maize through subsidies and other additional benefits associated with dairy farming.

In the case of the United Kingdom, and also England, agricultural policy still plays an important role in defining farming activities. The CAP offers market price support and aid or income support in many ways to support farming activities. In this situation, farmers are highly dependent on income support. This support offers farmers direct income for their arable crops in the form of area payments under the Arable Area Payments Scheme (AAPS). Brassley (2000) stated that, by the mid-1990s, maize qualified for AAPS of up to £320 per hectare. However, in 2001, payment rates declined to £225.64 per hectare but increased to £238.94 per hectare in 2002 and 2003. In 2005, all arable land in England was put under a new scheme called the Single Payment Scheme (SPS), following the CAP reform in 2003. Instead of subsidising arable land based on production as in AAPS, the SPS makes payments based on the 'environmentally friendly' concept. Broadly, the SPS divided land into three classes; moorland with uplands, regarded as Severely Disadvantage Areas (SDA), land in the upland SDA but outside the moorland line, and all land outside the upland SDA. The calculation of the arable area payment rates in these three zones is based on three factors, namely, the historic area, a flat rate, and a combination of the two.

In general, farmers have more freedom to farm to the demands of the market, as subsidies are being decoupled from production. On top of this, environmental friendly farming practices under the standard of Good Agricultural and Environmental Conditions (GAEC) are becoming better acknowledged and rewarded. This will probably have some influence on farmers in making decisions as to whether to grow maize in future. When considering whether farming practises qualify as 'environmentally friendly', soil erosion occurring during the winter after harvesting will need to be taken into account.

As indicated above, maize cultivation in the United Kingdom is undertaken to support dairy farming, and the growing of maize commenced in the 1950s, as forage for cattle. Before that, hay and silage were two main sources of dairy fodder in the UK. Among the factors that make silage maize cultivation important and occupy large area of cropland in the UK, is the importance of dairy farming itself. The major animal fodder in the UK is grass, beans, peas and maize. Maize silage is used to feed dairy cows during the winter prior to their returning from the fields during the summer. As reported later in this chapter, the area of maize cultivation expanded very strongly in the 1990s. Since the war, the pattern and productivity of the UK dairy farming has changed substantially, with better feeding systems, improved genetics and more skilful management of farms (Brigstocke, 2004). Under these conditions, more farmers became involved in dairy farming in England. According to DEFRA data, the number of dairy holders in 1990 totalled 28,756 farms in England and involved more than 1.997 million dairy cows. In 2000 and 2003, the number of dairy holders had decreased to 20,094 and 16,027 farms with the number of cows at 1.575 million and 1.434 million, respectively, for each of these years. Although the number of dairy holders and the number of cows had declined, maize still retains its importance as a fodder crop in England. To some extent, new technologies in making silage suggest that a combination of maize silage with high quality grass silage is a good alternative for winter rations in dairy farming. This situation will probably remain, with farmers continuing to grow maize in the future.

In addition, maize silage has also been shown to provide a better diet in dairy farming and to produce better quality milk. Maize silage at 30-32 percent of dry matter (DM) has been proved to be high in starch and fibre and ferments more slowly in the rumen. For example, milk yield is higher for maize silage (30% DM) at 33.0 kg/day compared with grass silage at only 28.0 kg/day (Advanta).

In general, growing maize for forage needs dry conditions to produce good quality silage. The weather in the UK offers almost ideal conditions for growing fodder maize, especially in England and Wales. Maize cultivation in England usually commences in April, starting with sowing the crop, and ending with harvesting in mid-September or early October. Maize grows well in areas with an annual rainfall below 760 mm and with good soil conditions. In areas with an annual rainfall greater than 760 mm, maize can still be grown (Huntseeds). However, in such cases, farmers are advised to use only early varieties to avoid the need to harvest in late autumn. With warm temperatures and sufficient solar radiation in summer in England, and especially in the Southwest region, maize can be grown in ideal conditions to produce viable yields (ECN).

Other factors motivating farmers to change from grass silage to maize are the overall costs of growing maize, which are relatively cheaper than grass silage. Although maize seed is relatively expensive (around £40 to £50 per acre or 0.4046 ha), compared to grass seed (£6 per 0.4046 ha), the overall costs are cheaper for maize. For example, the establishment and growing costs[1] for grass silage is cheaper than for maize at £76 and £90 per 0.4046 ha, respectively. However, the total fixed costs per 0.4046 ha[2] and the total fixed costs per tonne are relatively cheaper for maize at £6.60 against £7.90 for grass silage. A more detailed calculation involving yield of fresh matter, yield of dry matter, dry matter content and metabolizable energy for maize gives a cost of £196 per 0.4046 ha, compared to grass silage, which is more expensive at £202.50 per 0.4046 ha (Huntseeds).

Although silage maize cultivation is considered as an important crop in Europe and England, it also produces problems for the environment. This already been discussed in Chapter 1. In general, the environmental problems associated with maize cultivation can be related to soil erosion and diffuse water pollution from the area of maize cultivation. Soil erosion problems in maize fields can frequently be related to harvesting in late autumn, which leaves surfaces bare and unprotected from rainfall impact in winter. This could promote surface runoff and sediment mobilization and the transport of sediment to nearby watercourses, which can pollute the water with both nutrients and pesticides. The off-site impact associated with maize cultivation will be discussed in Chapter 7. This chapter will focus on temporal and spatial patterns of maize cultivation in England

[1] Establishment costs involved the cost of seed, agrochemicals and fertilizer before seeding, while the growing costs include fertilizer and agrochemical costs during the growing period.
[2] The total fixed costs per 0.4046 ha include the costs of cultivation, drilling, spraying, fertilizer or slurry spreading, and ensiling costs.

and the Southwest Region, and the factors that have influenced changes in these patterns.

4.3 The Data Used in this Analysis

This investigation of spatial and temporal patterns of maize cultivation in England and the Southwest region is based on data from two sources. The sources comprise, firstly, the Department for Environment, Food and Rural Affairs (DEFRA), and secondly, the Edinburgh Library (EL). Each source has a different background which was explained in the previous chapter.

The DEFRA data are based on the annual census through the Agricultural and Horticultural Census, which are released annually in June. These data are based on farmers' information returns, field-by-field, and the results are presented in acreage format. In the case of the EL data, the data are in digital map format, based on a spatial resolution of a 1 km^2 grid. It was necessary to manipulate the scale of the data from unsupervised format to a supervised format of five categories, based on the density of maize cultivation area in ha km^{-2}. The five categories are (i) less than 2 ha km^{-2}, (ii) 3-6 ha km^{-2}, (iii) 7-12 ha km^{-2}, (iv) 13-20 ha km^{-2}, and (v) more than 20 ha km^{-2}. The (i) and (ii) values are considered as a low density, (iii) as a moderate density, and (iv) and (v) as a high density. Although the manipulation of the EL data was applied to all available data, as mentioned in the previous chapter, for the purpose of this chapter, only relevant data will be used in order to review the spatial and temporal patterns of maize cultivation in England. This involves the data available for four years, namely, 1979, 1988, 1995 and 2000.

4.4 Maize Cultivation in England

As indicated in the introduction to this chapter, crops still constitute the largest area of agricultural land in England with most of cropland having used for the growing of cereals. Cereals have becomes the most important crops in England since 1950, and the area has probably never fallen below 2.4 million ha. The second most important crop in England is stock crops (not for stock feeding) such as potato and sugar beat. This crop increased in area by 25.9% between 1950 and 2003, increasing from 570,200 ha in 1950 to 717,700 ha in 2003. Fodder crops[3] occupied the third place for cropland in England. The area under fodder crops in 1950 extended 386,000 ha but this had decreased by 5.3% to 365,500 ha in 2003. Beans and peas have becomes important fodder crops in England and accounted for 62.9% or 229,900 ha of the fodder crop area in 2003. They are followed by maize in third place and the area cultivated for maize has expanded rapidly since the 1970s.

According to DEFRA data, maize has been grown as a fodder crops in England since 1970, but the area was small in the early years. Figure 4.1 shows the temporal trend in the area devoted to maize in England in the period from 1970 to 2004. In the early 1970s, the area of maize cultivation in England was relatively small, occupying an area of less than 10,000 ha, and representing less than 5.0% of the total area under fodder crops. The area of maize cultivation expanded to 20,800 ha in 1980, and increased by a further 60.1% to 33,300 ha in 1990. However, since 1990, the area expanded to 100,000 ha in 1995 and to 107,494 ha in 2004, an increased of 7.5%. The greatest area cultivated for maize in England was reported in 2001, when the crop occupied an area of 119,557

[3] This includes turnips, swedes, fodder beet, mangolds, kale, cabbage, savoy, kohl rabi, beans, peas and maize.

ha. Table 4.2 presents more detailed data for the trend in the maize cultivation area in England between 1970 and 2004.

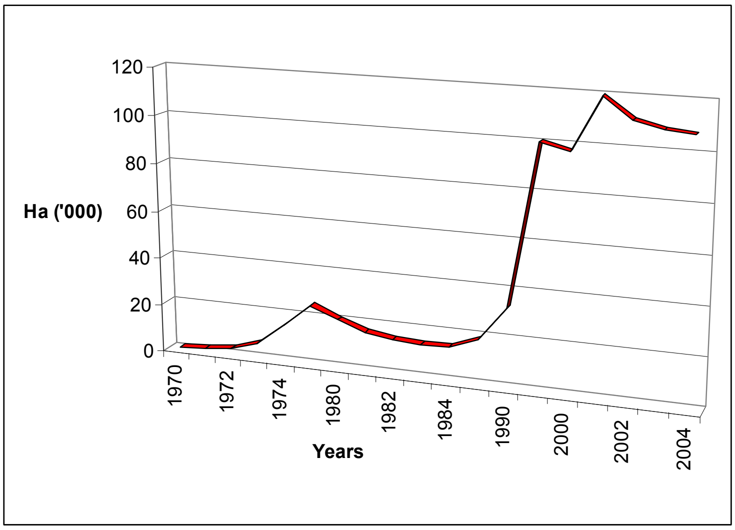


Figure 4.1: Trends in maize cultivation in England between 1970 and 2004

Table 4.2: Changes in the maize cultivation area in England between 1970 and 2004

Year	Area (ha x 10^3)	Change (%)	Year	Area (ha x 10^3)	Change (%)
1970	1.0	-	1984	14.7	1983-1984 (+2.1)
1971	2.0	1970-1971 (+100.0)	1985	19.0	1984-1985 (+16.2)
1972	3.5	1971-1972 (+75.0)	1990	33.3	1985-1990 (+75.3)
1973	6.6	1972-1973 (+88.6)	1995	100.4	1990-1995 (+67.0)
1974	15.7	1973-1974 (+137.9)	2000	97.6	1995-2000 (-2.8)
1975	25.5	1974-1975 (+62.4)	2001	119.5	2000-2001 (+22.4)
1980	20.8	1975-1980 (-18.4)	2002	111.3	2001-2002 (-6.9)
1981	17.0	1980-1981 (-18.3)	2003	108.4	2002-2003 (-2.6)
1982	15.0	1981-1982 (-11.8)	2004	107.4	2003-2004 (-0.9)
1983	14.4	1982-1983 (-4.0)	-	-	-

Source: DEFRA (various years)

Most of the area of maize cultivation during the 1970s was in the Eastern, Southeast and Southwest regions, as shown in Figure 4.2. In the Eastern region, the area of maize cultivation was greatest in the north-western and south-eastern parts. In the Southeast, the maize cultivation area spread to the south-eastern, south-western and north-western parts of the region but the greatest concentration was in the north-west of this region. The area of maize cultivation in the Southwest was greatest in the eastern part of the region.

Figure 4.3 shows the spatial distribution of maize cultivation area in England in 1988. After nine years, the main areas of maize cultivation in England had a similar location to that in 1979. However, in terms of the density, more areas of maize cultivation evidenced increased, especially in the Southeast and the Southwest regions. In the Southeast, more areas in the south-western and the north-western part of the region became moderate in density, whilst in the Southwest, some area in the eastern part of the region became high in density, and this area probably represented the greatest concentration of maize growing in England in the late 1980s.

Although the maps of the maize cultivation areas in England in 1979 and 1988, presented in Figure 4.2 and Figure 4.3, show some changes in density, in general many areas remained low. Growing maize in the United Kingdom has always been related to dairy farming, and more specifically to milk prices. Some small changes in the density of maize cultivation in the 1970s to 1980s could reflect decreases in the milk price. According to the Milk Marketing Board (DEFRA), the milk price in 1974-1983 (26.92 p/l) decreased by 9.1% when compared to that in 1964-1973 (24.48 p/l).

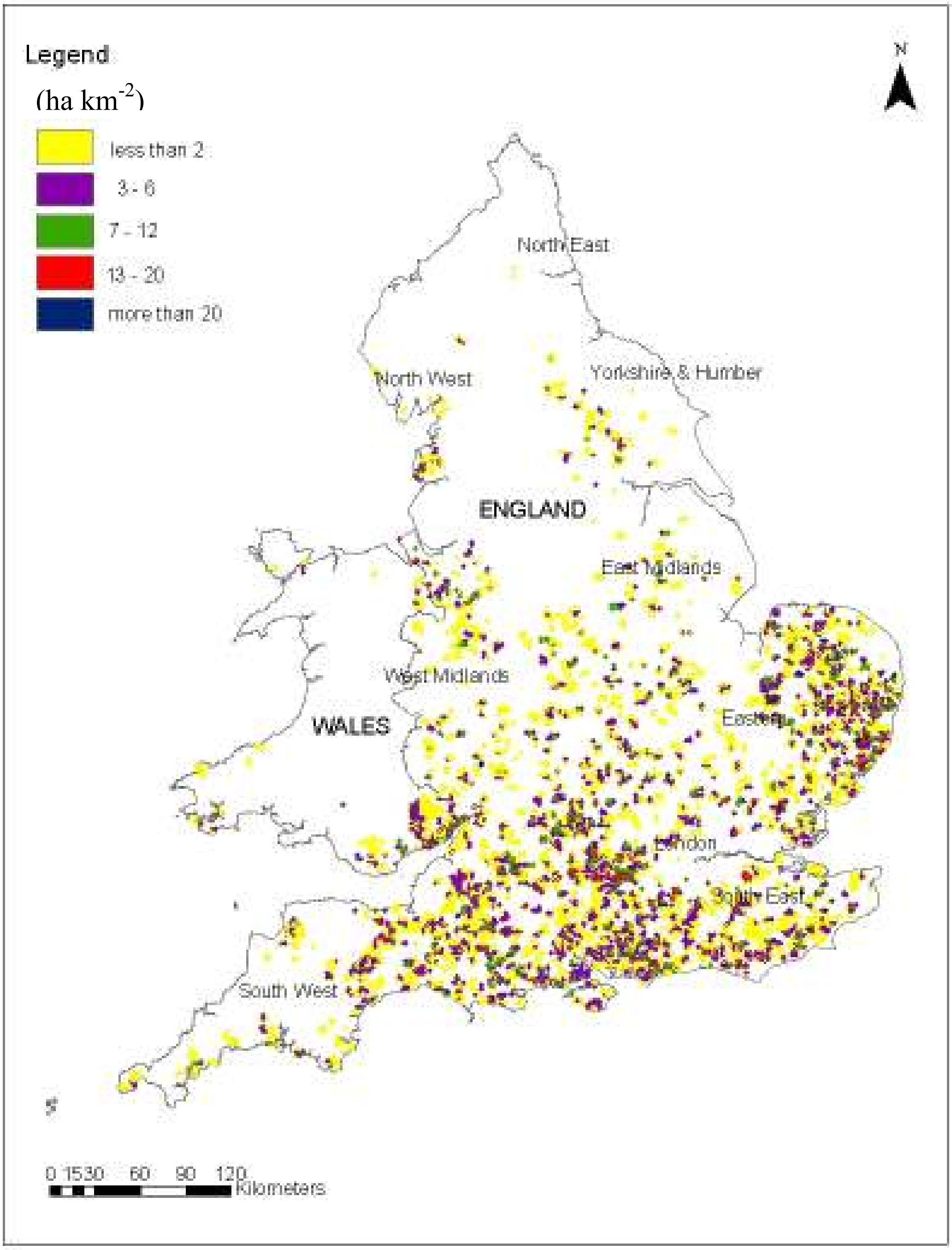


Figure 4.2: The distribution of maize cultivation in England in 1979

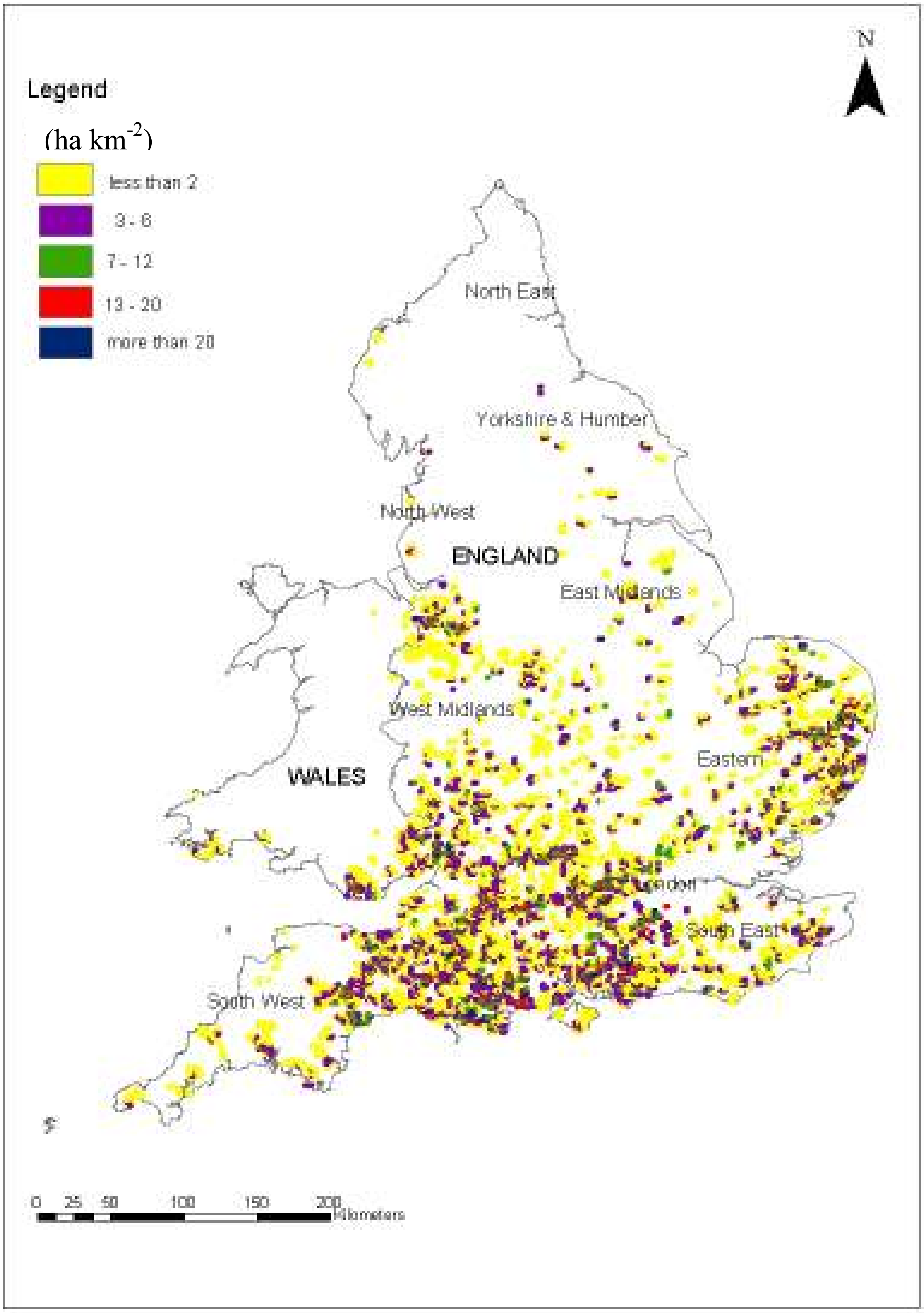


Figure 4.3: The distribution of maize cultivation in England in 1988

By 1995, there was very rapid expansion of the area of maize cultivation in England compared to 1990. The area cultivated with maize increased by 201.5% to 100,432 ha. With the exceptional of the Eastern region, all regions in England showed more than a 100.0% increase in their maize cultivation area, as shown in Table 4.3. The area cultivated for maize in the Eastern region increased by only 50.0%. The largest area cultivated with maize in 1995 was found in the Southwest region, occupying an area of 49,600 ha, followed by the Southeast region (18,900 ha), the West Midlands (12,700 ha), and the Eastern region (6,000 ha). According to Figure 4.4, the greatest concentration of maize growing in 1995 was in the Southwest and West Midlands regions, especially in the eastern part of the Southwest, and in the northern and southern parts of the West Midlands. Meanwhile, in the Southeast region, maize cultivation was greatest in the south-western part. Compared with 1988, more areas in England were characterized by a higher density of maize production.

This major change in area and density of maize cultivation can be related to incentives from the AAPS. As indicated in Section 4.2, by the mid-1990s, maize qualified for the highest payment of £320 per 0.4046 ha. Supporting this was an increase in the standard milk price from 19.35 p/l in 1985-1980 to 21.28 p/l in 1991-1998, which also caused growth in the dairy farming sector. The 1990s also saw changes in technology for maize growers. Improvement in mechanization allowed the use of larger machines that in turn led to an increase in field and farm sizes. New tractors for cultivation such as sprayers for weed pest and disease control, and the use of larger harvesting machines helped farmers to reduce overall costs, and encouraged farmers to grow maize on a large scale. In addition, genetic improvements, which focused on herbicide tolerance, and also

Table 4.3: The maize cultivation area for all regions in England

Region	Area in 1990 (ha x 10^3)	Area in 1995 (ha x 10^3)	Change 1991-1995 (%)	Area in 2000 (ha x 10^3)	Change 1995-2000 (%)	Area in 2001 (ha x 10^3)	Change 2000-2001 (%)	Area in 2002 (ha x 10^3)	Change 2001-2002 (%)	Area in 2003 (ha x 10^3)	Change 2002-2003 (%)
South West	15.0	49.6	+230.6	42.8	-13.7	51.6	+20.6	48.2	-6.6	47.8	-0.8
South East	9.0	18.9	+110.0	18.1	-4.2	22.1	+22.1	20.2	-8.6	18.7	-7.4
Eastern	4.0	6.0	+50.0	6.3	+5.0	7.7	+22.2	7.0	-9.1	6.2	-11.4
West Midlands	2.0	12.7	+535.0	13.0	+2.4	16.1	+23.8	15.3	-5.0	15.3	0.0
Northwest	1.2	5.8	+383.3	8.2	+41.4	10.1	+23.2	9.5	-6.0	9.6	+1.0
East Midlands	1.1	5.4	+390.9	6.8	+25.9	8.7	+27.9	8.0	-8.0	7.8	-2.5
Yorkshire and Humber	0.3	1.5	+400.0	2.0	+33.3	2.6	+30.0	2.7	+3.8	2.6	-3.7
Northeast	0.02	0.2	+900.0	0.2	0.0	0.2	0.0	0.2	0.0	0.2	0.0
London	0.06	0.2	+233.3	0.2	0.0	0.3	+50.0	0.1	-30.0	0.1	0.0

Source: DEFRA (various years)

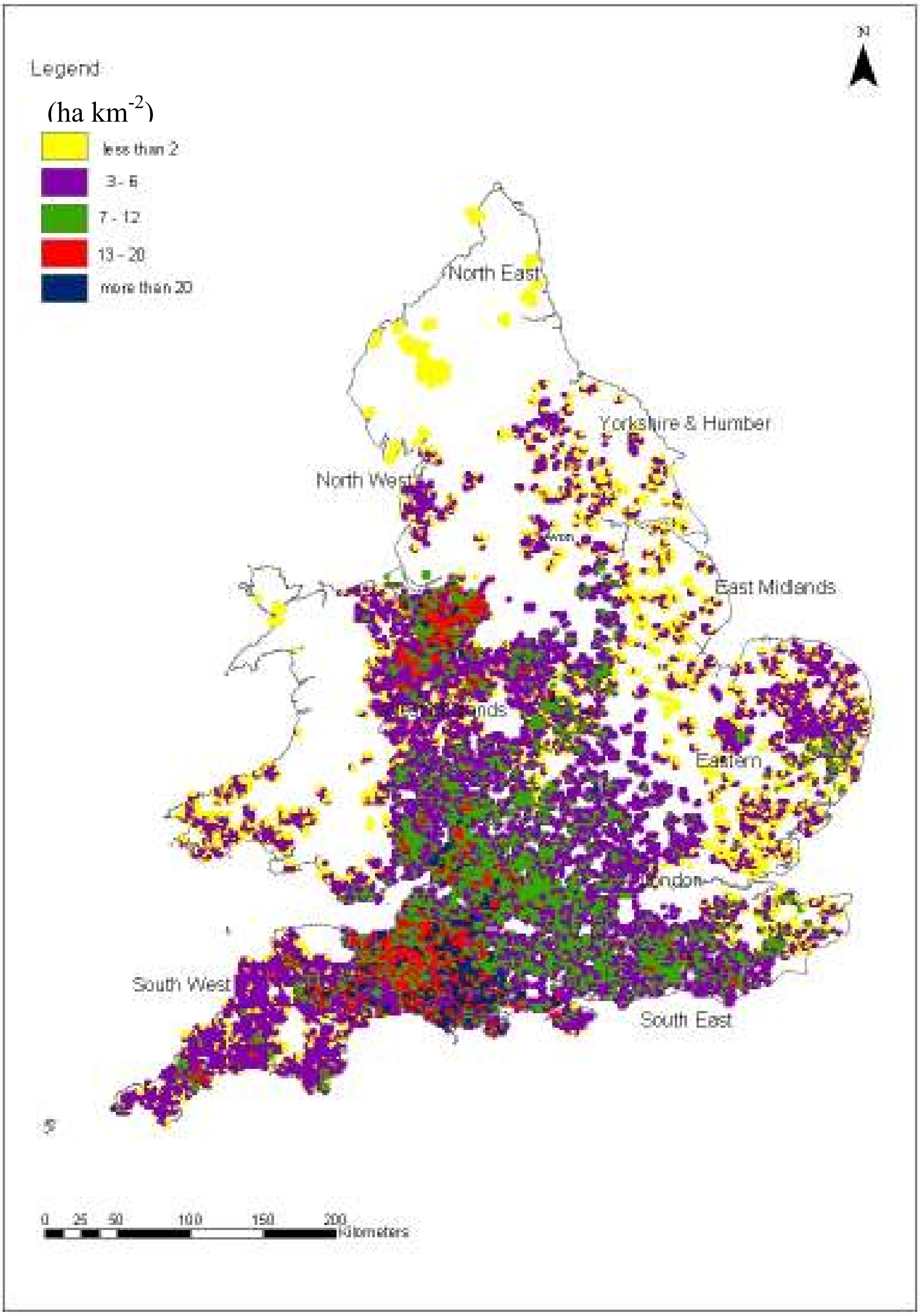


Figure 4.4: The distribution of maize cultivation in England in 1995

provided maize growers with various varieties of high yield seeds, increased maize yields and maize growers' incomes, on top of the AAPS.

By 2000, the area under maize cultivation in England slightly decreased by 2.8%, down to 97,623 ha, compared with area in 1995, but increased again in 2004 by 10.1% up to 107,494 ha. As in the 1980s and 1990s, the Southwest region and the Southeast still remained as the most important maize cultivation areas in England in 2000. However, the area under maize expanded more in the Southwest than in the Southeast, as shown in Figure 4.5. Most of the area under maize in the Eastern region and the West Midlands remained more or less static. The densest area cultivated with maize could thus be found in the Southwest, especially in the eastern part of Devon, Somerset and Dorset. The area cultivated with maize in the Southeast still remained densest in the western and southern parts of the region, whilst in the West Midlands, the densest area for maize cultivation could be observed in northern part, spreading out from there to the southern part of the region.

Small changes in the area of maize cultivation between 1995 and 2004 can be related to changes in the dairy farming sector. The number of dairy farming holders and the number of dairy cows in 2004 decreased by 37.0% (15,554 holders) and 24.0% (1,374,456 cows), respectively, compared with 1995, when there were 24,678 holders and 1,809,282 cows. This decrease can also be related to a decline in milk price, where the milk price in 2002-2003 was 18.33 p/l, a decrease of 13.9% from the price in 1997-1998 (21.28 p/l). The expansion of the area under maize in England, also has implications for environmental problems, especially the off-site impact of the silage maize area after harvesting during winter, in regard to soil erosion from bare maize fields. This is one of the DEFRA concerns in the CAP reform in 2000, which

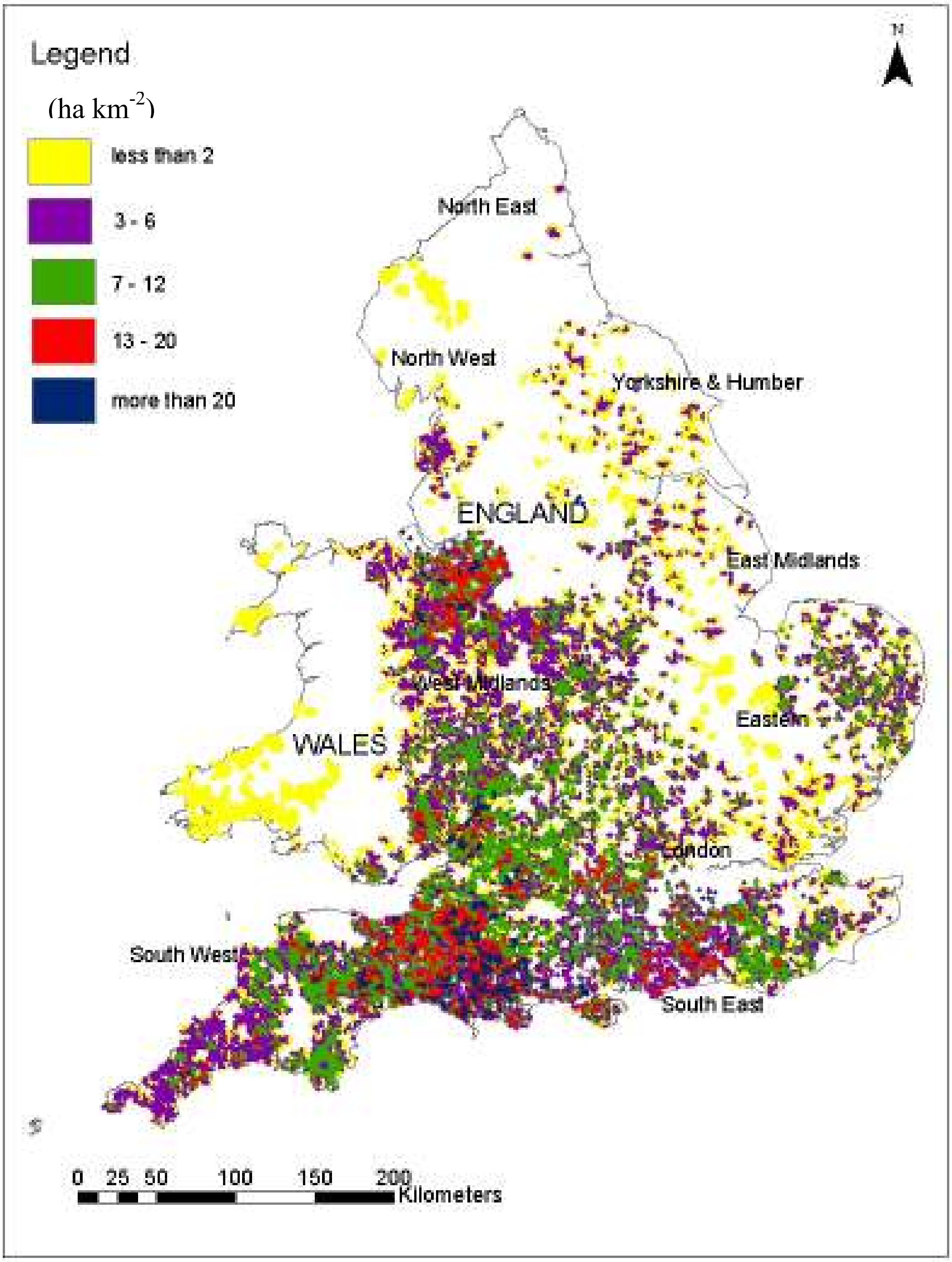


Figure 4.5: The distribution of maize cultivation in England in 2000

recognized that the degraded standard of water quality during winter could be caused by soil erosion from bare maize fields. One of the key changes associated with the CAP reform in 2000, aimed at reducing soil erosion, and avoiding diffuse pollution from maize area and other crop lands, was the AAPS, which declined by 29.5% in 2001 to £225.64 per hectare, compared with payment rates in the mid-1990s of £320.00 per hectare. Although DEFRA promoted environmentally friendly practises in cropping through the agri-environmental scheme, most farmers, including maize growers, were probably still not ready to change the management systems at that time, especially small holding farmers.

Although the area of maize cultivation shows a decline between 1990 and 2004, the author also believes that the area of maize cultivation will continue to show a small decrease in coming years, at least until 2010. This is based on the projection by the Milk Development Council, that milk price would be around 15.00 p/l from 2007 onwards. Compared with milk price in 2002-2003, this is a decrease by 18.2%. Under the CAP reform in 2003, farmers have to follow many environmentally friendly approaches recommended by DEFRA in order to sustain the environment. However, it seems that many farmers are still not ready to fulfil most of the environmentally friendly requirements, as for example mentioned in the Single Payment Scheme and the Environmental Stewardship Scheme, which required them to prepare Soil Management Plans and Soil Protection Reviews. All these could influence the area of maize cultivation in England in the future.

4.5 Maize Cultivation in the Southwest Region

In terms of cropland area, the Southwest is the fifth region in England after the Eastern region, the East Midlands, the Southeast, and Yorkshire and the Humber region. In

2003, the Southwest region accounted for 7.1% of the cropland in England. Cereals have become the most important crop in the Southwest region, and in 2003 occupied an area of more than 312,600 ha. Fodder crops were in second place with a cultivated area of greater than 80,800 ha. Somerset, Devon and Dorset had been the largest areas cultivated with cereals and fodder crops in 2003. Figure 4.6 shows the trends for cropland areas in the Southwest, whilst Figure 4.7 shows the trend for cropland areas for each county in the Southwest from 1950 to 2003.

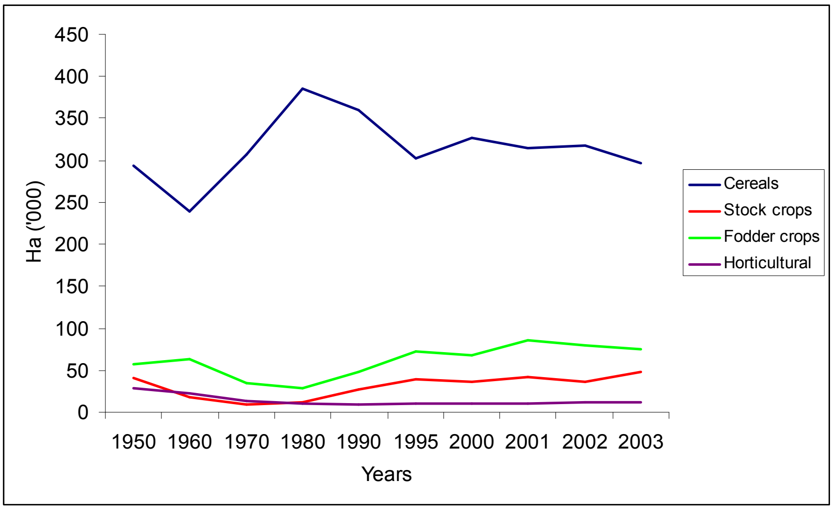


Figure 4.6: Trends in cropland area in the Southwest between 1950 to 2003

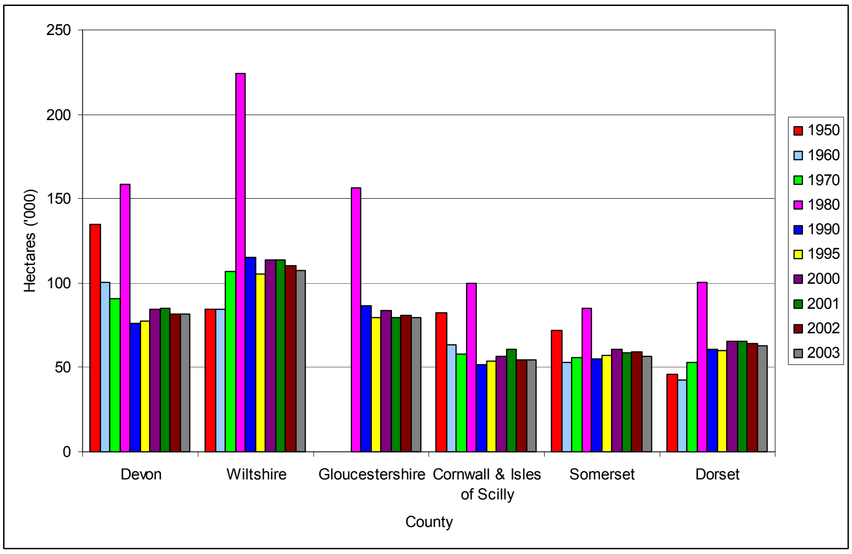


Figure 4.7: Trends in cropland area for each county in the Southwest between 1950 to 2003

As indicated in section 4.4, maize has probably been grown as a fodder crop since the late 1960s, and the area cultivated with maize also expanded very rapidly in the Southwest, especially in the 1990s and early 2000s. In 1990, the area under maize in the Southwest occupied 14,200 ha, and increased by 228.2% up to 46,600 ha in 1995. However, this figure declined by 14.2% in 2000 to 40,000 ha, but increased again in 2004 by 11.7% to 44,700 ha. According to Figure 4.8, Dorset and Somerset became the most important areas of maize cultivation in 1990, accounting for 3,400 ha and 3,300 ha, respectively. However, by 1995, Somerset had become the most important area of maize cultivation, with an area of 11,200 ha. Somerset was followed by Dorset and Devon in second and third places, with areas of 9,500 ha and 9,200 ha, respectively. Until 2003, Somerset and Devon were the most important maize growing areas in the Southwest, with a combined area of 20,500 ha.

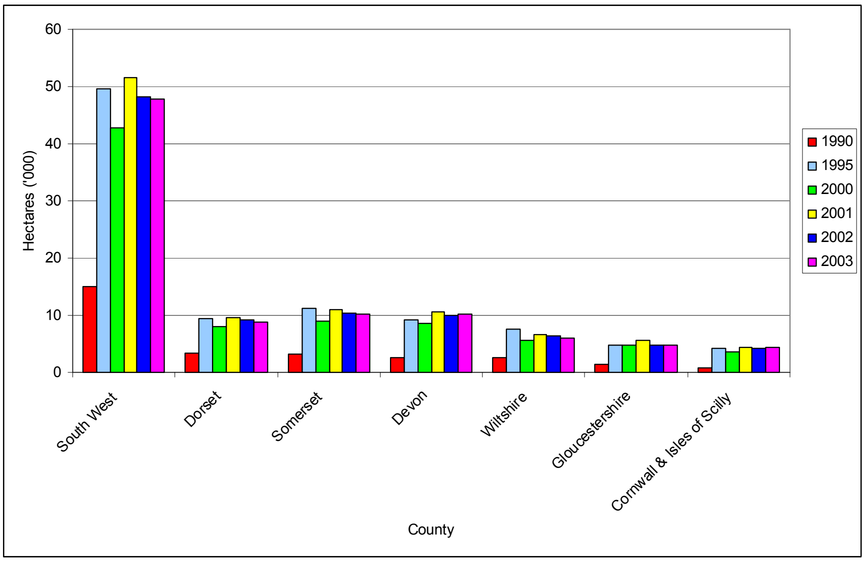


Figure 4.8: Trend in maize cultivation for each county in the Southwest between 1990 to 2003

As shown in Figure 4.9, Somerset, Dorset and Wiltshire were the most important areas for maize cultivation in 1979. In Somerset, maize cultivation was densest in the eastern and southern parts of the county. In Dorset, maize cultivation can be seen to be important in the eastern and south-eastern parts of the county, whilst in Wiltshire, most of the maize cultivation area can be found in the western and northern parts of the county. At this time, maize cultivation was relatively limited in Devon, Gloucestershire, Avon and Cornwall.

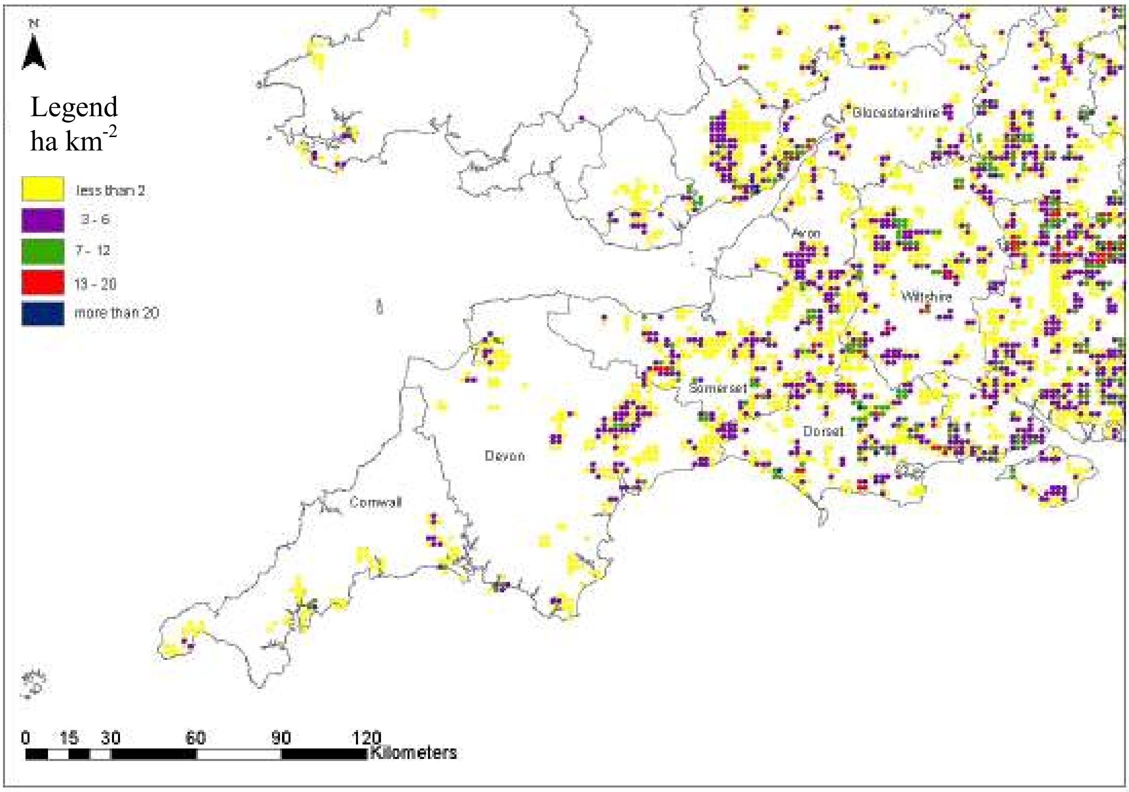


Figure 4.9: The distribution of maize cultivation in the Southwest Region (1979)

When compared with 1979, maize cultivation in the Southwest in 1988 expanded rapidly in Devon, as shown in Figure 4.10. The area of maize cultivation became moderately dense in the eastern and south-eastern parts of the county. Meanwhile, in Somerset, maize cultivation was widely distributed, whilst in Dorset, only limited changes were seen in terms of the area of maize cultivation, because it was largely grown within the same areas. These changes reflected similar trends to those found at the national scale, which can be related to increases in the number of dairy cows.

Overall, the number of dairy cows in the South declined by 7.7% between 1981 and 1988 from 778,880 cows in 1981 to 718,767 cows in 1988.

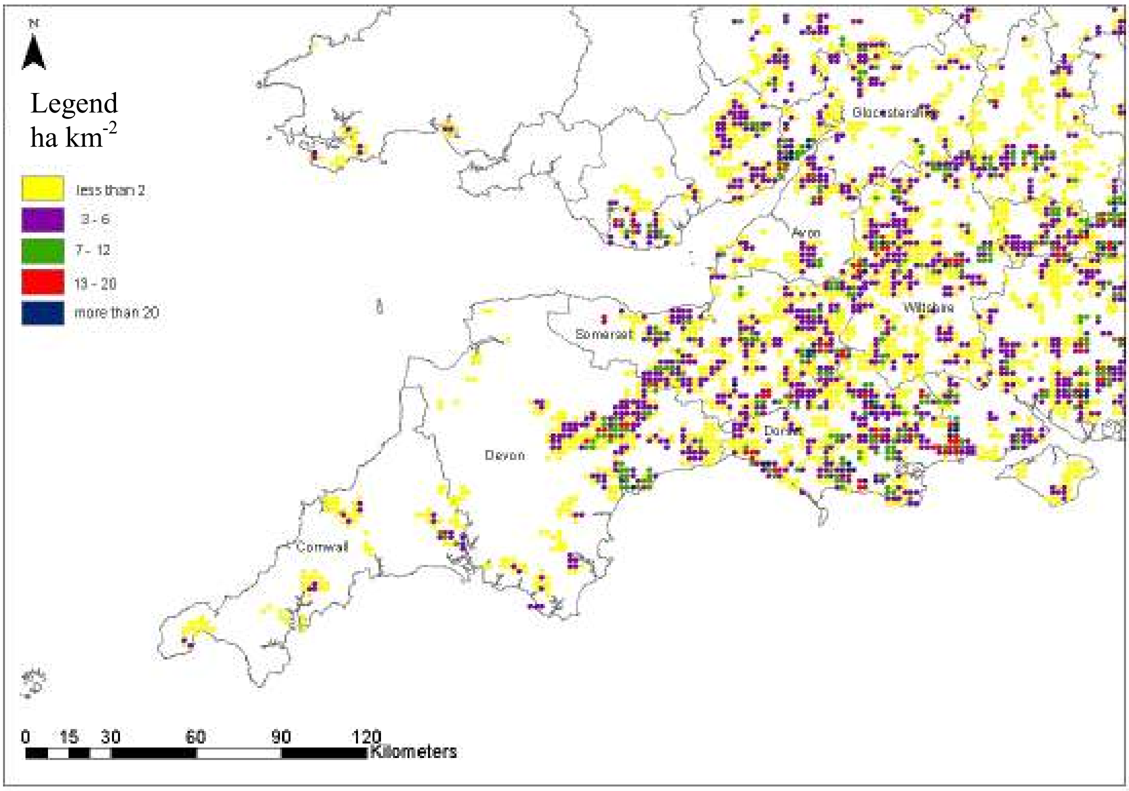


Figure 4.10: The distribution of maize cultivation in the Southwest Region (1988)

According to Figure 4.11, the density of maize cultivation in the Southwest in 1995 was denser than in 1988. By 1995, the densest area was in eastern part of Somerset and northern part of Dorset. In fact, the area under maize in Somerset expanded in every corner of the county except the north-western part. Other counties also show an expansion of the area of maize cultivation, and more new areas of maize cultivation can be found in southern, western and south-eastern parts of Devon and Cornwall. In 2000, the densest area of maize cultivation occurred in almost the same locations as in 1995, and there were not many changes can be found in terms of the absolute density (Figure 4.12). In some areas in Wiltshire that were cultivated with maize previously, the density of maize cultivation increased, especially in the northern and eastern parts of the county. However, in other counties, most of the areas previously under maize have remained so. In addition, the highest increases in the area under maize in the Southwest between 1995 and 2000 occurred in Devon, by 15% up to 10,599 ha.

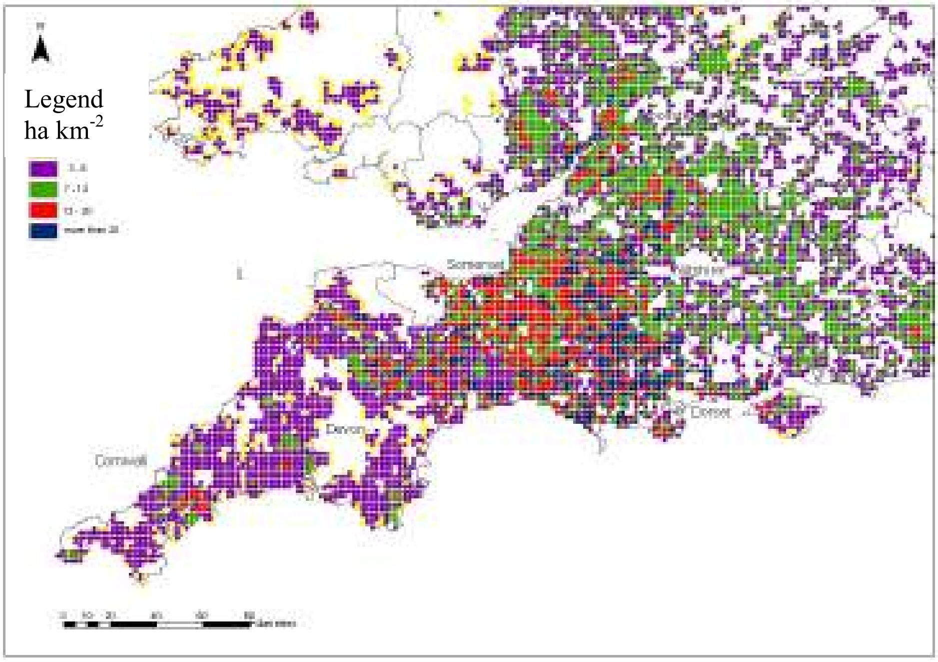


Figure 4.11: The distribution of maize cultivation in the Southwest Region (1995)

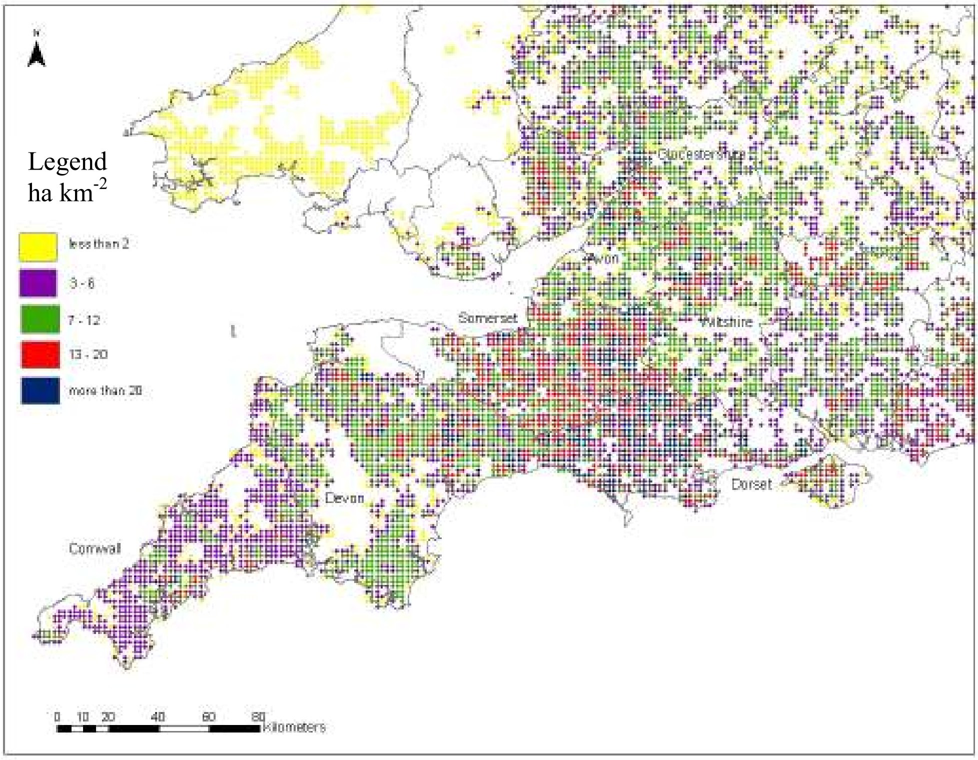


Figure 4.12: The distribution of maize cultivation in the Southwest Region (2000)

Some changes in the density of the area under maize in the Southwest between 1995 and 2000 show similar trends to the national level. In addition to the decline in milk price and incentive payment under the AAPS, the number of dairy cows in all counties in the Southwest also decreased. For example, the number of dairy cows in Devon in 2000 decreased by 11.5% (155,229 cows), compared with the number of dairy cows in 1995 (175,505 cows). Table 4.4 shows the decreases in number of dairy cows in the Southwest that could account for the changes in the area under maize in the region.

4.6 Conclusion

Agriculture is one of the important activities in England, especially in the Southwest region. Most of the agricultural land in England and the Southwest is cultivated with crops, especially for cereal and stock feeding. Fodder crops have become the third most important crops in England and the Southwest. Maize too has become an important fodder crop, and its cultivation expanded very rapidly between 1990 and 2000 in England and notably the Southwest region.

This chapter has discussed the temporal and spatial patterns of maize cultivation in England at the national level but with particular emphasis on the Southwest region. At the national level, growing maize as a fodder crop has become very important since the 1990s to support dairy farming. The rapid expansion of the maize area has occurred in almost every region in England, especially in the Eastern, Southeast and Southwest regions. From the 1970s to the 1980s, most of the maize cultivation area could be found in the Eastern and Southeast regions. However, since then, maize cultivation area has spread rapidly and has become denser in the Southwest region from the 1990s to the present. In the Southwest, the spatial distribution of maize cultivation area in the 1970s and 1980s became denser in Somerset, Dorset and Wiltshire. However, the situation has

Table 4.4: The area of maize cultivation and the number of dairy cows in the South West in 1990, 1995 and 2000

County	1990		1995	Changes in MC in 1990-1995 (%)	1995	Changes in DC in 1990-1995 (%)	2000	Changes in MC in 1995-2000 (%)	2000	Changes in DC in 1995-2000 (%)
	MC	DC	MC		DC		MC		DC	
Cornwall	841.0	103,115	4,211.2	+400.7	96,547	-6.4	3,670.9	-12.8	85,534	-11.4
Devon	2,567.0	184,786	9,216.6	+259.0	175,505	-5.0	8,708.4	-5.5	155,229	-11.5
Dorset	3,381.0	101,964	9,497.0	+180.9	93,943	-7.9	8,035.7	-15.4	77,954	-17.0
Gloucestershire	1,427.3	49,481	4,868.6	+241.1	45,461	-8.1	4,849.1	-0.4	38,406	-15.5
Somerset	3,347.5	140,541	11,178.2	+233.9	128,332	-8.7	8,992.5	-19.5	109,498	-14.7
Wiltshire	2,601.7	76,521	7,680.5	+195.2	68,337	-10.7	5,725.1	-25.4	55,639	-18.6
Total	14,165.5	656,404	46,652.1	+229.3	608,125	-7.3	39,981.7	-14.3	522,260	-14.1

Source: DEFRA (various years)

Note: MC – Area under maize cultivation (ha)
DC – The number of dairy cows

changed since the 1990s, and the maize cultivation area is now densest in Devon, Somerset and Dorset.

Most of the recent changes in the area of maize cultivation in England and the Southwest can be related to the state of dairy farming, which in more detail is related to milk prices and the number of dairy cows. On top of this is the incentive from the AAPS, especially in the 1980s, which probably reached the highest payment for growing crops, including maize. Technological developments, especially in the 1970s and 1990s, also became an important factor that could encourage farmers to grow maize. This could be related to the introduction of new machines for managing the crop (from sowing to harvesting), and improvements in herbicide tolerance, which increased both yields and incomes. All these factors contributed to the expansion of the area under maize in England and the Southwest region between the 1970s and mid-2000s.

CHAPTER 5: MAIZE CULTIVATION IN THE CULM AND TONE CATCHMENTS

5.1 Introduction

The previous chapter considered maize cultivation in the United Kingdom from a national and regional perspective, focusing on England and the Southwest region. This chapter considers the spatial and temporal patterns of maize cultivation at a local level, and this involves the two study catchments, namely the Culm and the Tone catchments. A detailed description of the background data used to support this analysis has already been presented in Chapter 3. As indicated in Chapter 2, the Culm and Tone catchments are located in the Southwest region, in the counties of Devon and Somerset, respectively. These two counties have the largest areas in the Southwest, and probably in the country, under maize, as reported in Chapter 4. The first section of the present chapter considers the spatial and temporal patterns of maize cultivation in both catchments. The second section considers in greater detail at the spatial location of current maize cultivation within the two catchments, with emphasis on its location with respect to the river networks.

5.2 Spatial and Temporal Patterns of Maize Cultivation in the Culm and Tone Catchments

As discussed in the previous chapter, maize has become an important fodder crop in England to support dairy farming. The following description of spatial and temporal patterns of maize cultivation within the Culm and Tone catchments is based on data provided by DEFRA, and the CEH land cover database, and on field mapping undertaken by the author as part of the current investigation. The data (DEFRA and CEH) have again been manipulated for the purpose of this study, which classifies the density of maize cultivation into five categories, as explained in Chapter 4 (Section 4.3).

The field mapping data for 2002, 2003, and 2004 were generated through field observation and direct interviews with farmers during the field surveys, aim at producing maps of the individual fields used for maize cultivation, based on the standard topographic 1:25,000 maps with field boundaries. These datasets were stored in GIS format, in raster format for the DEFRA and CEH data, and in vector format for the field mapping data, in readiness for further analysis of the spatial patterns involved.

5.2.1 Maize cultivation in the Culm Catchment

The Culm Catchment covers an area of 227.4 km^2. According to the MAFF agricultural land classification, the major part of the Culm Catchment area is classified as Grade 3, where the quality of land is classed as being between good to moderate for agricultural purposes, with moderate limitations for agricultural use. These limitations could be due to soil type, relief or climate, all of which might restrict the choice of crops and timing of cultivation. Small areas in the downstream part of the catchment, located in the vicinity of Cullompton and Kentisbeare, are classified as Grade 1, which represents land of an excellent quality with only minor or probably no physical limitations on its agricultural use. Maize growing in the Culm Catchment is most likely to be concentrated on Grade 1 land, especially in the downstream part of the catchment.

According to Figure 5.1(a), maize growing was of limited importance in the Culm Catchment in 1979. The area of maize cultivation was located in the downstream part of the catchment, and was characterized by very low density (less than 2 ha km^{-2}). The areas involved were around Cullompton, Kentisbeare, Uffculme, Willand and Halberton.

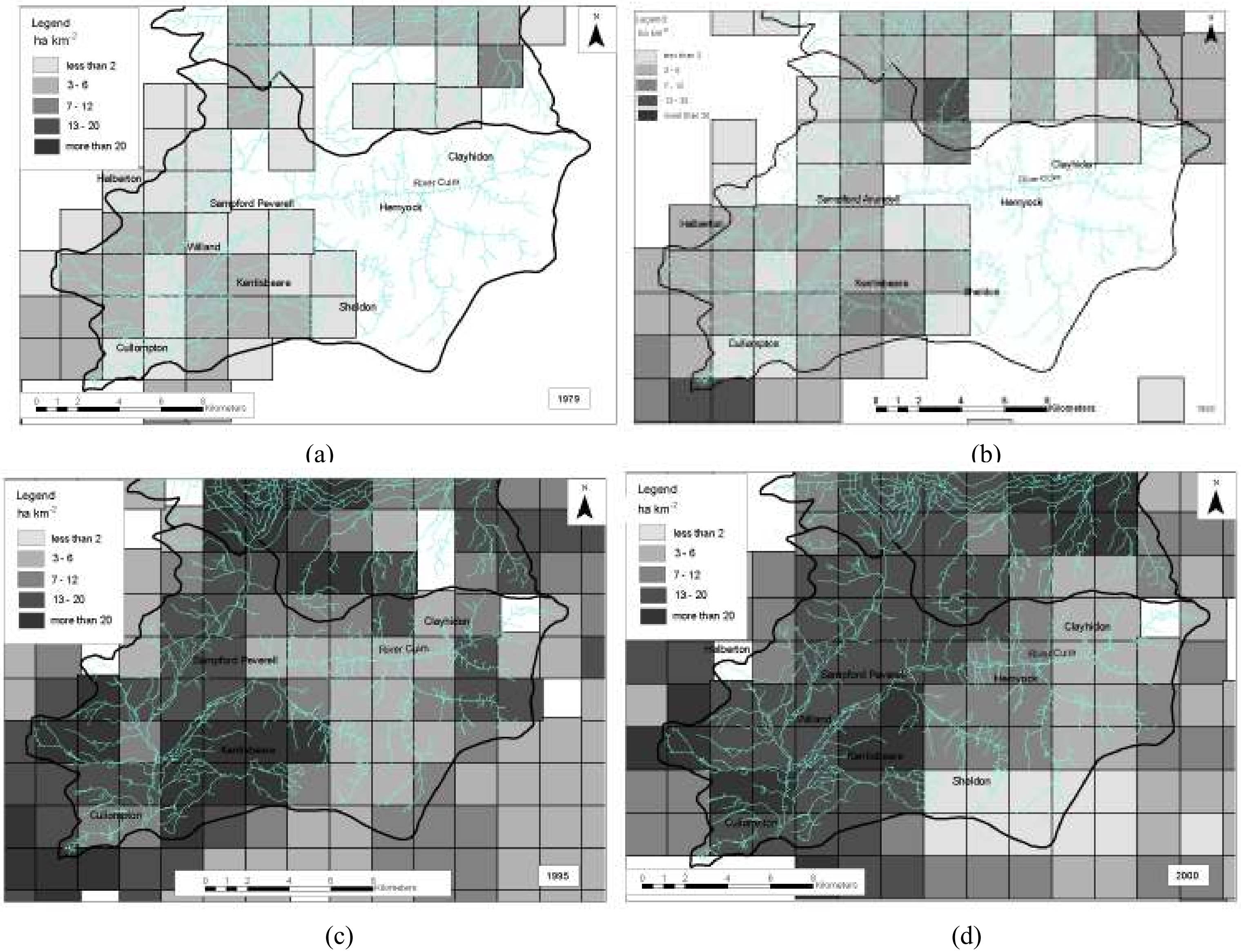


Figure 5.1: The spatial distribution of maize cultivation density in the Culm Catchment in 1979 (a), 1988 (b), 1995 (c) and 2000 (d)

Some changes in the spatial distribution and extent of maize cultivation can be identified in 1988, as shown in Figure 5.1(b). The area of maize cultivation can be seen to have expanded into the middle part of the catchment, especially around Burlescombe and Sheldon. Furthermore, in terms of the density of maize cultivation, the areas around Kentisbeare, Willand and Halberton (in the downstream part of the catchment) changed from very low to low density (3-6 ha km^{-2}).

By 1995, maize cultivation had spread across all the catchment, although the density varied, as shown in Figure 5.1(c). In general, the downstream part of the catchment increased from low to moderate density (7-12 ha km^{-2}), whilst in the middle part of the catchment, especially around Sheldon, it increased from low to high density (13-20 ha km^{-2}).

When compared with 1995, some further changes in the areas under maize occurred by 2000, as shown in Figure 5.1(d). Around Halberton, there was an area of maize cultivation characterized by a very high density (more than 20 ha km^{-2}). Within the downstream part of the catchment most other areas had changed from moderate density in 1995 to high density. In the middle part of the catchment, especially around Holcombe Rogus and Culmstock, the density of maize cultivation remained moderate or high.

There was little or no maize growing in the upstream part of the catchment before the 1990s. However, the area of maize cultivation can be seen to have expended into the upstream part of the catchment in the 1990s, and especially into the areas around Clayhidon and Churchstanton, providing an area of low density maize cultivation in 1995 and 2000.

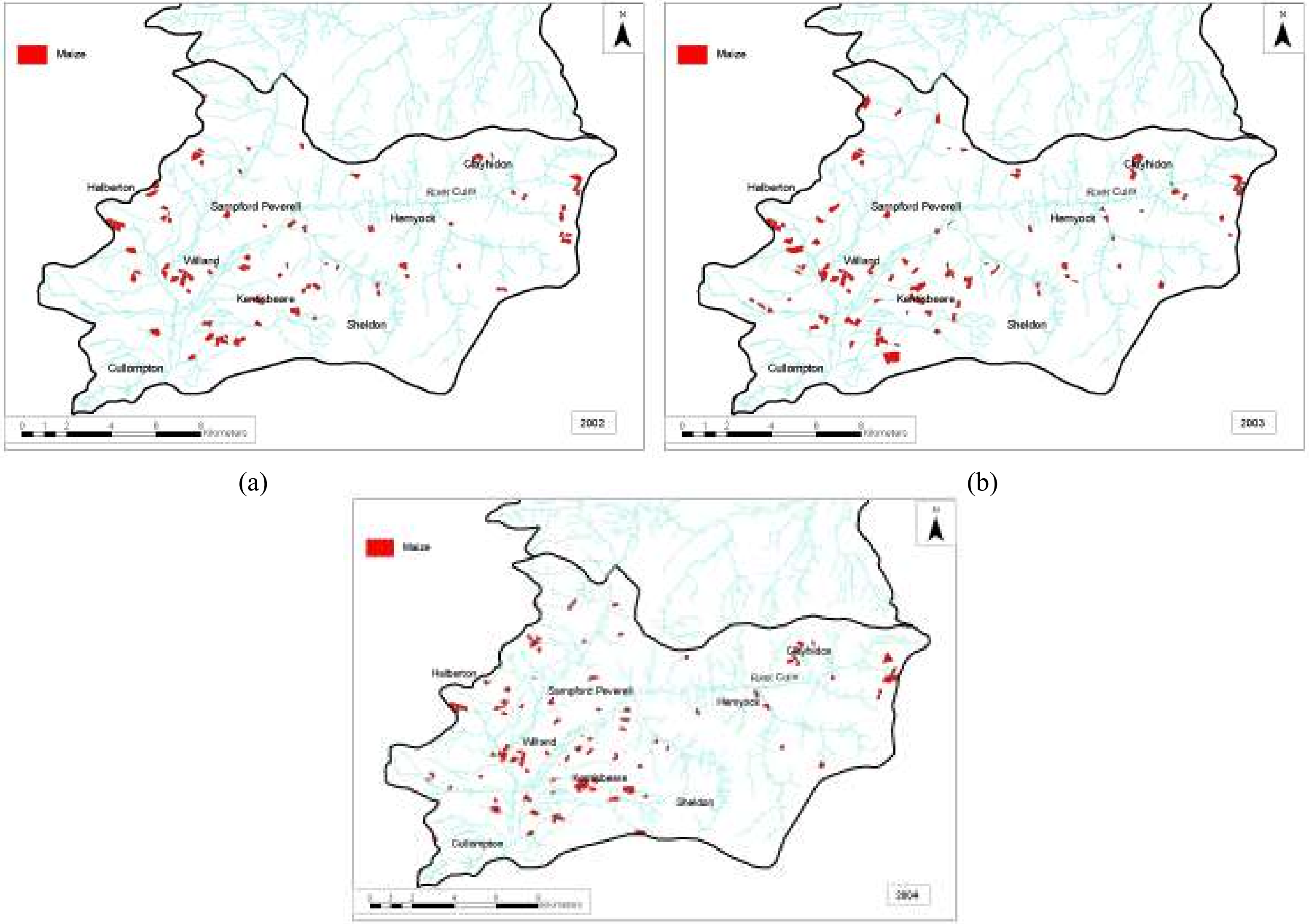
According to the CEH land cover database, the total area under maize in the Culm catchment in 2000 was 885.0 ha. Based on the field survey, this area reduced by ca. 22.5 ha to 862.5 ha in 2002, but expanded again in 2003 to 1,042.5 ha. However, in 2004, the area under maize in the Culm Catchment covered only 855.0 ha, a decrease of ca. 188 ha from 2003. From 2002 to 2004, most of the maize cultivation was located in the downstream part of the catchment, as shown in Figure 5.2.

The field mapping data available for 2002, 2003 and 2004 show that 115 fields were cultivated with maize in 2002, with the total increasing to 139 fields in 2003, but decreasing again to 114 fields in 2004. Table 5.1 summarize the area of maize cultivation and the number of maize fields in 2002, 2003, and 2004 in the Culm catchment.

Table 5.1: The area of maize cultivation and the number of maize fields in the Culm Catchment in 2002, 2003 and 2004

	2002	2003	% change (2002 & 2003)	2004	% change (2003 & 2004)
Area (ha)	862.5 (115 fields)	1,042.5 (139 fields)	+20.9	855.0 (114 fields)	-18.0

Note: (+) indicates increase
(-) indicates decrease



(a) (b)

(c)

Figure 5.2: The spatial distribution of maize cultivation in the Culm Catchment in 2002 (a), 2003 (b) and 2004 (c)

Table 5.2 presents the result from an overlay analysis aimed at company the distribution of maize fields in 2002, 2003 and 2004. The results show that for 2002 and 2003, 61 maize fields were cultivated in both years, with these fields being located particularly around Halberton and Shelton. The ‘new’ maize fields accounted for 585.0 ha in 2003. However, in 2003 and 2004, the number of maize fields cultivated in both years decreased to 48, but these fields accounted for 360.0 ha of the maize cultivation area in the Culm Catchment in 2004. In addition, an overlay analysis for 2002, 2003 and 2004 shows that maize was grown within the same fields over the three years in 35 fields. This represented an area of 262.5 ha of maize cultivation area in 2004.

Table 5.2: The overlay analysis results for the area of maize cultivation in the Culm Catchment for 2002, 2003 and 2004

	2002 and 2003	2003 and 2004	2002, 2003 and 2004
Same maize fields	61 fields (457.5 ha)	48 fields (360.0 ha)	35 fields (262.5 ha)
New maize fields	78 fields (585.0 ha)	66 fields (495.0 ha)	79 fields (592.5 ha)

To summarize, considering the trends of the temporal and spatial pattern of maize cultivation in the Culm Catchment in 1979, 1988, 1995, 2000, 2002, 2003 and 2004, it can be concluded that most of the area under maize was located in the downstream part of the catchment. This was particularly concentrated within the area around Kentisbeare, Cullompton, Halberton and Uffculme. In the middle part of the catchment, maize growing was mostly at a moderate density, and was concentrated in the area around Sheldon, Holcombe Rogus, Hemyock, and Culmstock. Maize is found only rarely in the upper part of the catchment but some areas were found around Clayhidon and Churchstanton. In general, the density of maize cultivation was low in 1979 and 1988, but changed to moderate in 1995 and to high in 2000.

5.2.2 Maize cultivation in the Tone Catchment

The Tone catchment covers an area of 206.8 km^2. Unlike the Culm Catchment, most of the area in the downstream and middle parts of the Tone Catchment can be classified as Grade 1 and Grade 2, according to the agricultural land classification. As indicated previously, Grade 1 land refers to land of excellent quality for agricultural use, while Grade 2 refers to good quality land with some minor limitations for agricultural use. However, in the upstream part of the catchment, most of the area was classified as Grade 4, which is poor quality land for agricultural use. Maize cultivation is likely to be limited to Grade 1 and Grade 2 land, which dominates the downstream and middle parts of the catchment.

In 1979, there was already an area with a high density of maize cultivation in the middle part of the of the Tone Catchment, especially around Langford Budville (Figure 5.3(a)). There was also an area with moderate density maize cultivation located around Nynehead, Oake and West Buckland. By 1988, significant changes in the density of maize growing in the Tone Catchment were apparent as shown in Figure 5.3(b). Compared with 1979, maize was grown within the catchment at a lower density, although it remained concentrated in the middle part of the catchment.

Small changes in the spatial pattern of maize cultivation in the Tone Catchment can be seen by 1995, as shown in Figure 5.3(c). Maize growing was found not only in the middle and downstream parts of the catchment, but also in the upper part. In terms of density, maize cultivation was still at a moderate level in the middle part of the catchment. Other areas of maize cultivation within the catchment were characterized by low density.

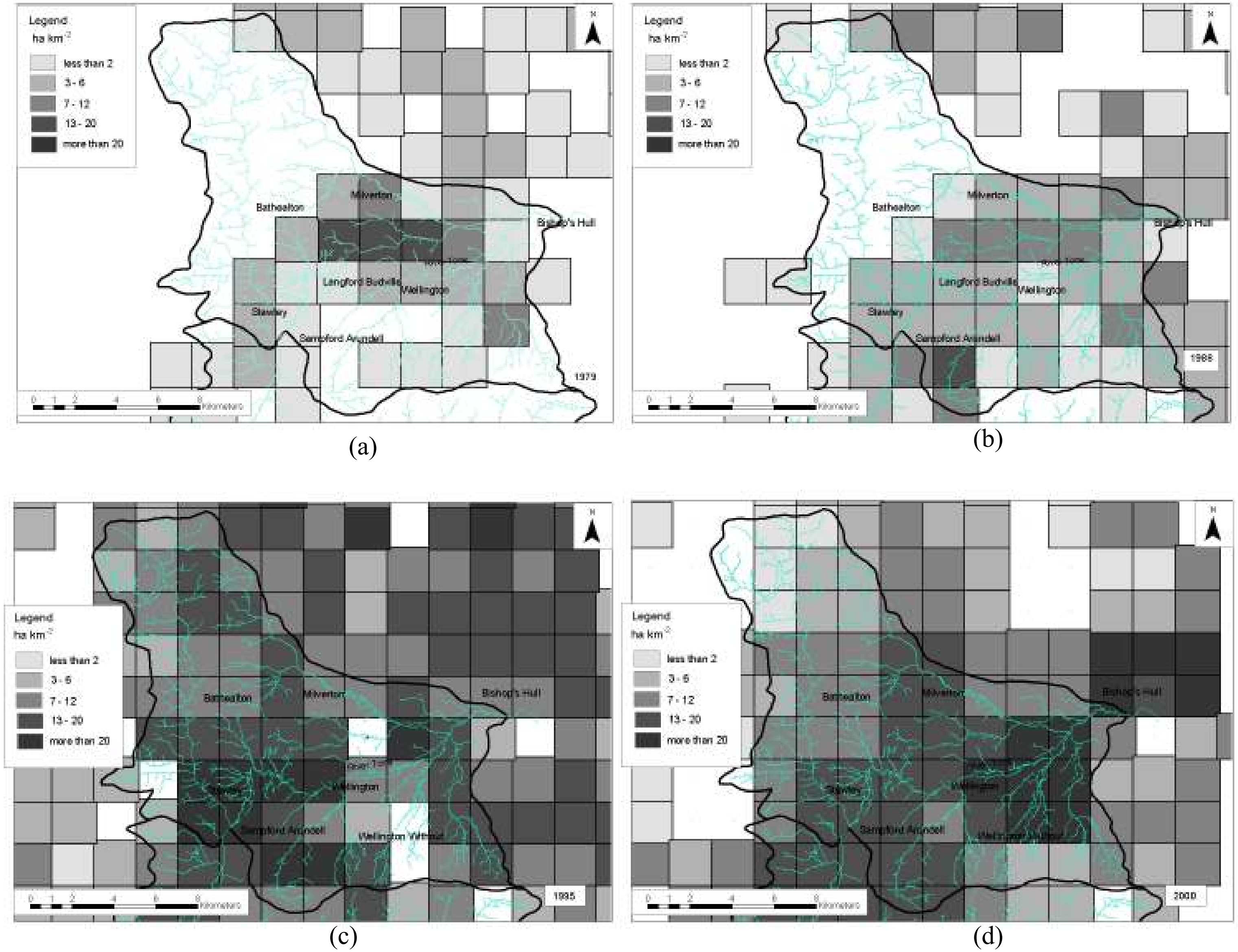
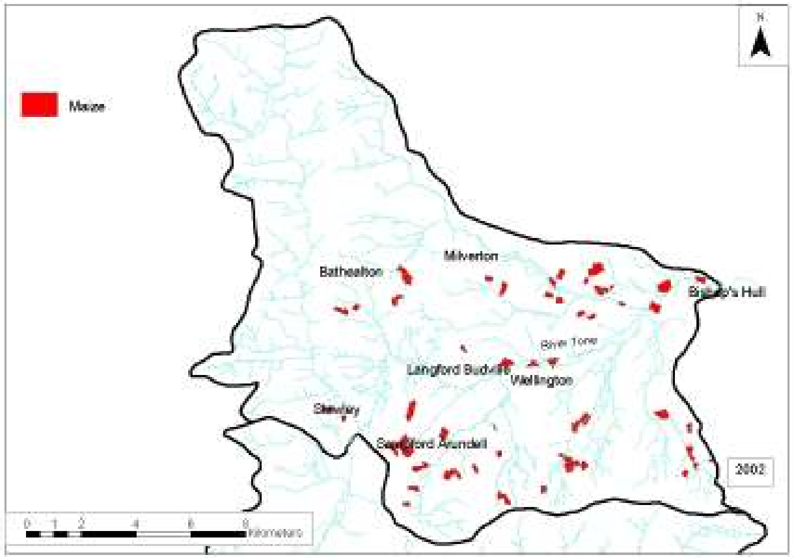


Figure 5.2: The spatial distribution of maize cultivation density in the Tone Catchment in 1979 (a), 1988 (b), 1995 (c) and 2000 (d)

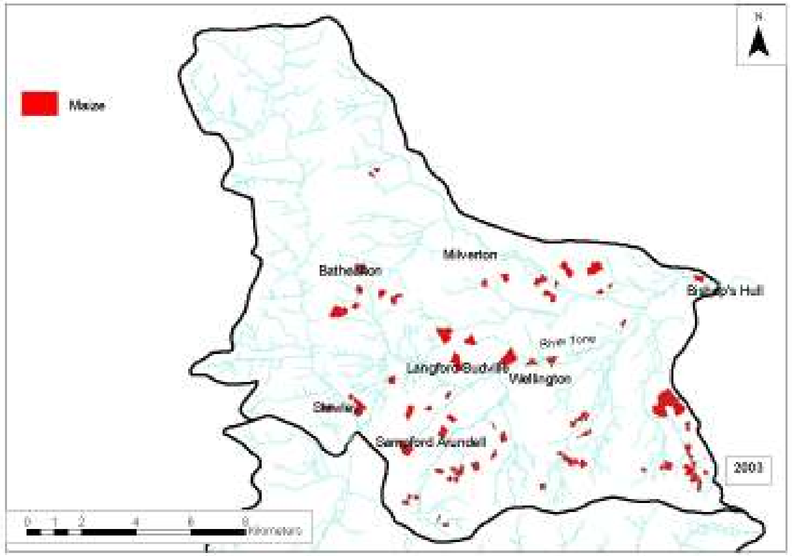
A significant change in the pattern of maize cultivation in the catchment was however evident by 2000, as shown in Figure 5.3(d). Several areas of maize growing in the catchment became denser compared with 1995, and the densest area under maize can be seen between Nynehead, Wellington and West Buckland. In addition, maize cultivation in the higher elevation area appears to have increased from low to moderate density, especially between Bathealthon and Wiveliscombe. These patterns show that maize cultivation in 2000 had become important, with the area under maize expanding in the middle and downstream parts of the Tone Catchment.

According to the CEH land cover database, 586.3 ha of the Tone Catchment was under maize in 2000. Based on the field survey, the area expanded to 622.5ha in 2002, to 802.5 ha in 2003 and to 832.5 ha in 2004. Most of the area of maize cultivation in 2002, 2003 and 2004 was located in the downstream part of the catchment, as shown in Figure 5.4. The main areas of maize cultivation were centred around Langford Budville in the middle part of the catchment, and Oake in the downstream portion of the catchment.

In the case of the Tone Catchment, field mapping data were also available for 2002, 2003 and 2004. As shown in Table 5.3, 83 fields were cultivated with maize in 2002. This increased to 107 fields in 2003 and 111 in 2004. Overlay analysis shows that (Table 5.4) for 2002 and 2003, 43 maize fields were the same in both years, and accounted for 322.5 ha out of the total 802.5 ha of maize cultivation area in 2003. For 2003 and 2004, the number of maize fields that were the same in both years increased to 61 fields, and accounted for 457.5 ha. In addition, an overlay analysis for 2002, 2003 and 2004 shows that only 28 fields had been cultivated for maize during all three years. This amounted to an area of 210.0 ha.



(a)



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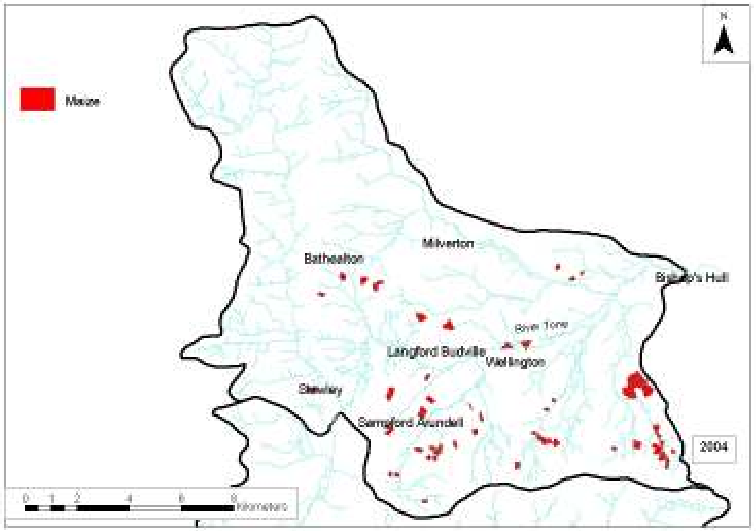


(c)

Figure 5.4: The spatial distribution of maize cultivation in the Tone Catchment in 2002 (a), 2003 (b) and 2004 (c)

Table 5.3: The area of maize cultivation and the number of maize fields in the Tone Catchment in 2002, 2003 and 2004

	2002	2003	% change (2002 & 2003)	2004	% change (2003 & 2004)
Area (ha)	622.5 (83 fields)	802.5 (107 fields)	+28.9	832.5 (111 fields)	+3.7

Note: (+) indicates increase

Table 5.4: The overlay analysis results for the area of maize cultivation in the Tone Catchment for 2002, 2003 and 2004

	2002 and 2003	2003 and 2004	2002, 2003 and 2004
Same maize fields	43 fields (322.5 ha)	61 fields (457.5 ha)	28 fields (210.0 ha)
New maize fields	40 fields (300.0 ha)	46 fields (345.0 ha)	83 fields (622.5 ha)

In conclusion, the spatial distribution of maize cultivation in the Tone Catchment was dominated by an important area of maize cultivation located in the middle part of the catchment, particularly around Langford Budville and Sampford Arundel. The area around Oake, representative of the downstream part of the catchment was also an important area for maize growing. During 1979 and 1988 the density of maize cultivation was low, but then increased to moderate in 1995 and to high in 2000.

5.3 The Connectivity of the Maize Fields and the River Networks

This section will examine the location of the maize fields in each of the study catchment with respect to the river networks and thus the likely field-river connections. GIS was used in this analysis, employing buffering analysis in the ArcMap software, as indicated in Chapter 3. For the purpose of this analysis, only the field mapping data for 2002, 2003 and 2004 were used as template maps. These template maps, which show the spatial distribution of maize fields within the Culm and Tone catchments, were overlaid with the river network information. The buffering analysis of the spatial distribution of maize fields with respect to the river network was made based on manipulation of the distances of a field from the closest river channel (registered as a line feature) represented by six categories:

1. Up to 100 m from the river.
2. From 100m to 250m from the river.
3. From 250m to 500m from the river.
4. From 500m to 750m from the river.
5. From 750m to 1000m from the river.
6. More than 1000m from the river.

The results of the overlay and buffering analysis are presented in map form to show the spatial distribution of maize fields related to the river network. However, in order to avoid 'messy' maps with buffering borders for each category of distance, the map will show only the 250 to 500 m result for the Rivers Culm and Tone. Further details of overlay and buffering results, in terms of the number of maize fields within each category are presented in table format.

5.3.1 The connectivity between maize fields and river network in the Culm Catchment

In the case of the Culm catchment, a buffering analysis was made for both the main channel of River Culm, which flows from the eastern part of the catchment and the main tributaries. These include the Spratford Stream, which covers the western part of the Culm catchment, and flows from the north-western part of the catchment, joining the Culm downstream near Cullompton, the Madford River in the upstream part of the catchment, the Bolham River in the central part of the catchment, and Kent River in the downstream part of the catchment.

Figures 5.5, 5.6 and 5.7 present the results of the buffering analysis for the Culm Catchment, whilst Tables 5.5, 5.6 and 5.7 show the number of maize fields for each distance category in 2002, 2003 and 2004, respectively. It is clear that the majority of maize fields in the Culm Catchment are located between 100 and 250 m from the river network. In 2002, this involved 43 (37.4%) maize fields, increasing to 47 (33.8%) in 2003, and 49 (43.0%) in 2004. There were also a large number of maize fields located within 100 m of the River Culm network. In 2002, 39 (33.9%) maize fields were identified located as being within 100 m from the river network, but this declined to 38 (27.3%) and 35 (30.7%) maize fields in 2003 and 2004, respectively.

The number of maize fields located between 250 to 500 m from the river networks is also considerable, giving 28 maize fields in 2002, 30 in 2003 and 20 in 2004. However, not many maize fields were located more than 500 m from the river networks during those years. Most of the maize fields located at distances of less than 250 m from the River Culm networks could be found around Kentisbeare in the downstream and Sampford Peverell in the middle part of the catchment.

5.3.2 The connectivity between maize fields and river network in the Tone Catchment

A buffering analysis for the Tone Catchment was also undertaken for the Tone River, which flows from the north-western part of the catchment to the eastern part of the catchment. Similar procedures of buffering analysis, as used for the River Culm networks, were also applied to the River Tone networks. This also covered the main

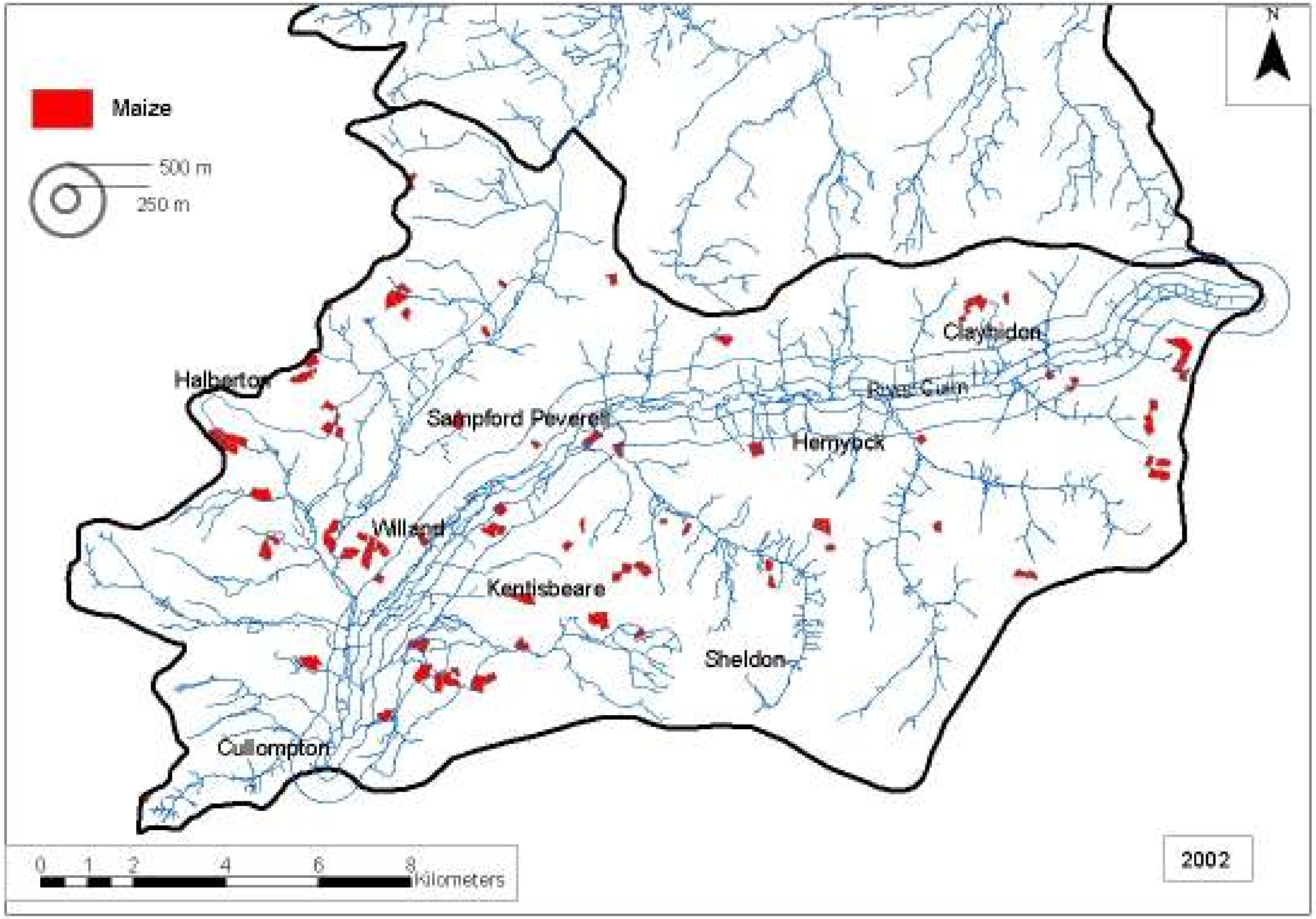


Figure 5.5: An example of buffering analysis and spatial distribution of maize cultivation in the Culm Catchment in 2002

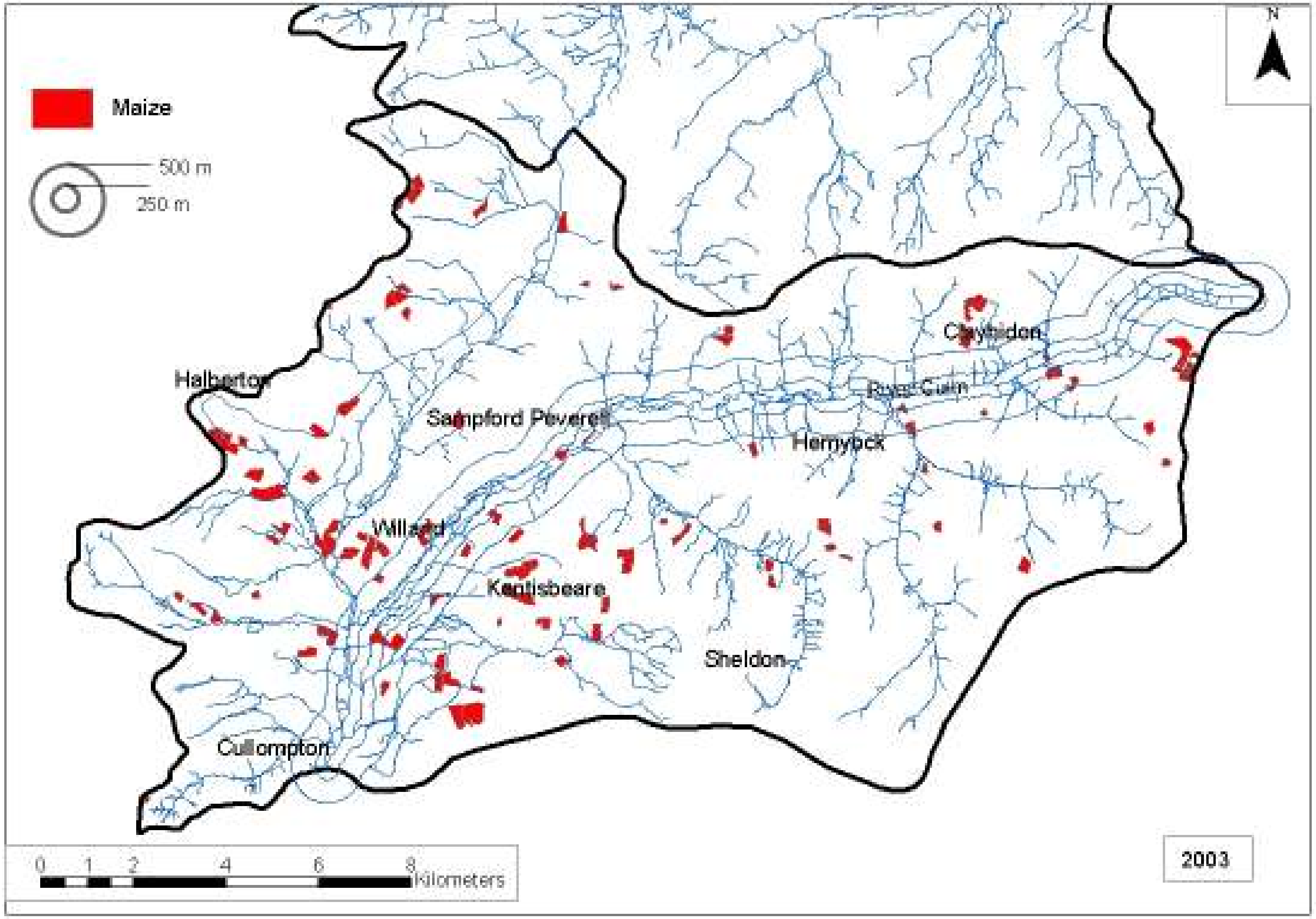


Figure 5.6: An example of buffering analysis and spatial distribution of maize cultivation in the Culm Catchment in 2003

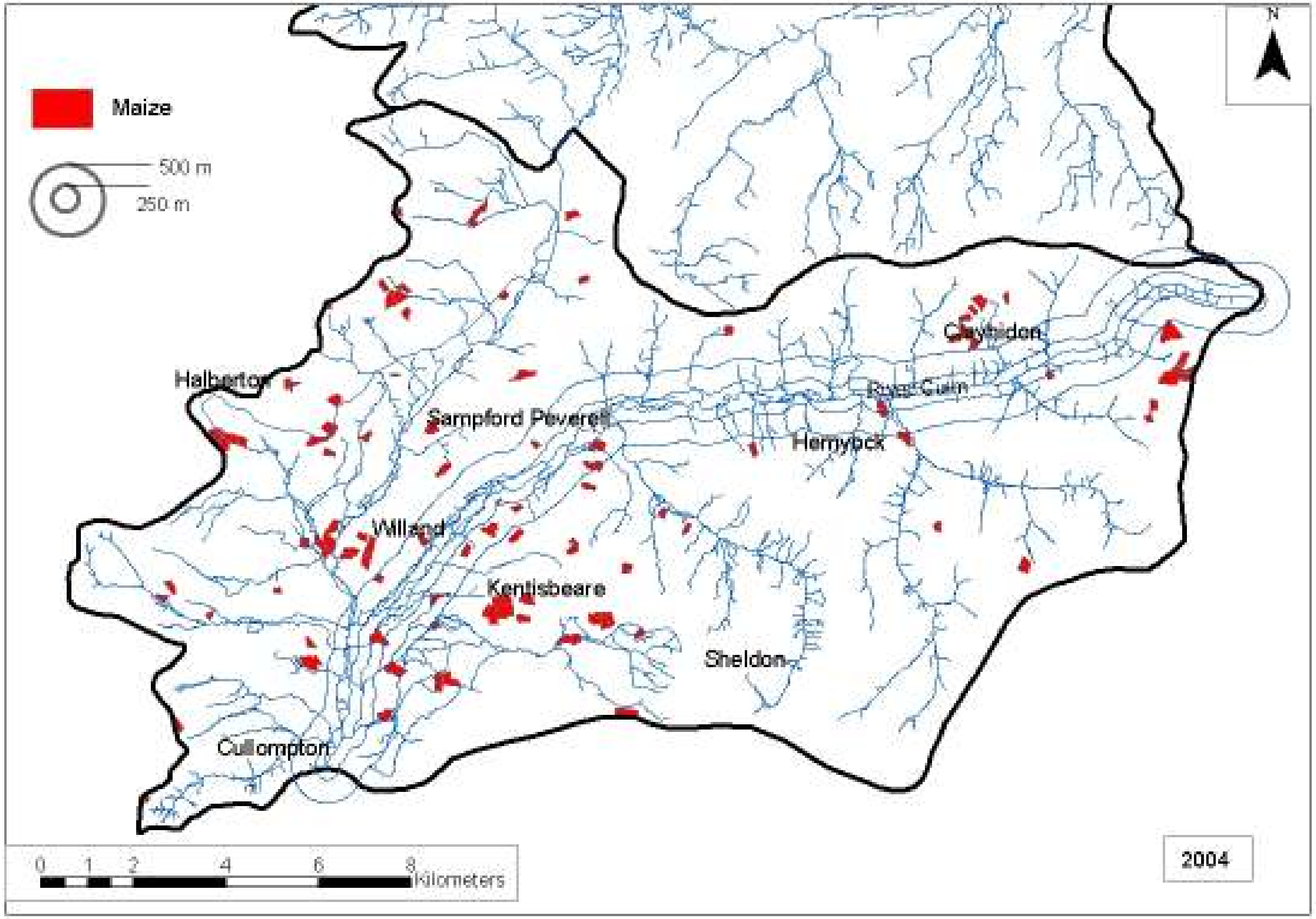


Figure 5.7: An example of buffering analysis and spatial distribution of maize cultivation in the Culm Catchment in 2004

Table 5.5: The number of maize fields with regard to distance from the River Culm channel network in 2002

Distance from the river networks	No. of maize fields	%
Up to 100 m	39	33.9
100 to 250 m	43	37.4
250 to 500 m	28	24.3
500 to 750 m	5	4.4
TOTAL	115	100.0

Table 5.6: The number of maize fields with regard to distance from the River Culm channel network in 2003

Distance from the river networks	No. of maize fields	%
Up to 100 m	38	27.3
100 to 250 m	47	33.8
250 to 500 m	30	21.6
500 to 750 m	21	15.1
750 to 1000 m	3	2.2
TOTAL	139	100.0

Table 5.7: The number of maize fields with regard to distance from the River Culm channel network in 2004

Distance from the river networks	No. of maize fields	%
Up to 100 m	35	30.7
100 to 250 m	49	43.0
250 to 500 m	20	17.5
500 to 750 m	8	7.0
750 to 1000 m	2	1.8
TOTAL	114	100.0

tributaries of the River Tone: the Hillfarrance Brook, which flows from the eastern part of the catchment; the Westford Stream, which flows from the southern part of the middle part of the catchment; and Haywords Water and Stoford Stream, which flow from the southern part of the catchment.

The results of the buffering analysis of the maize fields locations and network connectivity for the River Tone catchment in 2002, 2003 and 2004 are shown in Figures 5.8 (2002), 5.9 (2003) and 5.10 (2004). In addition, Tables 5.8, 5.9 and 5.10 show the number of maize fields with respect to their distances from the river network. Similar patterns of maize field distribution can be seen in the Tone Catchment as in the Culm Catchment, where most of the maize fields are located between the distances of 100 to 250 m from the river networks. In 2002, almost half of the maize fields (49.4%) in the Tone catchment were identified as located in that distance category, and the number increased to 45 maize fields in 2003 and 51 in 2004.

The number of maize fields up to 100 m from the river networks was also large with 20 maize fields in 2002, increasing to 32 in 2003 and 38 in 2004. Not many maize fields were identified at a distance of more than 500 m from the river networks. Most maize fields were located at less than 250 m from the river networks were found in the downstream and middle parts of the Tone Catchment. For 2002, more maize fields were identified at less than 250 m from Hillfarrance Brook.

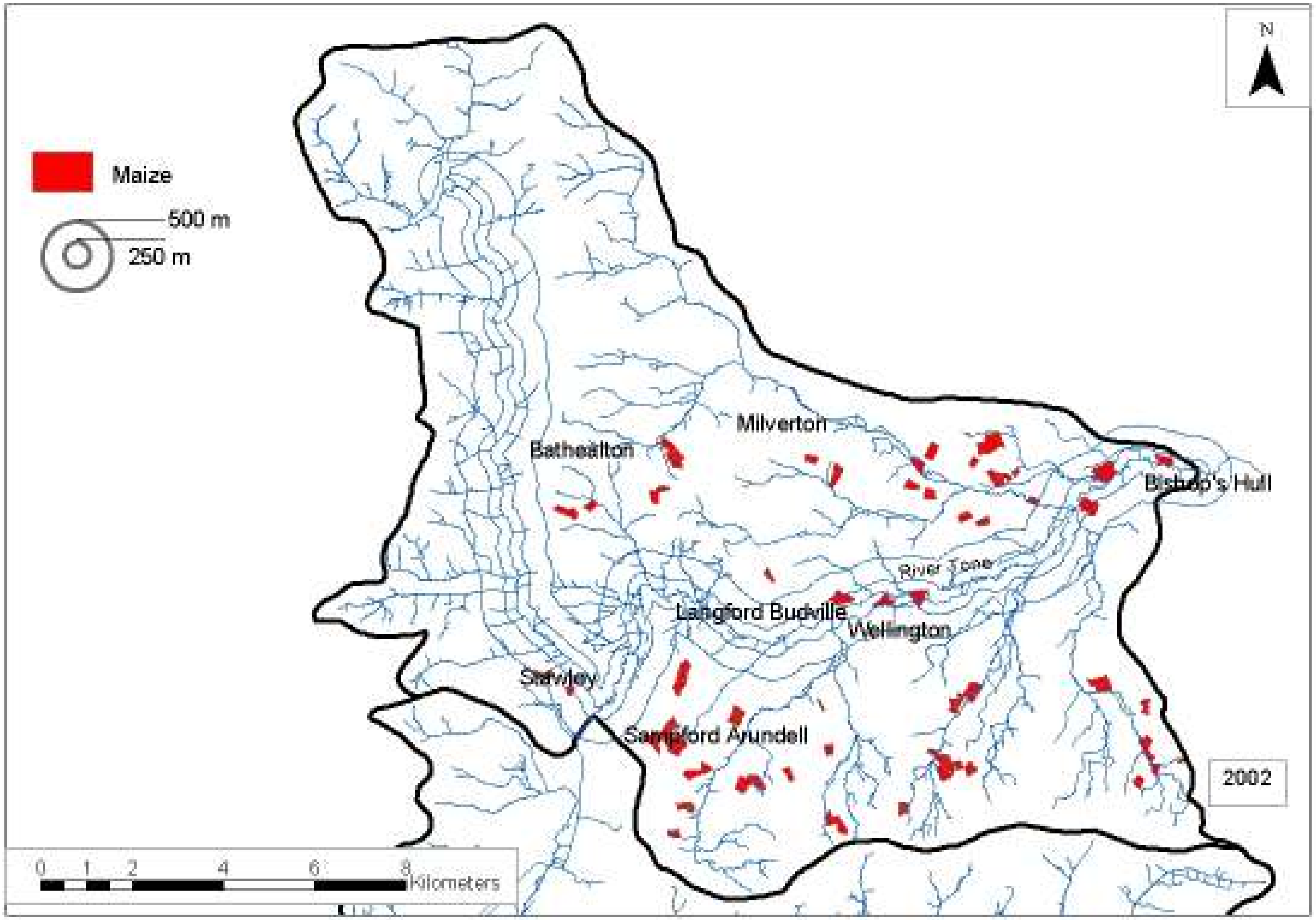


Figure 5.8: An example of buffering analysis and spatial distribution of maize cultivation in the Tone Catchment in 2002

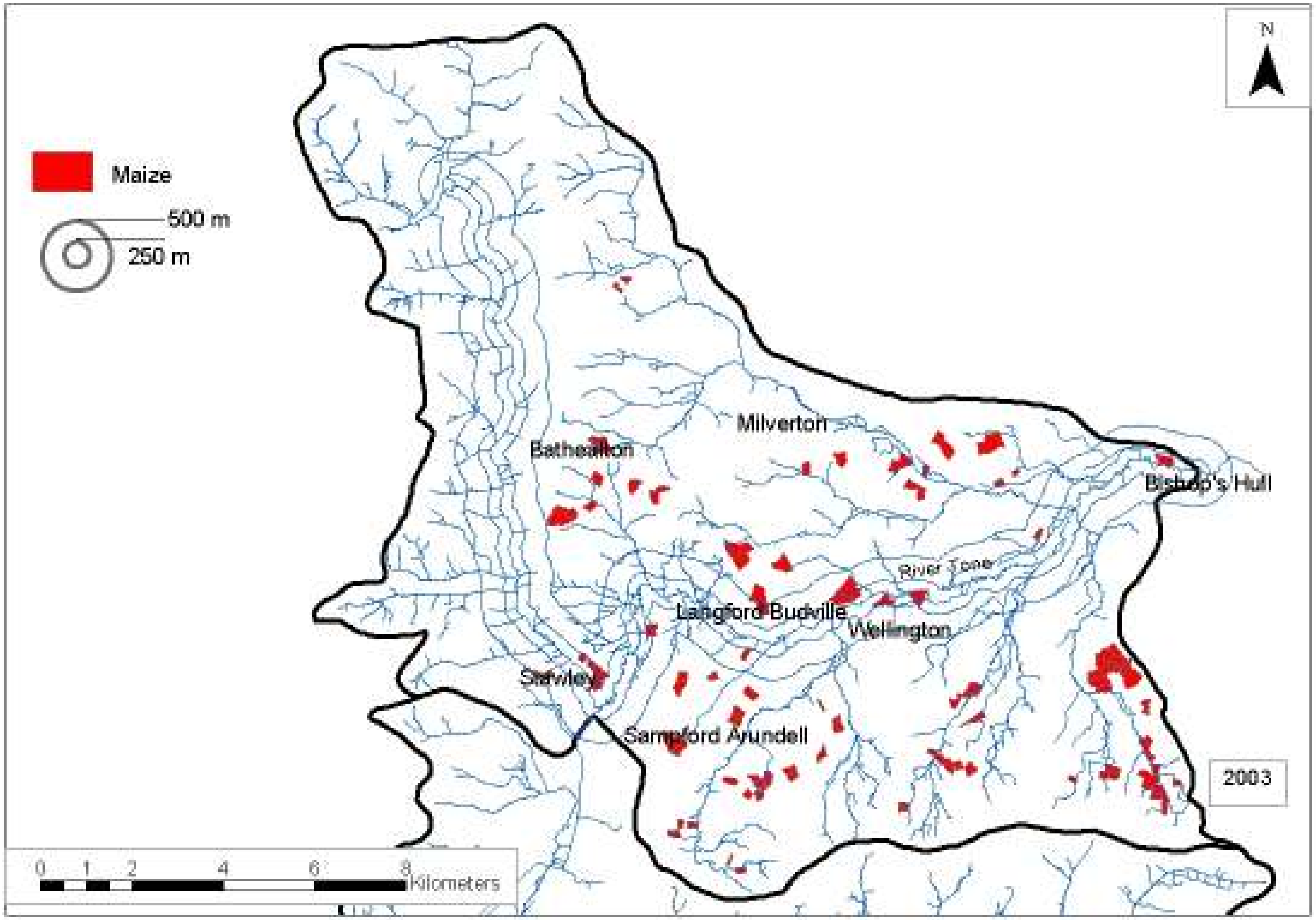


Figure 5.9: An example of buffering analysis and spatial distribution of maize cultivation in the Tone Catchment in 2003

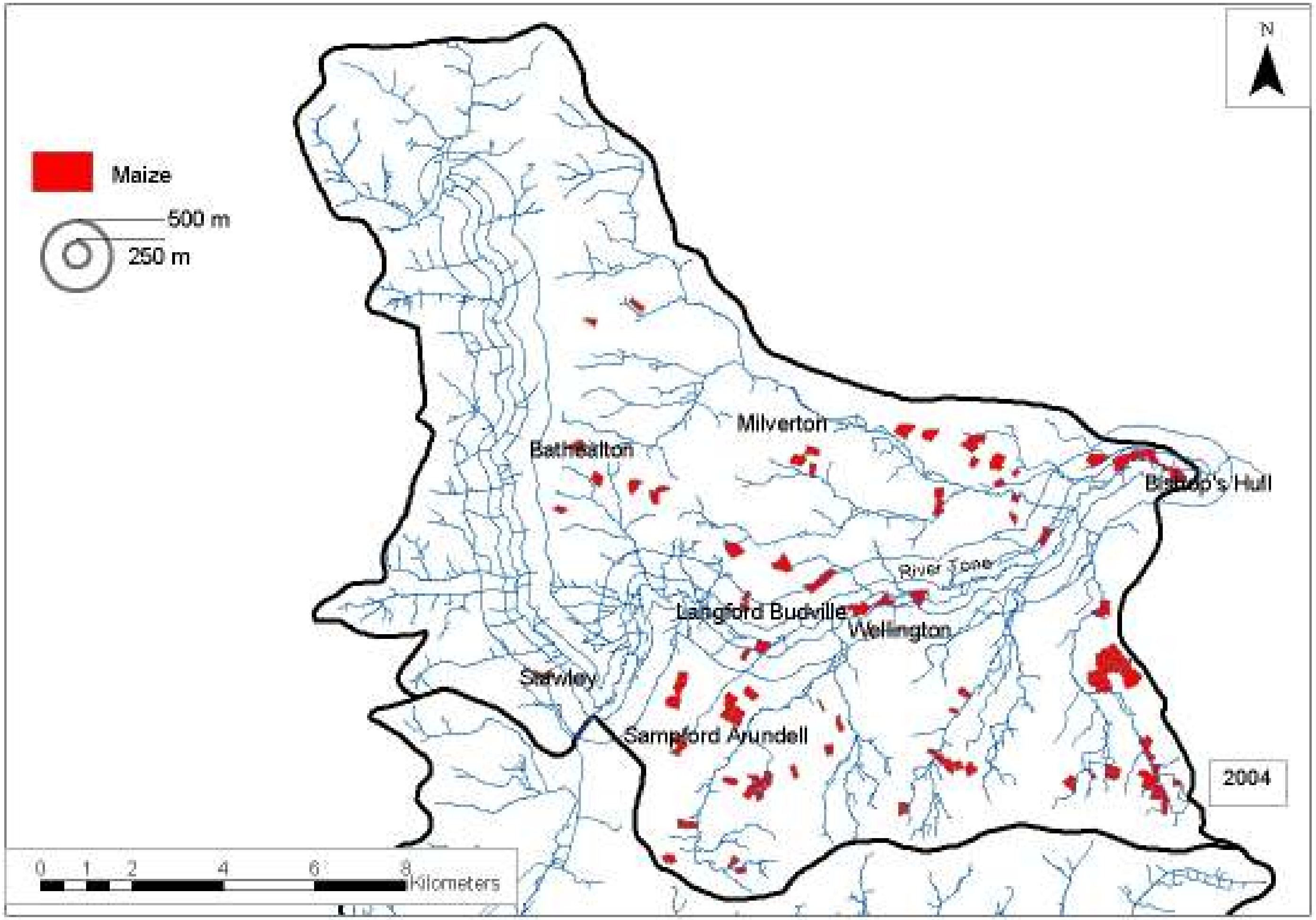


Figure 5.10: An example of buffering analysis and spatial distribution of maize cultivation in the Tone Catchment in 2004

Table 5.8: The number of maize fields in related to distance
from the River Tone network in 2002

Distance from the river networks	No. of maize fields	%
Up to 100 m	20	24.1
100 to 250 m	41	49.4
250 to 500 m	19	22.8
500 to 750 m	3	3.7
TOTAL	83	100.0

Table 5.9: The number of maize fields in related to distance
from the River Tone network in 2003

Distance from the river networks	No. of maize fields	%
Up to 100 m	32	29.9
100 to 250 m	45	42.0
250 to 500 m	25	23.4
500 to 750 m	3	2.8
750 to 1000 m	2	1.9
TOTAL	107	100.0

Table 5.10: The number of maize fields in related to distance
from the River Tone network in 2004

Distance from the river networks	No. of maize fields	%
Up to 100 m	38	34.2
100 to 250 m	51	45.9
250 to 500 m	18	16.2
500 to 750 m	4	3.7
TOTAL	111	100.0

5.3.3 Discussion

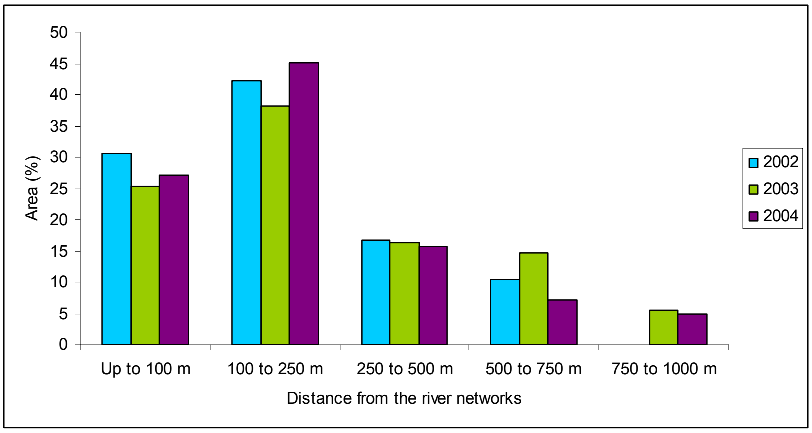
For both study catchments, most of maize fields were identified as being less than 250 m from river network and ranging from flat to undulating in nature, with elevations less than 250 m above sea level. The topography is suitable for growing maize and practical for the use of harvesting machinery.

In the case of the Culm Catchment, most maize fields located less than 250 m from river networks were found in the downstream part of the catchment, especially around Kentisbeare and Willand. In contrast, in the Tone Catchment, most maize fields within the same distance were found in the middle part of the catchment, especially around Stawley, Sampford Arundel and Langford Budville. These areas lie on the Bromsgrove and Whimple 3 soil types. The Bromsgrove series is a non-alluvial brown-earth soil with loamy or clayey subsoil, while the Whimple 3 series is argillic brown-earth soil, either loamy or clayey, with an ordinary clay-enriched subsoil. Both soil series are considered suitable for growing maize because of their slowly permeable subsoils.

In addition to the physical factors that probably influence the maize growers' decision to grow maize close to river network, there is a potential for damage to the environment, especially with regards to water quality. As mentioned in the introductory chapter, maize fields which are bare during winter easily expose soil to erosion caused by heavy rainfall and a high volume of surface runoff. The conditions of bare surface soil like this could mobilize and transport sediment from maize fields to nearby watercourses and cause diffuse source pollution. Based on buffering analysis findings for both catchments, indicates that majority of maize fields located closed to river networks. This likely caused river pollution during winter and pollutes the river with diffuse pollution. Based on the author's observations, with support from topographic maps, it is possible to judge that most of these fields are on undulating and quite steep slopes, which could encourage soil erosion.

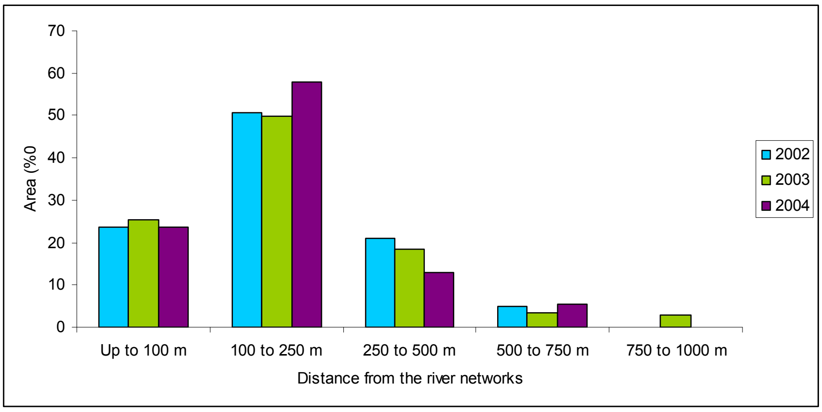
In the case of six study fields, the average of slope steepness is around 3 to 3.5^{o}. This could encourage very fast runoff and very easy erosion of the slope surface. The author made this assumption based on the observation during soil sampling, where many rills were observed from the top to the bottom parts of the slopes, especially in Cutsey, Dalwood, Westcoot, Ritherden and Little Landside maize fields.

In terms of area with respect to their distance from river networks, it is clear that most maize fields located between the distance of 100 to 250 m from the river networks, in both the Culm and Tone catchments as shown in Figure 5.11. For example, 57.8% or 481.2 ha and 45% or 384.7 ha of maize fields in 2004 were identified as being located between that distance in the Tone and Culm catchments, respectively. There was also a large area of maize cultivation up to 100 m from the river networks in both catchments. For example, 30.7% of the area of maize cultivation in the Culm Catchment in 2002, and 25.3% of the area of maize cultivation in the Tone Catchment in 2003 were found to be located up to 100 m distance from the river networks. All these figures show that maize growing in the Culm and Tone catchment was concentrated in the area of up to 250 m distance from the river networks.



2002 – Total area of maize cultivation = 862.5 ha
2003 – Total area of maize cultivation = 1,042.5 ha
2004 – Total area of maize cultivation = 855.0 ha

(a) The Culm Catchment



2002 – Total area of maize cultivation = 622.5 ha
2003 – Total area of maize cultivation = 802.5 ha
2004 – Total area of maize cultivation = 832.5 ha

(b) The Tone Catchment

Figure 5.11: The area of maize cultivation (%) with regard to the distance from river networks

5.4 Conclusion

This chapter has discussed the spatial and temporal patterns of maize cultivation in the Culm and Tone Catchments. In general, most of the area of maize cultivation in the Culm Catchment was densest in the downstream part. In the case of the Tone Catchment, this could be found in the middle part of the catchment. In both catchments, the number of maize fields that were grown within the same fields over the three years (2002, 2003 and 2004) decreased, but an increasing number can be seen for new maize fields in both catchments. With regard to the maize fields and their connectivity with river networks, the majority are located at less than 250 m from the river networks in both catchments. This seems likely to encourage the transportation of sediments through the river networks, thus causing a degradation of water quality in regard to diffuse pollution.

CHAPTER 6: SOIL EROSION ASSOCIATED WITH MAIZE CULTIVATION

6.1 Introduction

The use of radionuclides, and particularly ^{137}Cs, as tracers in soil erosion studies is already well developed around the world. However, there has been little work undertaken in using ^{7}Be as a tracer in investigating soil erosion. Because of its short half-life (53 days), ^{7}Be potentially offers a valuable tool for documenting short-term erosion rates. This chapter reports an attempt to use both ^{137}Cs and ^{7}Be in combination, in order to provide information on the increase in erosion rates associated with maize cultivation. ^{137}Cs measurements were used to derive estimates of the medium-term average erosion rate in selected fields over the past ca. 50 years and these estimates were compared with estimates of the short-term erosion in the same fields associated with winter rainfall falling on a soil compacted by harvesting in the preceding autumn.

6.2 Study Sites

In this study, six maize fields (Figure 6.1) were selected as study sites for investigating soil erosion rates associated with maize cultivation within the Culm and Tone catchments. Three of the study fields were located in the Culm Catchment and the other three were located in the Tone Catchment. All of the fields had been used for maize cultivation for at least three years in a row since 2002. The maize growing in these fields was sown during the spring, and harvested in autumn. The soil sampling for the ^{7}Be and ^{137}Cs measurements was carried out in these fields following an extended period of rainfall in December 2004 and early January 2005, after the maize was harvested in the autumn of 2004.

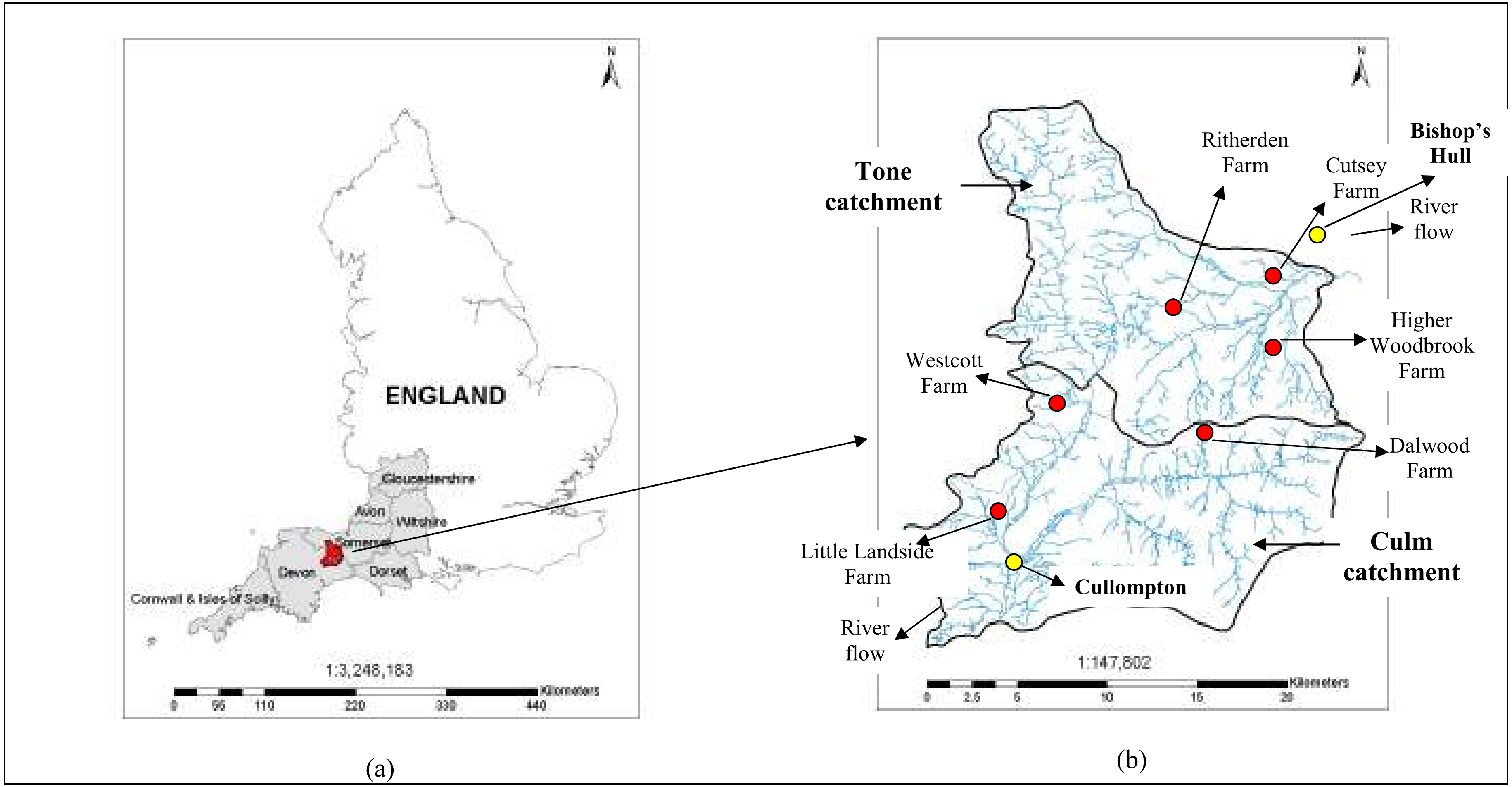


Figure 6.1: (a) The location of Culm Catchment (Devon) and Tone Catchment (Somerset) in the Southwest region, and (b) six study fields in the both catchments

In order to derive quantitative estimates of rates of soil erosion and deposition from ^{7}Be and ^{137}Cs measurements, it is necessary to establish a reference inventory for each study field. Estimates of soil redistribution rates for individual sampling points in the field are derived by comparing the inventory obtained for the sampling point with the reference inventory measured at a nearby reference site where neither erosion or deposition has occured. A decrease in the inventory relative to the reference inventory is indicative of erosion, whereas an increase indicates depositions. The soil sampling for the ^{7}Be and ^{137}Cs measurements from reference sites was carried out at the same time as the sampling of the six study fields.

6.2.1 Study sites in the Culm Catchment

The study sites in the Culm catchment included three maize fields, at Dalwood Farm, Little Landside Farm, and Westcott Farm. The location of these fields within the Culm Catchment is shown in Figure 6.1. The geographical location, physical characteristic and agricultural history of each field are described below.

6.2.1.1 The Dalwood Farm study site

The Dalwood Farm study site is located, approximately 3 km to the south-east of Culmstock. The field covers 3.84 ha and the altitude ranges from 170 to 200 m above sea level, with slope steepness varying between 2.0^{o} to 4.6^{o}. The soil type is the Bearsted 2 series, which comprises brown earths and podzols, and stoneless sand. This soil is well drained, with a porous profile (Findlay *et al*., 1984). Maize has been grown continuously in this field since 2001 and it had previously been used for grass and winter wheat. The field used to establish the reference inventory was located nearby, about 30 m from the study field. This flat pasture field had a similar soil type to the study site and had been under pasture for at least 15 years.

6.2.1.2 The Little Landside Farm study site

The study site at Little Landsite Farm is located in the north-west of the Culm Cathment, approximately 7 km to the north of Willand, near Sampford Peverell. The size of the field is 5.62 ha, and its altitude ranges from 150 to 180 m above sea level. The slope gradient ranges between 2.2^o to 6.4^o. A small stream rises at the foot of the slope and drains to the Grand Western Canal. The soil is a typical brown earth, with some stones, which is representative of the Crediton series. The reference inventory field was located about 300 m from the study field, and has been under pasture for at least 15 years.

6.2.1.3 The Westcott Farm study site

The study field at Wescott Farm is located in the western part of the Culm Catchment, approximately 4.5 km to the west of Willand. The field is relatively small, extending to approximately 3.3 ha and its altitude ranges from 85 to 100 m above sea level. The slope gradient ranges from 1.4 to 6.4^o. The nearest watercourse to the field is the Grand Western Canal, which is located about 200 m from the field. The field is underlain by Permo-Triassic rocks, and the Bromsgrove series soils consist of well-drained reddish coarse loamy soils, which contain fine and medium grained sands (Findlay *et al*., 1984). The field has been used for growing maize since 1999 and was previously cultivated with winter wheat, potatoes and sugar beet. The reference inventory field is located about 400 m from the study field and has been under pasture for many years.

6.2.2 Study sites in the Tone Catchment

Three maize fields were selected within the Tone Catchment. There were located at Cutsey Farm, Higher Woodbrook Farm and Ritherden's Farm, as shown in Figure 6.1. A detailed description of each field is provided below.

6.2.2.1 The Cutsey Farm study site

The study field at Cutsey Farm is located about 4 km to the east of Wellington and very close to West Buckland. The field covers 4.1 ha and its altitude ranges between 55 and 70 m above sea level. The field is quite steep, with minimum and maximum slopes of 1.6^{o} and 7.5^{o}, and an average slope of 5.5^{o}. The soil type is the Worcester series, which is dominated by reddish clayey soils developed on the Permo-Triassic mudstones and clay shales (Findlay *et al.*, 1984). Maize has been grown in this field since 1994. The reference inventory field is located about 100 m from the study field, and has been under pasture for many years.

6.2.2.2 The Higher Woodbrook Farm study site

The study field at Higher Woodbrook Farm is located close to Angersleigh, approximately 10 km from Taunton. The field covers 11.0 ha and its altitude ranges between 90 and 130 m above sea level. The slope gradient ranges from 2.3^{o} to 4.8^{o}. The field is underlain by Permo-Triassic and Carboniferous mudstones and clay shales, and the soil type is the Whimple 3 series. This type of soil is a reddish fine loamy silt over clay, and its permeability is very low (Findlay *et al.*, 1984). The field has been used for maize cultivation since 2002, before which it was cultivated with winter wheat. The reference inventory field is located about 150 m from the study field and has been under pasture for many years.

6.2.2.3 The Ritherden Farm study site

The study field at Ritherden Farm is located approximately 1.5 km to the south-east of Wellington. The field covers 3.2 ha and its altitude ranges from 90 to 105 m. The maximum slope steepness is 5.3^{o} and the slope average is 2.9^{o}. The field is underlain by Permo-Triassic strata and the soil is the Brockhurst 1 series. This soil type is mainly fine loam over clay and is associated with low permeability subsoil (Findlay *et al*., 1984). This field has been used for maize cultivation since 2002 and had been previously cultivated with grass, winter wheat and potatoes. The small reference inventory field is located about 50 m from the study field and has been under pasture for more than 20 years.

6.3 Use of ^{7}Be to Document Short-Term Erosion Rates

6.3.1 Origin of ^{7}Be

^{7}Be is produced in the upper atmosphere by cosmic ray spallation of nitrogen and oxygen and has a half-life of 53.4 days (Olsen *et. al*, 1985; Bonniwell *et al*., 1999). The production of ^{7}Be in the atmosphere varies both spatially and temporally and is influenced by both latitude and altitude. Lal *et al*. (1958) stated that ^{7}Be production is highest at higher latitudes and relatively constant over the same latitude. In addition, Brost *et al*. (1991) reported that ^{7}Be production is greatest in the upper stratosphere, still significant in the upper troposphere, and least in the lower troposphere.

Olsen *et al*. (1985) noted that BeO is produced by nuclear reactions, and that its subsequent deposition onto the land surface occurs as both wet and dry fallout. Wallbrink and Murray (1996) stated that in most environments ^{7}Be fallout reaching the soil surface will be rapidly and strongly fixed by the surface soil.

It has also been demonstrated by several authors that ^{7}Be fallout occurs primarily as wet fallout associated with precipitation. Blake (2000) investigated the ^{7}Be concentrations in rainfall at a study site at Keymelford, near Crediton, Devon. He reported that the ^{7}Be concentration in the rainfall at Keymelford ranged from 0.23 to 7.44 Bq l^{-1}. However, there was no significant correlation between rainfall amount and ^{7}Be concentration, and this strongly suggests that the principal control of the ^{7}Be fallout is a regional meteorological effect.

Blake (2000) also reported that the amount of deposition per unit precipitation was significantly higher in the spring. The spring period accounted for 28.4% of the total annual ^{7}Be fallout and only 21.4% of the total annual precipitation. However, during autumn, the ^{7}Be fallout accounted for 37.1% of the annual total and was associated with 41.8% of the total annual precipitation. During winter, 21.0% of the total annual ^{7}Be fallout was associated with 20.8% of the total annual precipitation.

6.3.2 Use of ^{7}Be to investigate soil redistribution

As indicated in the introduction to this chapter, relatively little work has been undertaken to date using ^{7}Be as a tracer in soil erosion investigation. Blake *et al*. (1999) noted that previous work, such as that by Walling and Woodward (1992) had demonstrated how ^{7}Be could be used to fingerprint sediment derived from surficial sources, rather than its use to document soil erosion rates. The reason for this lack of work with ^{7}Be might be because of the short half-life of ^{7}Be (53.3 days), which can introduce problems for measuring large numbers of samples before decay reduces sample activity below the detection level. Work by Blake *et al*. (1999) has explored the potential for using ^{7}Be as a short-term tracer in soil erosion investigations for establishing soil erosion rates and patterns of soil redistribution. The investigation assumed that the ^{7}Be fallout input associated with the period of erosional rainfall was spatially uniform and that any pre-existing ^{7}Be within the surface soils of the study area was uniformly distributed across the area. The authors concluded that ^{7}Be could be used in investigating the magnitude of the erosion rates. Work by Wilson *et al*. (2003) has also supported previous work by Wallbrink and Murray (1996), Bonniwell *et al*. (1999) and Blake *et al*. (1999), which showed significant relationships between soil and ^{7}Be loss, and Wilson *et al*. (2003) concluded that the erosion rates documented using ^{7}Be were consistent with the longer-term erosion rates estimated using ^{137}Cs. The results also demonstrated that ^{7}Be could be used as a tracer to determine areas of erosion and deposition.

6.3.2.1 Assumptions of the ^{7}Be technique

The use of the ^{7}Be technique in documenting rates and patterns of soil loss in this study was based on several key assumptions and requirements. A number of potential limitations and uncertainties were also taken into consideration in the study. Three important assumptions must be taken in account when using the ^{7}Be technique to investigate soil erosion to estimate short-term erosion rates. Blake *et al*. (1999) noted that, firstly, the fallout input of ^{7}Be associated with the erosional event must be assumed spatially uniform. Secondly, it is also assumed that any pre-existing ^{7}Be within the surface soils of the study area is uniformly distributed across the area. Since significant amounts of ^{7}Be can also be adsorbed or taken up by plants, the presence of vegetation cover introduces complications and application of the ^{7}Be technique is effectively limited to bare surfaces or surfaces with very limited vegetation cover.

The reference inventory is established by sampling an adjacent area, where neither erosion nor deposition has occurred (Zapata *et al*., 2002). By comparing measurements of the ^{7}Be inventory obtained for sampling points in a field with the reference inventory, it is possible to identify areas of erosion where the sampled inventory is less than the reference inventory, and areas of deposition, where the inventory is greater. Estimates of the amount of erosion or deposition can be derived from the ^{7}Be measurements, using a conversion model, which relates the gain or loss of ^{7}Be to the amount of soil removed by erosion or added by deposition.

In this study, the estimates of soil erosion amounts were obtained on the basis of a single site visit during the winter of 2005 (January) after an extended period of heavy rainfall. The estimates of soil redistribution were based on individual sampling points located along representative transects.

6.3.2.2 Converting ^{7}Be measurements into estimates of soil redistribution

In order to convert the ^{7}Be measurement into soil redistribution rates, a profile distribution model was used. This model is a theoretical method for converting ^{7}Be measurement into estimates of soil redistribution. The model is applicable to soils that remain uncultivated during the study period and it was therefore, necessary to assume that the six study sites had remained uncultivated during the period extending from the main period of ^{7}Be input to the end of the period of erosion studied. The assumption was correct, since the study field were previously cultivated in the spring of 2004, prior to sowing of the maize crop.

The model assumes that the depth distribution of ^{7}Be in the soil can be characterized by an exponential function (Walling and Quine, 1990; Zhang *et al*., 1990 and Walling *et al*., 2002). Because the depth distribution of ^{7}Be is represented by an exponential decline with depth, this can be described by an exponential function of the form;

$$C(x) = ce^{-x/h_0} \tag{6.1}$$

where $C(x)$ is the ^{7}Be activity (Bq m^{-2}), at mass depth x, c is a constant, x is the mass depth from the soil surface (kg m^{-2}), and h_0 is the coefficient describing profile shape (kg m^{-2}). h_0 is also known as a the relaxation mass depth. If the value of h_0 increases, the penetration of ^{7}Be into the soil profile can be assumed to be deeper. The h_0 value obtained for the reference sites and used in this study was 5.4 kg m^{-2}.

The mass depth of soil lost can be estimated using this model by comparing the ^{7}Be inventory measured at each sampling point within the study field with the reference inventory. Blake (2000) described in detail a procedure for calculating the spatial distribution of soil redistribution rates for ^{7}Be. The h_0 value is critical in determining soil redistribution rates, because the measured ^{7}Be inventory at the sampling point will reflect the depth of soil lost. This can be represented as follows:

$$A = \quad C(x)dx = A_{ref}e^{h/h_0} \tag{6.2}$$

where A is the measured ^{7}Be inventory (Bq m^{-2}), A_{ref} is the local ^{7}Be reference inventory (Bq m^{-2}), and h is the depth of soil lost (kg m^{-2}). The h value than can be calculated as follows:

$$h = h_0 \ 1\text{n} \ (A / A_{ref}) \tag{6.3}$$

Deposition can be assumed to have occurred if the measured ^{7}Be inventory at any point exceeds the reference value. In this case, the depth of deposition h' (kg m^{-2}) can be estimated as:

$$h' = (A - A_{ref}) / C_d \tag{6.4}$$

where C_d is the ^{7}Be concentration of deposited sediment. This value can be estimated using the mean ^{7}Be concentration of the sediment eroded from eroding points, which can be calculated as:

$$C_d = \int_S hC_e\,dS \,/ \int_S h\,dS \qquad (6.5)$$

where C_e is the concentration of ^{7}Be in soil transported from an eroding point. The C_e value can be calculated as:

$$C_e = (\,A_{ref} - A\,)\,/\,h \qquad (6.6)$$

Based on these equations, the soil redistribution rates for ^{7}Be was calculated using the conversion model software developed by the School of Geography, University of Exeter. The result will be reported and discussed in the next section.

6.3.3 ^{7}Be soil sampling programme

The soil sampling programme used to investigate soil erosion rates within the maize fields in this study was conducted in mid January 2005, from January 10-12, immediately after an extended period of winter rainfall, which was known to have caused erosion in many maize fields within the study area. Available rainfall records obtained from the Environment Agency for the Hemyock rain gauge station (representative of the Culm Catchment) and the Clayhanger rain gauge station (representative of the Tone Catchment), are summarized in Figure 6.2. Heavy rainfall fell in December 2004 in both catchments, amounting to 85.4 mm and 110.0 mm, respectively. In the 10 days of early January (from 1 to 10 January 2005) the amount of rainfall recorded for the Hemyock station was 30.3 mm, whilst the Clayhanger station recorded 35.7 mm (Figure 6.3). Based on these records, it can be seen that the period

December 2004 to early January was associated with ca. 115 mm of rainfall over the Culm Catchment and *ca*. 145 mm over the Upper Tone Catchment. As indicated above, this rainfall caused significant erosion on many maize fields within the study area and there was evidence of both sheet erosion and minor rilling in many of these fields.

The sampling programme involved the manual collection of shallow soil cores along two transects extending from the top to bottom of the slope in each study field, using a 15 cm diameter corer to a depth of 30 mm. The number of sampling points along each transect for each field differed between fields, depending on the length of the slope. Table 6.1 shows the number of sampling points for each study field.

For each study field, soil cores were also collected from a flat area in an adjacent cultivated field which had been cultivated in early autumn the previous year to provide a reference inventory for comparison with the ^{7}Be inventories measured in the field. Nine bulk soil cores were collected from each reference site using the same equipment and a similar approach to that employed for the soil sampling in the study fields. In addition, in order to provide the value of relaxation depth required to convert the observed ^{7}Be inventories into estimates of soil redistribution, as required by profile distribution model, a sectioned core was also collected from each reference site. These cores were sectioned into 5 mm depth increments. All soil samples from the study fields and reference sites were processed and analysed for ^{7}Be activity, as described in Chapter 3. All measured activities were decay corrected to the sampling date, and the results obtained from the measurements of ^{7}Be concentration and the associated estimates of redistribution are presented in the following section.

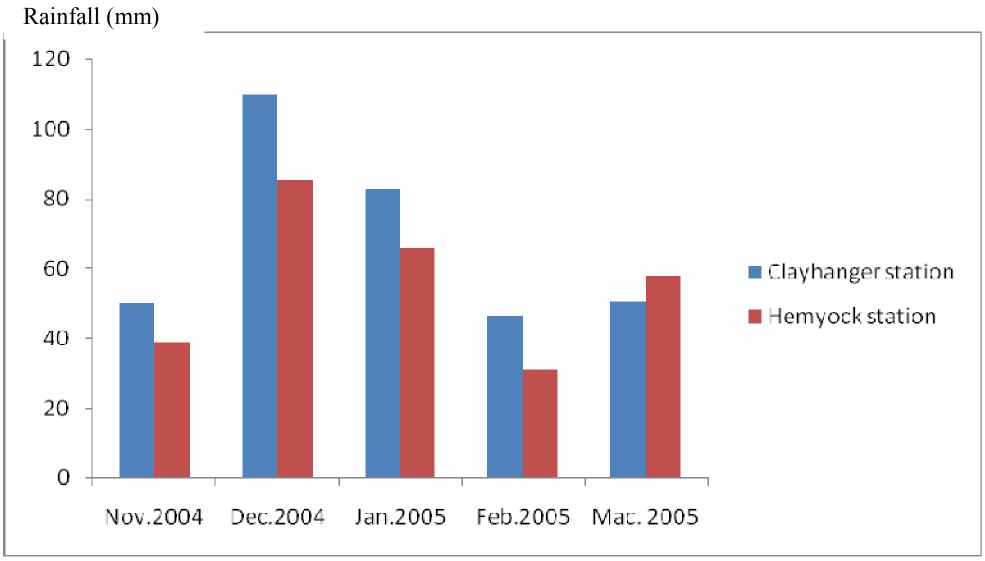


Figure 6.2: Total rainfall at the Hemyock and Clayhanger rain gauge stations for the period November 2004 to March 2005

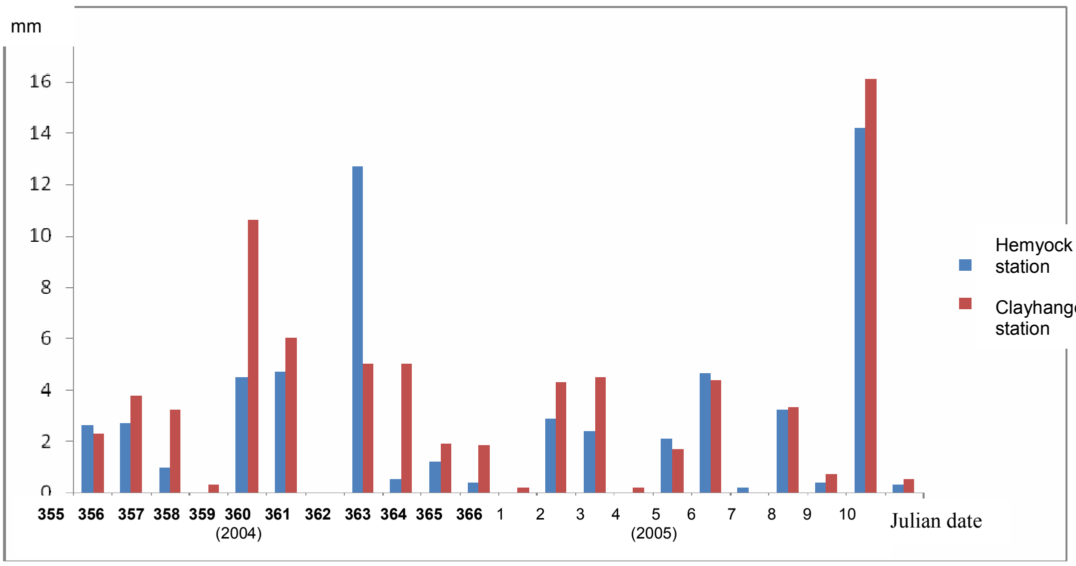


Figure 6.3: Total daily rainfall at the Hemyock and Clayhanger rain gauge stations for the period 20 December 2004 to 10 Janaury 2005

Table 6.1: Number of sampling points

Study site	Transect		
Culm catchment	**Transect 1**	**Transect 2**	**Total**
Dalwood	14	11	25
Little Landside	14	11	25
Wescott	12	11	23
Tone catchment	**Transect 1**	**Transect 2**	**Total**
Cutsey	10	9	19
Higher Woodbrook	14	13	27
Ritherden	15	14	29

6.4 Investigation of Short-Term Soil Erosion in the Study Fields

This section will report and discuss the estimates of soil erosion on maize fields in the Culm and Tone catchments, derived from measurements of ^{7}Be activity at each of the study sites. The first part of the section focuses on the ^{7}Be measurements and the estimates of short-term soil erosion and deposition obtained from these measurements and the associated patterns along each transect in the six study fields. The second part discusses the soil erosion and deposition, in terms of gross erosion rates (GER), net erosion rates (NER), and sediment delivery ratio (SDR).

6.4.1 ^{7}Be measurements

Figure 6.4 presents a representative example of the depth distribution of ^{7}Be documented for the reference sites. This confirms that most of the ^{7}Be is held within the upper few millimeters of the soil as reported by Blake *et al*. (1999). Values of h_0 the relaxation depth (see Eq. 6.1), were obtained for each reference site and the mean value of 5.4 kg m^{-2} was used for estimating the soil redistribution (Blake *et al.* 1999).

The mean ^{7}Be inventory values for the individual study fields are compared with the mean reference inventory value for that field. In all cases, as shown in Table 6.2, the mean ^{7}Be inventory reported for the field is considerably less than the mean reference inventory.

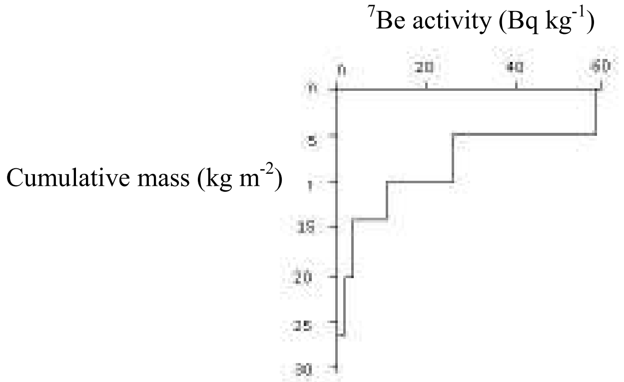


Figure 6.4: The depth distribution of ^{7}Be in a stable soil profile from a reference site

Table 6.2: The mean inventory and reference inventory values for the study fields

Study field	Mean inventory (Bq m^{-2})	Reference inventory (Bq m^{-2})	Reduction (%)
Culm Catchment			
Dalwood	245.8	321.4	30.8
Little Landside	150.3	259.0	72.3
Westcott	278.5	486.0	74.5
Tone Catchment			
Cutsey	261.9	289.2	10.4
Higher Woodbrook	202.7	235.5	16.2
Ritherden	185.9	295.2	58.8

The highest difference between the reference inventory value and the mean inventory for the field can be seen for Westcott and Little Landside farms where there are reductions of 74.5% and 72.3%, respectively. In the case of Cutsey and Higher Woodbrook farms, the difference between the means measured inventory and the reference inventory is much less, but the two values are, nevertheless still significantly different. These results indicate that significant erosion occurred within all study fields during the period of heavy rainfall that extended from December 2004 until early January 2005.

Figure 6.5 and Figure 6.6 present the values of erosion-deposition (t ha^{-1}) for all six study fields. The estimated erosion for all sampling points in the study fields of the Culm Catchment ranged from *ca*. 0.6 to 121.9 t ha^{-1}. These values are very similar to those obtained for the fields in the Tone Catchment which ranged from *ca*. 0.9 to 130.8 t ha^{-1}.

The information on erosion and deposition presented in Figure 6.5 and Figure 6.6 were used to derive estimates of gross erosion rates (GER), net soil erosion rates (NER), and sediment delivery ratio (SDR) for the individual fields. Table 6.3 shows the GER, NER and SDR values for the six study fields.

The GER value are estimated to range from *ca*. 21 t ha^{-1} to 47 t ha^{-1}, whilst the NER value are estimated to range from *ca*. 18 t ha^{-1} to 42 t ha^{-1}. Based on the erosion and deposition rates presented in Figure 6.5 and 6.6, the SDR values for the six study fields associated with the period of erosion occurring in December 2004 and early January 2005 were estimated to range between 55% and 95%. These results indicate that a substantial proportion of the soil eroded from the maize stubble fields was transported out of the fields and towards the local stream network.

Table 6.3: The values of GER, NER and SDR associated with the estimate of short-term erosion rate for the six study fields

	GER (Gross Erosion Rate) ^{7}Be (t ha^{-1})	NER (Net Erosion Rate) ^{7}Be (t ha^{-1})	SDR (Sediment Delivery Ratio) (%)
Dalwood	31.3	24.2	77
Little Landside	46.7	42.3	89
Wescott	41.1	38.7	95
Cutsey	21.4	19.7	89
Higher Woodbrook	31.5	18.1	55
Ritherden	34.6	32.6	94

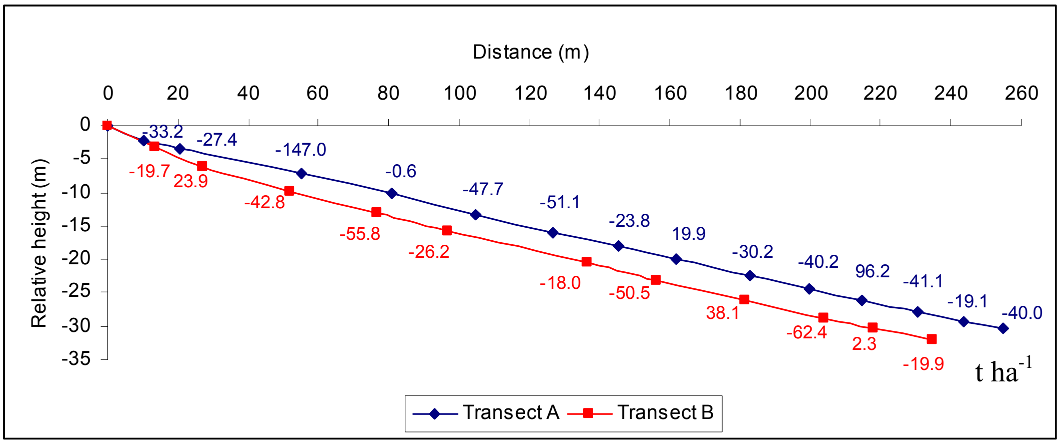
The results presented above are judged to confirm that significant erosion occurred in the six study fields. It is also demonstrates that a significant proportion of the mobilized soil was transferred out of the fields and therefore that SDR values were quite high. Most of the eroded sediment was contributed from the top and middle part of the slopes. A small proportion of the eroded sediment is subsequently deposited at intermediate points on either the central or lower slopes.

6.5 Use of ^{137}Cs to Document Longer-Term Erosion Rates

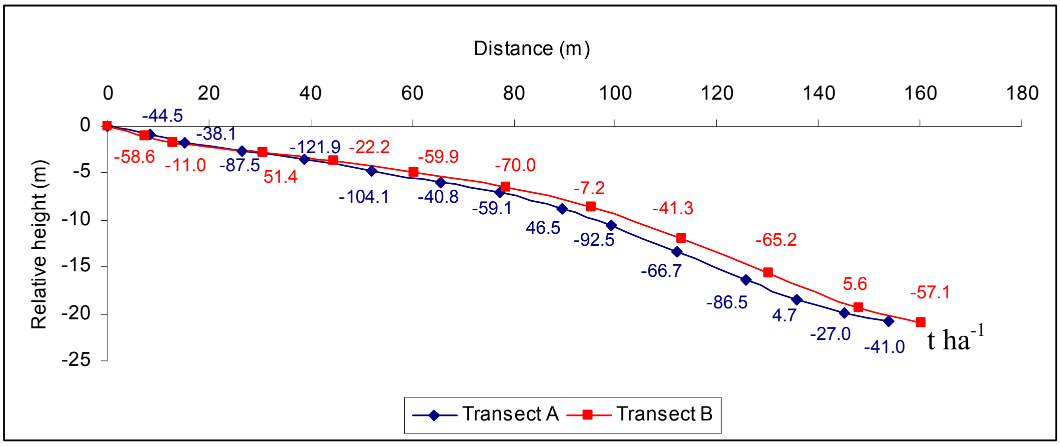
6.5.1 Production of ^{137}Cs

^{137}Cs is an artificial fallout radionuclide produced by weapon testing during the 1950s and 1960s, which can therefore be used to document medium term erosion rates. It has a half-life of ca. 30.2 years. Ritchie and McHenry (1990) stated that most ^{137}Cs reached the soil surface by wet fallout, and on contact with the soil surface, the radionuclide rapidly and strongly adsorbed by the soil particles especially by clay and organic colloids within the soil (Blake, 2000; Tamura and Jacobs, 1960; Owens *et al.* 1996). ^{137}Cs was globally distributed but the deposition of ^{137}Cs is not spatially uniform. Blagoeva and Zikovsky (1995) stated that ^{137}Cs fallout was greater in the northern hemisphere than in the southern hemisphere. Furthermore, Kiss *et al*. (1988) reported that in the northern hemisphere the total fallout of ^{137}Cs declines from middle to higher latitudes, and that within a given region, fallout commonly also varies as a linear function of the mean annual precipitation.

a) Dalwood



b) Little Landside



c) Wescott

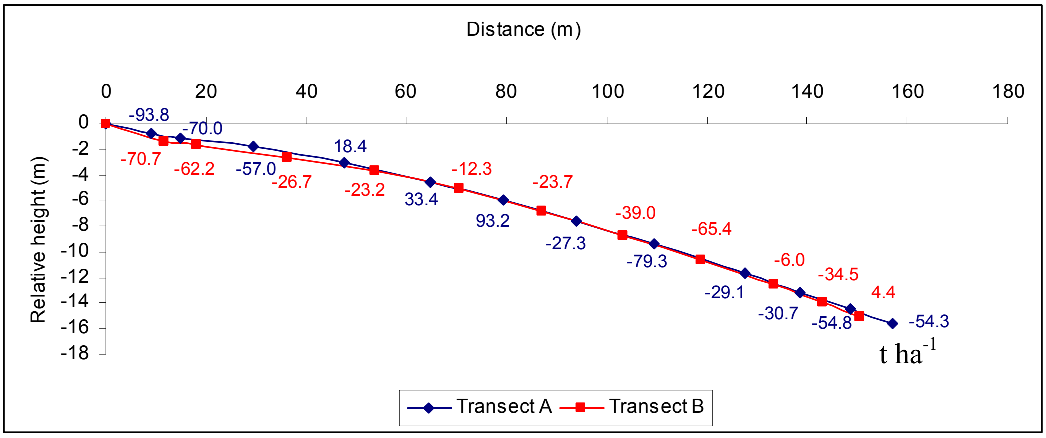
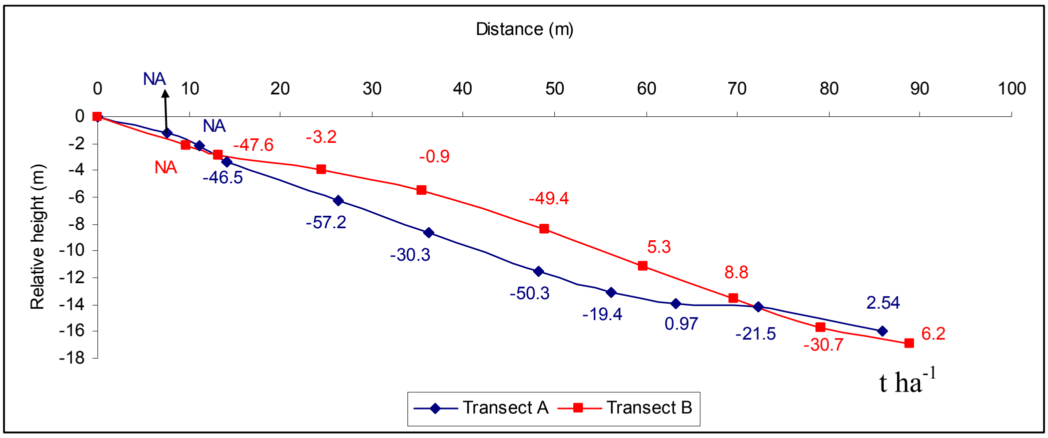
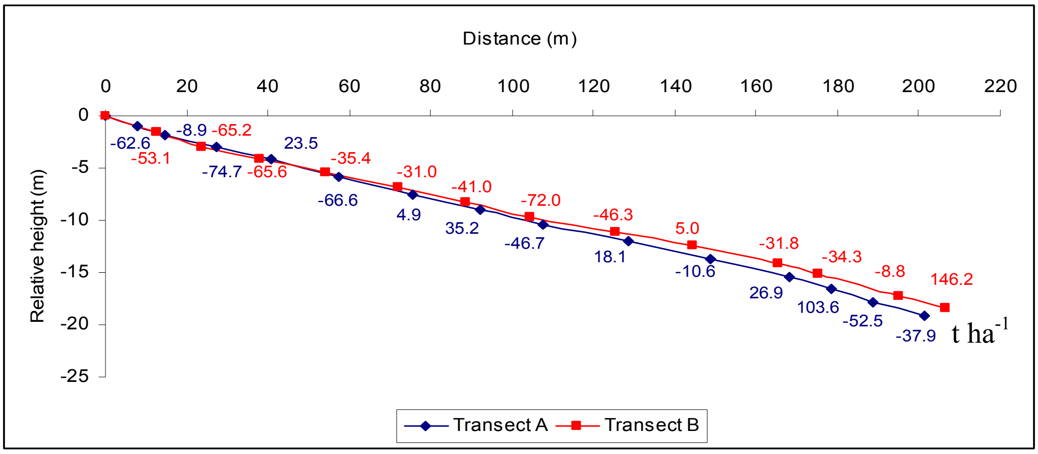


Figure 6.5: Estimates of erosion and deposition derived from ^{7}Be measurements for the two transects representative of three maize fields in the Culm Catchment at (a) Dalwood, (b) Little Landside, and (c) Wescott

a) Cutsey



b) Higher Woodbrook



c) Ritherden

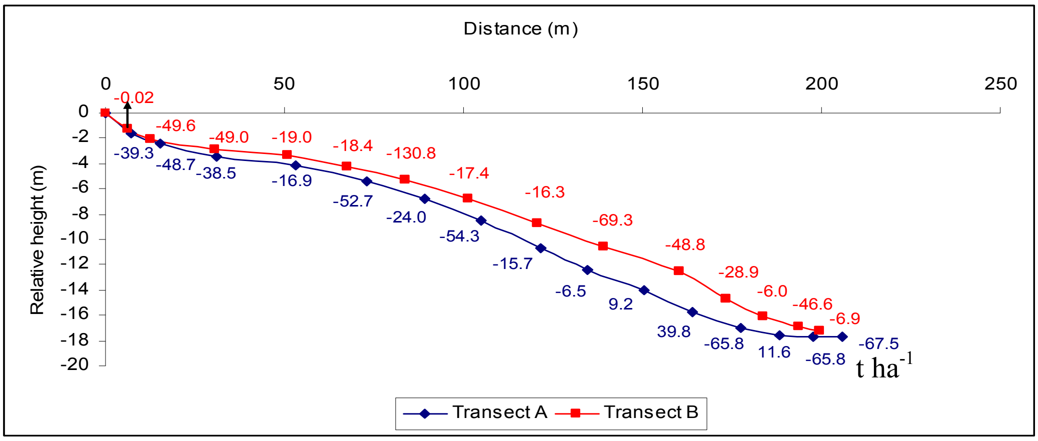


Figure 6.6: Estimates of erosion and deposition derived from ^{7}Be measurements for the two transects representative of three maize fields in the Tone Catchment at (a) Cutsey, (b) Higher Woodbrook, and (c) Ritherdeen

^{137}Cs was ejected into the stratosphere beginning in November 1952 during high-yield thermonuclear weapons tests. It was circulated globally before being deposited on the landscape. Davis (1963) reported that precipitation rates and the number of surface nuclear weapon tests would have affected the temporal pattern of deposition of ^{137}Cs on the landscape. However, global fallout began in 1954, and peaked in 1963 to 1964, immediately after the Nuclear Test Ban Treaty that was implemented in 1963. In the absence of further release of ^{137}Cs from weapons testing, fallout subsequently declined and reached negligible levels by the early 1970s. Cambray *et al*. (1989) reported a similar trend in ^{137}Cs deposition fluxes based on their measurements at Milford Haven. Approximately, 60% of the total fallout of ^{137}Cs from weapons testing could still remain within the environment. In addition to the thermonuclear weapons tests, in the early 1950s, further inputs of ^{137}Cs to the atmosphere were provided by the Chernobyl accident in 1986. However, the influence of this incident was essentially restricted to Europe and areas adjacent to Chernobyl.

6.5.2 The ^{137}Cs technique

In contrast to the use of ^{7}Be as a fallout radionuclide tracer for documenting short-term erosion rates, ^{137}Cs method has been developed and successfully employed over the past few decades. It has been widely applied in many environments to determine sediment deposition and erosion. The ^{137}Cs measurement technique is widely accepted as an effective and valuable approach for obtaining information on medium-term rates and patterns of soil redistribution. Rogowski and Tamura (1970) originally showed significant exponential relationships between soil loss and ^{137}Cs loss and concluded that ^{137}Cs movement on the landscape was related to soil movement and could be used to estimate soil redistribution patterns (Zapata, 2003). Since that early work there have been many important advances in the development and application of the approach.

6.5.2.1 Assumptions of the ^{137}Cs technique

A number of assumptions were made in this study in order to use the ^{137}Cs technique to document rates and patterns of soil loss from six study fields. The assessment of ^{137}Cs redistribution is traditionally based on a comparison of measured inventories at individual sampling points with an equivalent estimate of the inventory representing the cumulative atmospheric fallout input at the site (Zapata *et al*. 2002). The cumulative input or reference inventory can be established by sampling stables sites, where neither erosion nor deposition has occurred. In this study, a stable site from a pasture field was available close to each study field.

To derive quantitative estimates of rates of soil erosion and deposition from ^{137}Cs measurements, which will provide an assessment of medium-term (30.2 years) rates of soil redistribution, it is necessary to relate the erosion or deposition rate to the magnitude of the reduction or increase in the ^{137}Cs inventory (Zapata *et al*., 2002). Mass balance model III described by Walling and He (1999) was used as the conversion model to provide the estimates.

Other assumptions that also need to be taken into account are that (1) the distribution of the total atmospheric fallout of ^{137}Cs over the study field is uniform, (2) the fallout ^{137}Cs is rapidly and strongly absorbed by soil upon reaching the ground surface, and (3) subsequent redistribution of ^{137}Cs occurs in association with soil erosion (Walling and Collins, 2000). The first assumption ensures that the initial spatial distribution of ^{137}Cs fallout inputs was uniform and any deviations in the measured ^{137}Cs content of soil samples from the local inventory represent the net impact of soil redistribution during the period since fallout occurred in the mid 1950s (Walling and Quine, 1990; Walling and He, 1997; Walling and Collins, 2000). The second and third assumptions are supported by many empirical studies e.g. Livens and Loveland 1988; and Walling and Collins 2000.

6.5.2.2 Converting the ^{137}Cs measurements into soil redistribution rates

There are many conversion models that have been used in soil-erosion investigations. Walling and Quine (1990) classified the models in two categories, namely empirical and theoretical models. Empirical models are based on a relationship between the erosion or deposition rate and the percentage loss or gain in the ^{137}Cs inventory, relative to the reference inventory value, that is derived empirically, using the results from long-term erosion plots (Walling *et al*., 2002). The main problems with empirical conversion models are that the results are not transferable to another area and that they relate to the period for which the relationship was developed rather than the present.

Theoretical calibration models have also been developed to define the relationship between the fraction of initial ^{137}Cs lost and the rate of soil loss. One of the most commonly used theoretical models is proportional model. This model can be used for estimating soil-erosion rates from ^{137}Cs measurements on cultivated soils. The model is based on the premise that ^{137}Cs fallout inputs are completely mixed within the plough layer and the depth of soil lost as a result of erosion during the period since beginning of ^{137}Cs accumulation is directly proportional to the reduction in the ^{137}Cs content of the soil profile relative to the reference inventory (Walling *et al*., 2002). However, this assumption is an over-simplification of the behaviour and accumulation of ^{137}Cs in the soil because ^{137}Cs will have accumulated in the soil profile over a number of years and a proportion of the fresh fallout will have remained on the surface and been subject to removal by erosion prior to cultivation. The model also does not account for dilution of the ^{137}Cs concentration in the plough layer by incorporation of subsoil as erosion processes and this will cause soil loss to be underestimated. Walling *et al*. (2002) note that when the reduction in the ^{137}Cs inventory relative to the reference inventory exceeds 50%, the proportional model could underestimate the erosion rate by more than 40%.

Quine (1989), Walling and Quine (1990, 1993) and He and Walling (1997) suggested an alternative approach to overcome the limitations of the proportional model. This involves the use of mass-balance models to account for the changes in the ^{137}Cs content of the soil profile through time in response to fallout ^{137}Cs inputs and losses of ^{137}Cs from the profile due to erosion. In this study, mass-balance model III as described by Walling and He (1999) was used. The model incorporates the effects of soil redistribution by tillage. Other mass-balance models, namely mass-balance model I (the simplified mass-balance model), and mass-balance model II (the improved mass-balance model), do not take account of soil redistribution caused by tillage.

Mass-balance model I, proposed by Zhang *et al*. (1990) assumed that the total ^{137}Cs fallout occurred in 1963. However, this model does not take account of particle size effects or the fate of fresh fallout prior to incorporate into the soil by tillage. To overcome this problem, Walling and He (1999) developed mass-balance model II to take account of the fate of the freshly deposited fallout before its incorporation into plough layer by cultivation and the effects of particle-size (Walling *et al*., 2002). Mass-balance model III, developed by Walling and He (1993) can only be used for a complete slope with transects parallel to the flow direction, since it assumes down-slope transfer of soil by tillage. The details of mass-balance model III are described by Walling *et al*. (2002).

As indicated above, mass-balance III was used in this study as the conversion model to derive estimates of soil erosion rates from ^{137}Cs measurements. Following Walling *et al.* (2002) the down-slope sediment flux from a unit contour length associated with tillage can be expressed as:

$$F_Q = \o \sin \beta \tag{6.7}$$

where F_Q is the down-slope sediment flux (kg m^{-1} yr^{-1}), $\o$ is a constant related to the tillage practice employed (kg m^{-1} yr^{-1}), and β is the steepest slope angle (^{o}).

$\o$ can be determined as

$$\O = (R_{t,out,1}L_1) / (\sin \beta_1) \tag{6.8}$$

where $R_{t,out,1}$ is the net soil transfer rate (kg m^{-1} yr^{-1}), L_1 is slope length and β_1 is slope angle. $R_{t,out,1}$ can be calculated from the measured total ^{137}Cs inventory.

Erosion and deposition are assumed to occur along the transect. For a point experiencing water erosion, the variation of the total ^{137}Cs inventory $A(t)$ (Bq m^{-2}) with time can be expressed as:

$$dA(t)/dt = (1 - \Gamma)I(t) + R_{t,in}\, C_{t,in}\,(\mathrm{t}) - R_{t,out}\, C_{t,out}\,(\mathrm{t}) - \mathrm{R}_w\, \mathrm{C}_{w.out}\,(\mathrm{t}) - \lambda A(t) \tag{6.9}$$

where $C_{t,in}$, $Ct_{,out,}$ and $\mathrm{C}_{w.out}$ is the ^{137}Cs concentrations of the sediment associated with tillage input, tillage output and water output, respectively, in Bq kg^{-1}.

For a point experiencing water-induced deposition, variation of the total ^{137}Cs inventory with time can be expressed as:

$$dA(t)/dt = I(t) + R_{t,in}\, C_{t,in}\,(t) - R_{t,out}\, C_{t,out}\,(t) + R'_{w}\, C_{w.in}\,(t) - \lambda A(t) \tag{6.10}$$

where $C_{w.in}$ is the ^{137}Cs concentration of the sediment input from water-induced deposition (Bq kg^{-1}).

In addition, the ^{137}Cs concentration of soil within the plough layer for a net erosion site can be described as a function below:

$$Cs(t') = A(t') / d \tag{6.11}$$

and the ^{137}Cs concentration of soil within the plough layer for a net deposition site can be expressed as:

$$Cs(t') = 1/d\,[A(t') - (|R|^{t-1}/d) \int_{t_0} A(t'')e^{-\lambda t''}\, dt''] \tag{6.12}$$

where ($|R|$ (R<0) is the net deposition rate.

The ^{137}Cs concentration of water-derived deposited sediment ($C_{w.in}(t')$) can be expressed as:

$$C_{w.in}(t') = (1/\int_{s} RdS) \int_{s} P'\, C_{w.in}(t')RdS \tag{6.13}$$

As for ^{7}Be measurements, and based on theses equations, the soil redistribution rates for ^{137}Cs was calculated using the conversion model software developed by the School of Geography, University of Exeter.

6.5.3 ^{137}Cs soil sampling programme

The soil sampling programme used to document medium-term rates of soil loss from the six study fields was conducted from October to November 2004 in the same field where the ^{7}Be investigation was undertaken. Bulk soil cores were collected at sampling points spaced uniformly along two parallel transects in each study field, extending from the top to the bottom of the slope. A metal core tube 69 mm in diameter coupled to a motorized percussion corer was used to collect cores ranging from 30 to 60 cm depth, depending on the depth of the soil and the stone content. Soil cores were also collected at the same pasture fields as for the ^{7}Be investigation to establish the reference inventory. Information on the number of cores collected from the transects in each field is provided in Table 6.4. All core samples were dried at 50^{o}C, disaggregated and sieved to < 2mm prior to gamma assay to determine the ^{137}Cs activity, using the procedures described in Chapter 3 (Section 3.3.1.1).

Table 6.4: Number of sampling points

Study site	**Transect**		
Culm Catchment	**Transect 1**	**Transect 2**	**Total**
Dalwood	13	11	24
Little Landside	14	11	25
Wescott	12	9	21
Tone Catchment	**Transect 1**	**Transect 2**	**Total**
Cutsey	9	7	16
Higher Woodbrook	14	13	27
Ritherden	15	14	29

6.6 Investigation of Longer-Term Soil Erosion Rates

Reporting and discussion of the rates and patterns of longer-term soil erosion rates associated with the study fields in the Culm and Tone catchments derived from ^{137}Cs measurements follows a similar approach to that employed for the ^{7}Be measurements.

6.6.1 ^{137}Cs measurements

As shown in Table 6.5, the mean inventory values for the sampled fields are in all cases significantly lower than the local reference inventory, indicating that erosion has occurred in all the study fields. The greatest difference between the mean inventory and the reference inventory value (23.4%) is found at Little Landside Farm, whilst the smallest difference (7.2%) is found at Higher Woodbrook Farm. In the case of Cutsey and Higher Woodbrook farms, the mean inventory value shows only a limited reduction relative to the reference inventory.

Figure 6.7 and Figure 6.8 show the erosion-deposition values (t ha^{-1} yr^{-1}) documented for each sampling point in the six study fields in the Culm and Tone catchments. Both erosion and deposition are also evident along each transect in all study fields. As noted in both figures, the NA refers to NOT AVAILABLE. This is because the first sampling point is used in mass-balance model III to initiate the calculations and must be an eroding point. The estimates of erosion rates for the individual sampling points in the three study fields in the Culm Catchment range from *ca*. 0.4 to 40 t ha^{-1} yr^{-1} whilst for the Tone Catchment they range from *ca*. 0.1 to 24.1 t ha^{-1} yr^{-1}.

Table 6.5: The mean inventory and reference inventory values

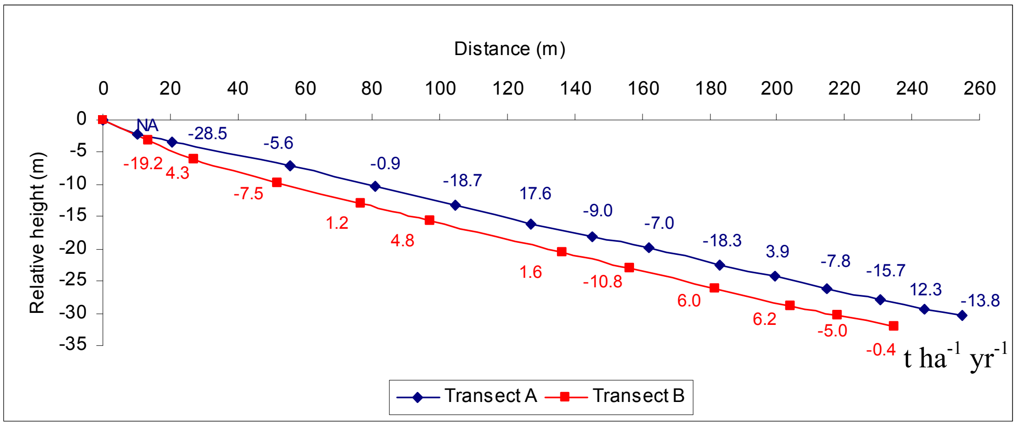
Study field	Mean inventory (Bq m^{-2})	Reference inventory (Bq m^{-2})	Reduction (%)
Culm Catchment			
Dalwood	2127.8	2400.2	12.8
Little Landside	1966.6	2427.8	23.4
Westcoot	1918.3	2114.0	10.2
Tone Catchment			
Cutsey	1579.4	1703.8	7.9
Higher Woodbrook	1866.0	2000.0	7.2
Ritherden	1755.4	1950.2	11.1

Based on the above information on erosion and deposition rates recorded for the individual sampling points, estimates of the GER, NER and SDR were also derived, and the results are presented in Table 6.6. The GER values range from *ca*. 6 to 10 t ha^{-1} yr^{-1}, whilst the NER values range from *c*a. 2 to 6 t ha^{-1} yr^{-1}. The longer-term SDR values for the six study fields were estimated to range between 28% and 89%. The highest SDR value is associated with the field at Little Landside Farm. These results again indicate that a substantial proportion of the soil mobilized from the maize fields is transported out of the fields towards the local stream network. However, the SDR values for the six study fields show appreciable variation. In the case of the field at Little Landside Farm, this can probably be related to soil type, since the field is underlain by soils of the Crediton series, which are particularly susceptible to surface runoff during periods of heavy rainfall. In the case of the field at Higher Woodbrook Farm, the deposition that occurs between 50 to 150 m along the slope may reflect reduced slope steepness.

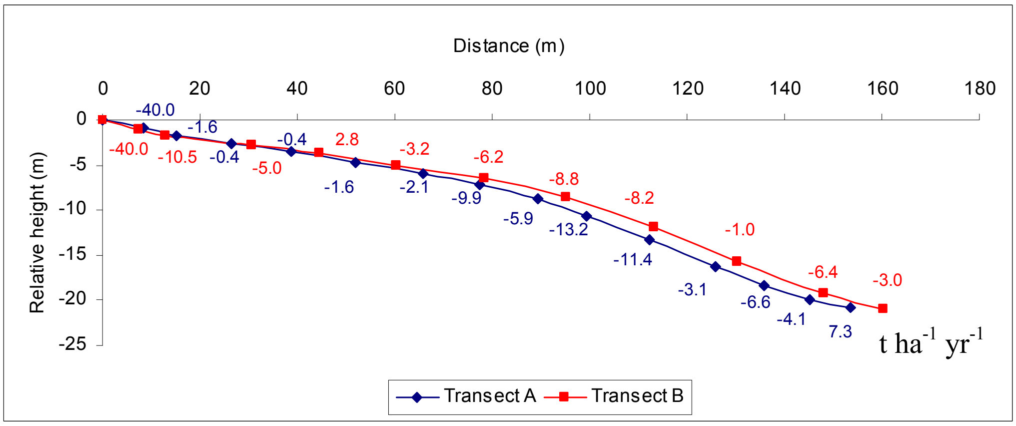
Table 6.6: The estimates of longer-term values of GER, NER and SDR provided for the six study fields by the ^{137}Cs measurements

	GER (Gross Erosion Rate) ^{137}Cs (t ha^{-1} yr^{-1})	NER (Net Erosion Rate) ^{137}Cs (t ha^{-1} yr^{-1})	SDR (Sediment Delivery Ratio) (%)
Dalwood	10.4	3.4	33
Little Landside	7.2	6.4	89
Wescott	6.2	4.1	66
Cutsey	9.1	3.6	40
Higher Woodbrook	7.3	1.6	22
Ritherden	8.9	2.5	28

a) Dalwood



b) Little Landside



c) Wescott

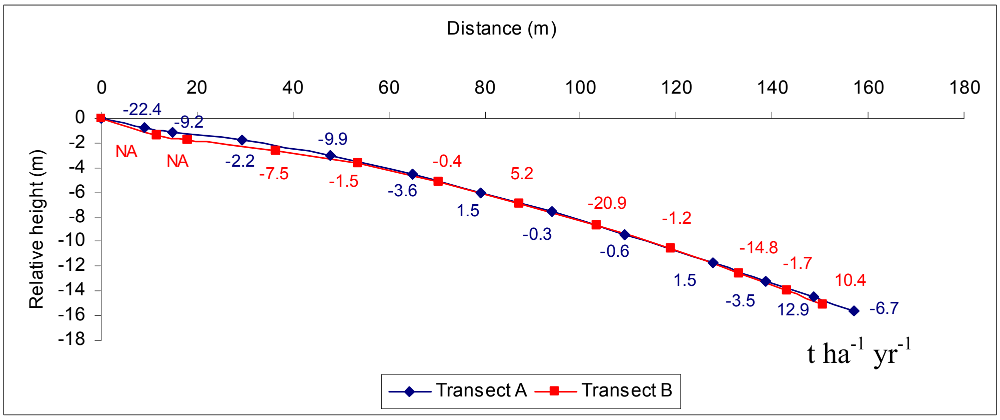
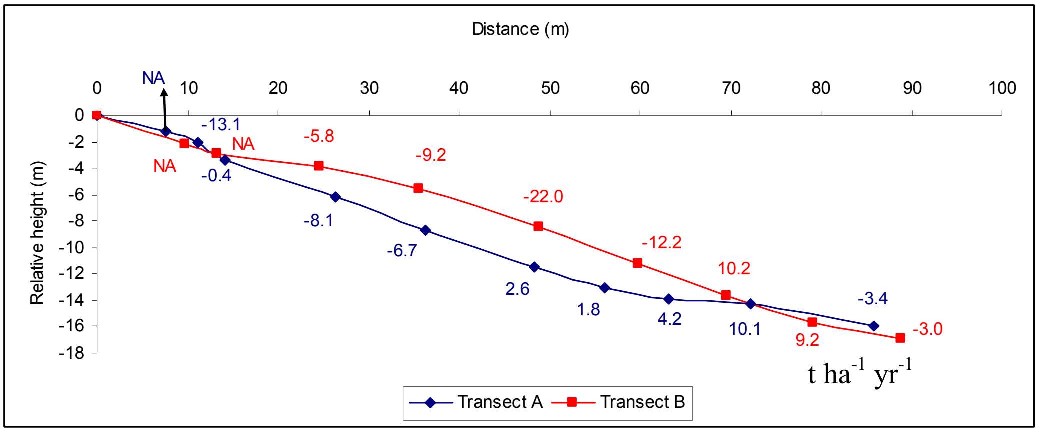
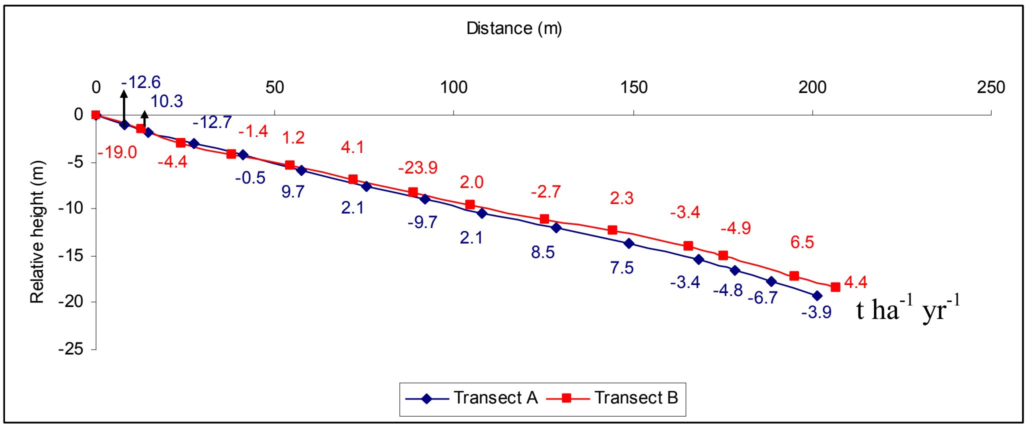


Figure 6.7: ^{137}Cs estimates of erosion and deposition for the two transects representative of three maize fields in the Culm Catchment at (a) Dalwood, (b) Little Landside, and (c) Wescott

a) Cutsey



b) Higher Woodbrook



c) Ritherden

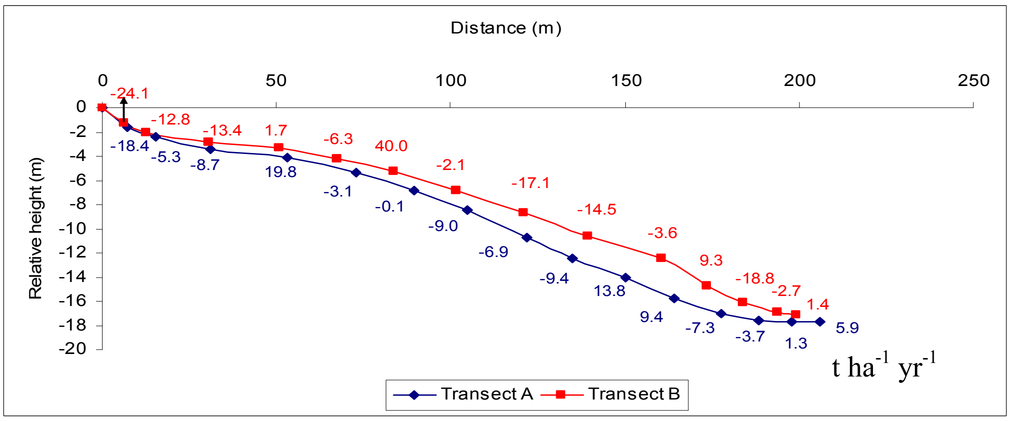


Figure 6.8: ^{137}Cs estimates of erosion and deposition for the two transects representative of three maize fields in the Tone Catchment at (a) Cutsey, (b) Higher Woodbrook, and (c) Ritherdeen

6.7 Discussion of the Estimates of Short-Term and Longer-Term Erosion Rates Provided by the ^{7}Be and ^{137}Cs Measurements

The estimates of gross and net erosion provided by the ^{7}Be and ^{137}Cs measurements, as shown in Table 6.3 and Table 6.6 and conflated in Table 6.7 provide a valuable basis for assessing the impact of maize cultivation in increasing winter erosion rates. In the case of ^{7}Be, it must be recognized that the values of gross and net erosion were related only to the period of heavy rainfall occurring in late December 2004 and early January 2005. These are likely to underestimate the annual rate of soil redistribution. Equally, in the case of ^{137}Cs, it is important to recognize that the estimates of mean annual soil redistribution will include the periods when the study fields were cultivated for maize. Therefore, the erosion estimates based on the ^{7}Be measurements are likely to underestimate the annual erosion rate and the estimates based on the ^{137}Cs measurements are likely to overestimate the longer-term mean annual erosion rate associated with cultivation of other crops or other land use. It is therefore important to note that any assessment of the increase in erosion rates associated with maize cultivation, based on this study should be seen as a minimum estimate of the increase.

According to the information presented in Table 6.7, it can be suggested that maize cultivation causes the mean for GER associated with the study fields to increase by 4.2 times, whilst the mean NER increases by 8.1 times. For two study fields (Little Landside and Westcott) the GER increased at least by 6 times, compared to the longer-term erosion rate. In terms of NER, all the study fields shows very high increases, particularly the study fields of Ritherden, Higher Woodbrook and Wescott, where increases of 13, 11.3 and 9.4 times, respectively, were documented. In addition, the study field at Ritherden provided the highest increase of SDR, which is 3.3 times greater. Other fields such as Dalwood, Cutsey and Higher Woodbrook show an increase in SDR by at least 2 times. The increases of SDR, therefore, account for the greater increase in NER, relative to the increase in GER for most study fields. The increases in GER, NER and SDR indicate that the heavy winter rainfall associated with the study period, combined with the condition of the maize fields during the post-harvest period caused short-term erosion rates to increase significantly over the longer-term values. These findings can be compared with those reported by Walling *et al*. (1999a), who used similar approach involving ^{7}Be and ^{137}Cs measurements to study the impact of maize cultivation on winter erosion rates in another field in Devon. They reported that both GER and NER were about 5 times greater than the longer-term mean annual erosion.

Table 6.7: Comparison of GER, NER and SDR of short- and longer-term soil erosion, represented by ^{7}Be and ^{137}Cs

Fields	GER			NER			SDR		
	^{7}Be (t ha^{-1})	^{137}Cs (t ha^{-1} yr^{-1})	Increase (times)	^{7}Be (t ha^{-1})	^{137}Cs (t ha^{-1} yr^{-1})	Increase (times)	^{7}Be (t ha^{-1})	^{137}Cs (t ha^{-1} yr^{-1})	Increase (times)
Dalwood	31.3	10.4	3	24.2	3.4	7.1	77	33	2.3
Little Landside	46.7	7.2	6.5	42.3	6.4	6.6	89	89	0
Wescott	41.1	6.2	6.6	38.7	4.1	9.4	95	66	1.4
Cutsey	21.4	9.1	2.3	19.7	3.6	5.5	89	40	2.2
Higher Woodbrook	31.5	7.3	4.3	18.1	1.6	11.3	55	22	2.5
Ritherdeen	34.6	8.9	3.9	32.6	2.5	13	94	28	3.3
Mean	34.4	8.2	4.2	29.3	3.6	8.1	83	46	1.8

The findings reported above can be seen as reflecting the magnitude of the rainfall during the winter period and the condition of the maize fields in the post-harvest period. Since the growing of maize as a fodder crop in England has only expanded greatly during the past 10-15 years, any increase in erosion rates can be expected to have a limited effect on the longer-term erosion rates as estimated from the ^{137}Cs measurements (Walling *et al*. 1999a). However, based on field observation and interview with maize growers, recently, many maize fields are frequently left bare after the maize harvest. This condition can increase erosion rates associated with heavy winter rain.

As mentioned above, in the case of the Little Landside field, the SDR values for the two time periods were the same. This indicates that, at least for this field, the increased erosion rates associated with maize cultivation were not associated with a change in the proportion of the mobilized sediment exported from the field. However, if the mean value of SDR is taken to represent the situation of maize cultivation in England, or at least for the Culm and the Tone catchments, it is clear that maize cultivation increases both gross erosion rates and the proportion of the mobilized sediment that is exported from the fields towards the watercourses. The latter increase is particularly significant in terms of the potential for increased sediment inputs to river systems and degradation of aquatic habitats.

The results from this study also demonstrate that the sediment delivery ratios associated with individual fields can vary significantly. In the case of ^{7}Be, the SDR was reported high for five study fields, ranging from 77-95%. In the case of ^{137}Cs, only one study field indicated a high SDR of 89%, whilst the SDR for the other study fields ranged from 22-66%. These findings are similar to the SDR of *ca.*80% reported by Walling *et al*. (1999a) for another maize field in Devon. In general, the SDR values for both ^{7}Be and ^{137}Cs, emphasize the potential for high connectivity between slopes and the stream network, although it is possible that a significant proportion of the sediment leaving the study fields may be trapped and stored before reaching the stream network.

As an example, the field at Little Landside Farm documented the highest NER and very high SDR of 89% for both tracers. These could reflect both soil type (Crediton series of sandy loams) and the steepness of the slope, especially in the middle part of the field. The soil type is easily detached by raindrops since the soil strength after harvest is low. Studies by Fox and Bryan (1999) and Porto *et al*. (2003) have confirmed that runoff and rainsplash on sandy loams soil are conducive to increased soil loss.

In terms of slope steepness, in the case of the field at Little Landside Farm, the gradient of the slope from top to the middle part of the slope (0-100 m) continuously increases up to 6.2^{o}, and this would encourage rapid runoff and increase the rate of surface erosion. Experiments reported by Fox and Bryan (1999) demonstrate the influence of slope gradient in increasing erosion rate, where rain-impacted flow erosion was significantly related to slope gradient and promoted more sediment mobilization. Other studies by Fox *et al*. (1997), Huang and Bradford (1993) and Mathier *et al*. (1989) have also demonstrated that slope gradient exerts a significant influence in increasing erosion.

In addition of soil type and slope steepness, the length of slope can also be expected to influence the pattern and rate of soil erosion. In this study, the length of slope for all fields, with the exception of that for the field at Cutsey Farm, is more than 150 m. Although this study does not investigate the relationship between slope length and soil erosion rate, the author believes that variation in the rate of soil erosion between the study fields also reflects the influence of slope in promoting soil loss as reported by Mathier *et al*. (1989), El-Swaify (1997) and Gabriels (1999).

Loughran *et al*. (1987) also indicated that soil loss was significant correlated with slope length, in the case of the upper basin of the Jackmoor Brook in Devon. However, there was no statistically significant relationship in the lower part of the Jackmoor Brook basin. These findings could also be related to slope steepness, since the upper part of the Jackmoor Brook basin is steeper compared to the lower part of the basin. In terms of this study, the field at Higher Woodbrook Farm probably provided the best example. The field is located in the lower part of the Tone Catchment with elevation less than 130 m above sea level and slope gradient ranges up to *ca.* 5^{o}, with slope length more than 200 m. However, for the both tracers, the SDR for this field is the lowest (55% for ^{7}Be and 22% for ^{137}Cs).

In addition, as mentioned in introductory chapter, the use of the heavy harvesting machinery compacts and destroys the structure of the surface soil. These conditions would also promote erosion as infiltration would decrease, and detachment of soil would increase. Investigations reported by Basher and Ross (2001) indicated that the infiltration rate for uncultivated wheel tracks was very low; thereby generating high volumes of runoff and transporting more sediment beyond the field. Earlier, Fullen (1985) also indicated that compaction by agricultural machinery increased soil erosion, as the rate of infiltration also decreased. His investigation showed that compacted subsoils impeded infiltration and so contributed to surface runoff and serious topsoil erosion (Fullen, 1985).

The findings presented in this section have important implication for further assessment of the impact of the expansion of maize cultivation in England on soil erosion. It is also suggested that erosion rates caused by maize cultivation have the potential to contribute to diffuse source pollution and sediment-related problems in nearby watercourses.

6.8 Conclusion

This chapter presents findings for short- and longer-term soil erosion rates obtained from ^{7}Be and ^{137}Cs measurements from the six study fields associated with maize growing. Quantitative estimates of short-term rates of soil erosion-deposition based on ^{7}Be measurements were assembled using a profile distribution conversion model, whilst mass balance model III has been used to estimates the longer-term rates of soil redistribution from measurements of ^{137}Cs. The results clearly highlight the potential magnitude of the increase in soil erosion caused by maize cultivation associated with leaving bare compacted stubble fields exposed to the ensuing winter rainfall. The results indicate a mean increase of NER by 8 times and a mean increase in SDR by 2. Both changes will result in increased sediment inputs to the river system. The next chapter will discuss further the off-site impact of maize cultivation, in terms of suspended sediment fluxes in the Rivers Tone and Culm.

CHAPTER 7: RIVER MONITORING AND SEDIMENT INVESTIGATIONS IN THE RIVERS CULM AND TONE

7.1 Introduction

The previous chapter has discussed soil erosion rates associated with maize cultivation in the Culm and Tone catchments. In this chapter, attention turns from the fields to the river and focuses on the results of the river monitoring and sediment investigations undertaken in the Rivers Culm and Tone. This work aimed to assess the downstream impact of the maize cultivation.

As indicated in the introductory chapter, one of the most serious off-site environmental impacts associated with maize cultivation in the United Kingdom is the potential degradation of river water quality during the winter period and the impact of the increased sediment flux in degrading aquatic habitats. These problems are closely linked to late harvests and the occurrence of bare compacted soil surfaces in the maize fields during the winter period after harvest. In order to explore further the off-site impact of maize cultivation on the receiving river, the following discussion of the results of the sediment investigation is divided into two sections. The first section focuses on assessment of suspended sediment transport by the Rivers Culm and Tone and the possible impact of sediment inputs from eroding maize fields during the winter period on the magnitude of the sediment loads, and the second section focuses on the geochemical properties of the suspended sediment and their possible links with sediment mobilized from the areas of maize cultivation in both river basins.

7.2 The River Monitoring and Sediment Investigation Programme

One of the main objectives of river monitoring in sediment studies is frequently to quantify the suspended sediment load, in order to obtain information on slope-channel connectivity and delivery of fine sediment to watercourses. However, to establish an effective river monitoring programme is always challenging, in terms of selecting suitable points or locations for the monitoring stations. The process of choosing suitable monitoring points must be related to the objective of the study and other factors such as the size of the river basin, measurement techniques, availability of pre-existing data, and the environmental characteristic of the river basin.

The outlet of a river basin is commonly selected as the most appropriate point for establishing a river monitoring programme, and many water pollution, sediment delivery and sediment budgets investigations have selected the river basin outlet as a monitoring point (Blake, 2000; Walling *et al*., 2006). In some cases, additional river monitoring and suspended sediment sampling are also carried out on tributaries, especially major tributaries (Wass *et al*., 1997; Walling *et al*., 1999b; Heywood and Walling, 2003; Smith *et al*., 2003; Walling, 2005; Evans *et al*., 2006) or along the targeted river network (Kenworthy and& Rhoads, 1995; Minh *et al*., 2007; Vanacker *et al*., 2007), to help in providing additional information for individual sub-catchments. Each approach has its own advantages. Within the constraints of this study, the outlet approach has been favoured and emphasis has been placed on documenting the suspended sediment load via turbidity monitoring. Further details of the river monitoring programme are provided below.

The focus of river monitoring in sediment studies is commonly on collecting data on suspended sediment concentrations or turbidity. The former relies on collection of water samples, either manually or automatically. Ideally, the sampling programme should aim to define the record of variation of sediment concentration in the river and this is likely to involve an intensive sampling programme in small catchments where sediment concentrations can fluctuate rapidly. The availability of personnel for sampling and laboratory facilities for analysing the samples frequently exerts an important control on the scope for implementing an effective sediment sampling programme. The use of turbidity measurements aims to avoid the need for intensive sampling and involves the continuous recording of turbidity and conversion of the record of turbidity to a record of suspended sediment concentration (SSC), using a field-derived calibration relationship. Since turbidity can be recorded continuously, it is possible to obtain a continuous record of sediment concentration. Sampling is still required in order to derive the calibration relationship and it is therefore important that such sampling should cover a wide range of turbidity and sediment concentration. Wass *et al*. (1997) have argued that the existence of a close relationship between both parameters has been established in a wide range of watercourses and it is now generally expected that an adequate calibration relationship between suspended sediment concentration and turbidity can be established (Gippel, 1989).

Suspended sediment transport by the Rivers Culm and Tone was monitored between November 2004 and March 2005, which corresponded to the main period of erosion and sediment delivery of the 2004-5 winter period. As reported in the methodology chapter, the station for the River Culm was located at the Environment Agency Woodmill gauging station, and that for the Tone was located at the Environment Agency Bishop's Hull gauging station.

An in situ turbidity sensor was installed at each site and these were used to provide continuous records of turbidity which were in turn used to derive continuous records of suspended sediment concentration. The sensor was linked to a data logger and turbidity was recorded at 15 minutes intervals. A self-cleaning sensor was used to minimize problems associated with the fouling of the optical lens. Calibration of the turbidity probes involved two components. Firstly, to ensure that the turbidity meter provided reliable absolute data, routine calibration was undertaken over the period of deployment of the turbidity probe, in order to confirm its stability. This calibration was undertaken using a formazin reference standard. Secondly, it was necessary to develop a field-derived calibration relationship for each of two sites that related the turbidity to the sampled suspended sediment concentration in the river.

In order to establish the relationships between suspended sediment concentration and turbidity for the two sites, suspended sediment samples were collected from the two rivers during a representative range of flood events. The procedures for surface water sampling have been described in Section 3.2.4 in the methodology chapter. Overall, twenty water samples were collected from each catchment between November 2004 and March 2005. In addition, bulk water samples were also collected during flood events to provide larger quantities of sediment for further analysis. The procedures employed have also been explained in the same section.

The next section will report the data assembled for the two monitoring stations on the Rivers Tone and Culm.

7.3 Results from the Sediment Monitoring Programme

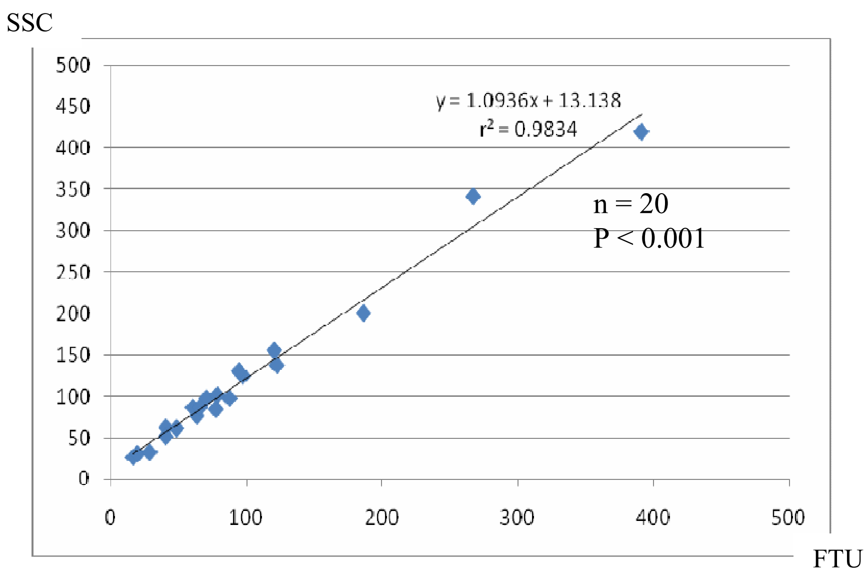
7.3.1 The relationships between sediment concentration (SSC) and turbidity (FTU)

As shown in Figure 7.1, the relationships between suspended sediment concentration and turbidity were well defined for both catchments. They were characterized by r^2 values of 0.983, in the case of Bishop's Hull station, and 0.988 for the Woodmill station. Although both rivers provided a clear positive relationship between SSC and turbidity (T), there is some scatter in both relationships, which can be related to variations in the grain size and mineralogy of the sediment associated with individual samples. The equations for both rivers have been used to derive an estimated SSC for the recorded values of turbidity. The calibration equation for the River Tone is SSC = 1.0936T + 13.138 whilst that for the River Culm is SSC = 1.1984T + 6.48. Figure 7.2 presents the synthesis records of SSC for the study period for the Rivers Tone and Culm.

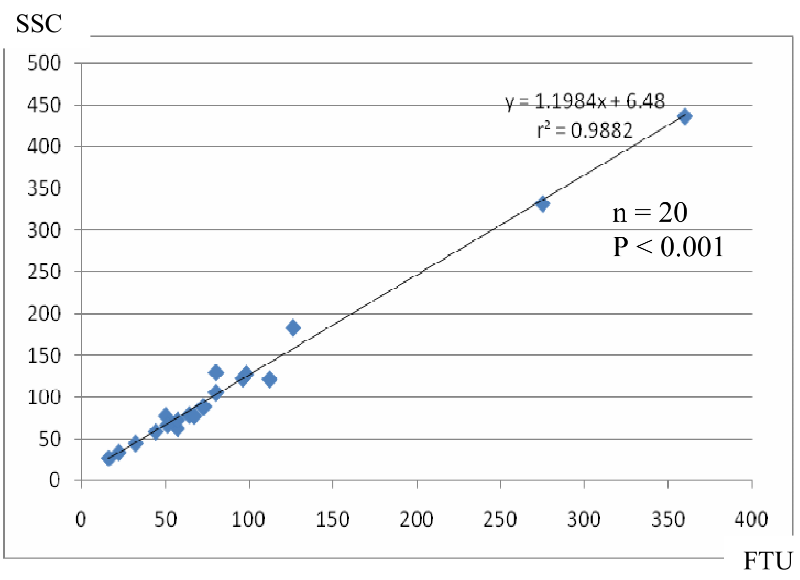
In the case of River Culm, the average value of SSC for the period November 2004 to March 2005 was 53.1 mg l^{-1} which is higher than the equivalent value for the River Tone (Table 7.1). It is clear that both the rivers are turbid and transport considerable amounts of suspended sediment during the winter period. This may possible be linked to the high rates of net soil loss from the bare maize fields during the same period demonstrated by the ^{7}Be measurements reported for selected fields in the Tone and Culm catchments in Chapter 6.

7.3.2 Estimation of sediment load (SSL) and sediment yield (SY)

The suspended sediment load of the Rivers Culm and Tone for the study period were estimated using the records of water discharge for the flow gauging stations and the records of suspended sediment concentration derived from the continuous turbidity records. Calculations were based on the daily mean values of discharge and sediment concentration.

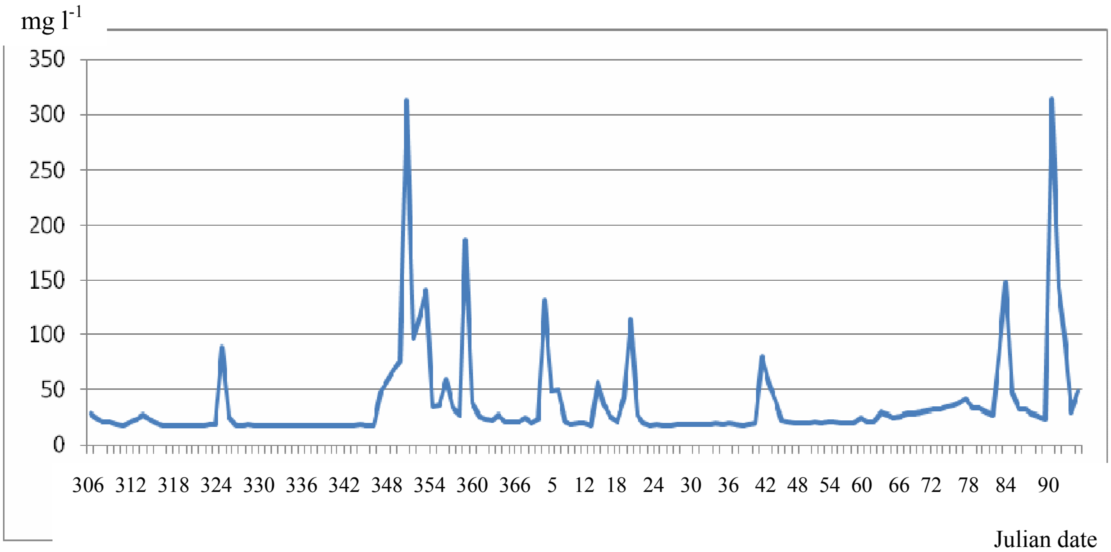


(a) Bishop's Hull station

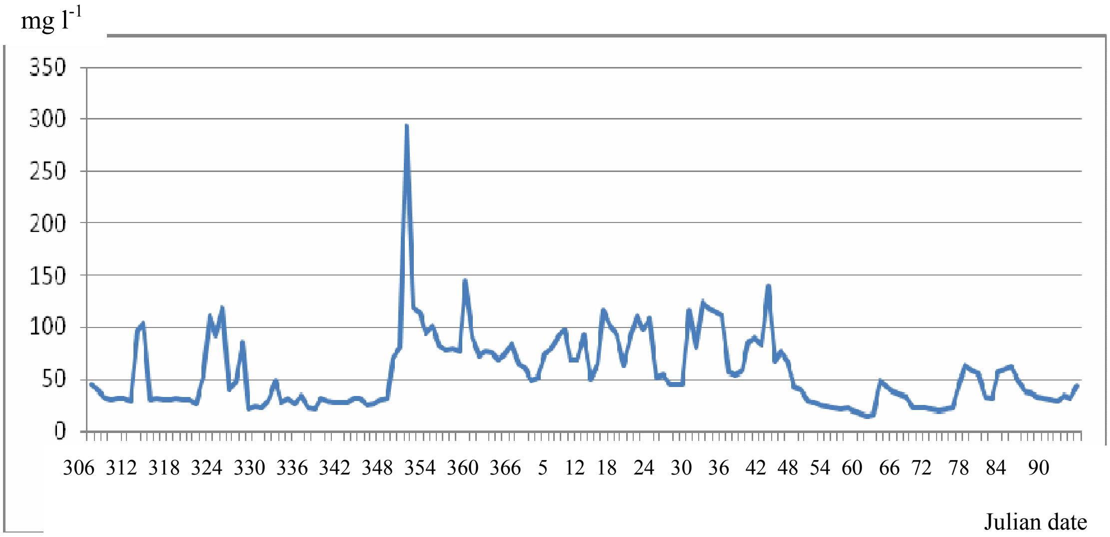


(b) Woodmill station

Figure 7.1: The relationships between suspended sediment concentration and turbidity established for (a) the River Tone at the Bishop's Hull gauging station, and (b) the River Culm at the Woodmill gauging station



(a) Estimated SSC record for the River Tone for the study period, based on the turbidity record



(b) Estimated SSC record for the River Culm for the study period, based on the turbidity record

Figure 7.2: Estimates of daily mean SSC for the two study catchments for the study period November 2004 to March 2005

Table 7.1: Mean values of estimated SSC (mg l^{-1}) for the Rivers Tone and Culm during the study period

	River Tone	River Culm
	Estimated mean SSC (mg l^{-1})	Estimated mean SSC (mg l^{-1})
November 2004	22.5	46.9
December 2004	52.8	64.8
January 2005	31.9	60.9
February 2005	24.6	40.1
March 2005	51.8	39.1
Mean*	37.1	53.1

*The mean value is based on the records of turbidity and estimated SSC for the period from November 1st 2004 to 31st March 2005

The calculation of SSL is based on following formula:

$$SSL = \sum_{i=1}^{n} (C_i Q_i) \tag{7.1}$$

where C_i is the suspended sediment concentration and Q_i is the water discharge. The results are presented in Table 7.2.

Table 7.2: Estimated values of SSL and SY for Rivers Tone and Culm

	River Tone		River Culm	
	SSL (t)	SY (t km^{-2})	SSL (t)	SY (t km^{-2})
November 2004	145.3	0.7	446.2	2.0
December 2004	1,322.7	6.4	960.2	4.3
January 2005	497.3	2.4	722.7	3.2
February 2005	283.7	1.4	640.6	2.9
March 2005	390.9	1.9	399.4	1.8
TOTAL	2,639.9	12.8*	3,169.1	14.2*

*The total value is based on the records of SSL for the period from November 1st 2004 to 31st March 2005

The suspended sediment load for the River Tone for the study period is estimated to be 2,639.9 tonnes and that for the River Culm is estimated to be 3,169.1 tonnes. It is also important to note that the maximum sediment loads were transported by both rivers in December and January, when most rainfall occurred.

Based on the SSL values, the suspended sediment yields (SY) for the two catchments can be calculated using formula below:

$$SY = SSL/A \tag{7.2}$$

where SY is the yield, SSL is the sediment load and A is the catchment area.

The Tone Catchment has a catchment area of 206.8 km^2, whilst the River Culm Catchment has an area of 222.4 km^2. As shown in Table 7.2, the sediment yield of the River Culm is slightly greater than that of the River Tone during the study period. This could suggest that the area of maize cultivation in the Culm Catchment may be a more important sediment source than in the River Tone. However, although the SY value for River Culm is higher than River Tone, the difference is small. Overall, there would seem to be no great difference between the loads transported by the Rivers Culm and Tone.

7.3.3 Comparison of the sediment loads of the Rivers Culm and Tone with estimates of the sediment generated by erosion of the maize fields during the study period

It is useful to compare the estimates of the sediment loads of the Rivers Culm and Tone derived above with an estimate of the sediment input to the two rivers from eroding maize fields within their catchments, in order to obtain an indication of the likely importance of the latter input to the sediment loads of the rivers. Although it is not possible to derive an accurate value for the amount of sediment mobilized from the eroding maize fields during the study period, a tentative estimate can be obtained from the results of the ^{7}Be measurements reported previously. These provide estimates of net rates of soil loss for three fields located in each of the two catchments. These values have been used to provide a representative mean value of soil loss from eroding maize fields in the Culm and Tone Catchments during the study period. Combination of this values with information on the total area of maize fields within each catchment (i.e. 855.0 ha in the Culm Catchment and 832.5 ha in the Tone Catchment) provides an estimate of the total net soil loss from the maize fields. These values are 30,010.5 t for the River Culm Catchment and 19,563.7 t for the River Tone Catchment. It is however important to recognize that these values of net soil loss represent estimates of the net soil export at the boundaries of the fields. A significant proportion of this sediment is likely to be deposited before reaching the stream network and this conveyance loss must be taken into account. The precise magnitude of the conveyance loss for an individual field will vary according to the location of the field relative to the stream network and the nature of the topography within the area between the field and the stream channel. As reported in Chapter 5, most of the maize fields (*ca*. 60%) in both catchments are located between 100-500 m from the nearest stream network. This limited distance is likely to promote reasonably efficient delivery of sediment to the stream networks, but significant conveyance losses are still likely. Walling *et al*. (2002) report a study aimed at constructing sediment budgets for the small Rosemaund and New Cliftonthorpe catchments in the English Midlands. This work attempted to link the net soil loss from individual fields to the sediment input to the channel system and estimated that the field-channel conveyance loss was of the order of 80%. Since the topography and drainage density of the Rosemaund and Cliftonthorpe catchments were similar to those of the Culm and Tone catchments, a field to channel conveyance loss of 80% has been assumed and combined with the estimates of net soil loss from the maize fields in two catchments to estimate the likely sediment input to the river system (see Table 7.3).

Table 7.3: A comparison of the estimates of sediment input to the river systems of the Culm and Tone catchments from the maize fields during the new winter of 2004-5 with the measured suspended sediment load for this period

Catchments	Sediment input (t)	Sediment load (t)	
		(a)	(b)
Culm	6,002.1	3,169.0	5,282.0
Tone	3,906.7	2,640.0	4,400.0

(a) Measured load at catchment outlet
(b) Estimate of total sediment input to the channel system from the catchment

These estimates of sediment input from the maize fields to the channel systems of the Culm and Tone catchments could be seen as inconsistent with the measured sediment loads for the same period, in that they are significantly greater. However, it must be recognized that a significant proportion of the suspended sediment load passing through the river system during flood events is likely to be deposited within the channel system and more particularly on the river floodplains. Walling (2008) reviewed existing evidence of the magnitude of such in-channel conveyance losses and concluded that they were typically about 40%. Using this value, the total sediment input to the channel systems of the Culm and Tone catchments can be estimated as 5,282 t and 4,400 t, respectively. Using these estimates of the total sediment input to the channel system of the Tone and Culm catchments, the estimated contribution from maize fields in the Culm catchment still exceeds the total input, but the contribution from maize fields in the Tone catchment is slightly less than the total input. However, as discussed below, these results still point to some inconsistencies in the estimation of the inputs to the channel system from the maize fields.

The apparent inconsistencies between the estimates of sediment input to the river systems within the Culm and Tone Catchments from the maize fields highlighted above, introduce problems for any attempt to compare the two values. The value obtained for the sediment input from the maize fields, should not exceed the measured sediment load, when account is taken of channel and floodplain conveyance losses within each catchment. The maize fields only occupied ca. 4% of two catchments and it is unreasonable to assume that the remaining 96% of the catchment will have a zero or minimal sediment contribution. These stream and river channels must also be expected to make some contribution to the total load passing through the river system. It would seem that field to channel and in-channel/floodplain conveyance losses may have been underestimated. Further work is clearly required to resolve these uncertainties. However, based on the results presented in Chapter 6, it can be suggested that the introduction of maize cultivation is likely to have increased net soil losses from the maize fields by ca. 8 times. If maize fields occupy ca. 4% of the two catchments and the net soil loss from the non-maize growing areas is substantially less than 10% of that estimated for the maize fields (e.g. 5%), due to the presence of significant areas of grassland with low net soil loss, it could be suggested that the maize fields and non-maize fields contribute approximately the same amount of the sediment to the overall sediment yields of the two catchments. This tentative conclusion emphasizes the potential important of the off-site impact of maize cultivation in increasing the sediment loads of the Culm and Tone Catchments.

Further information on the likely importance of sediment mobilized from maize fields within the study catchments to the sediment loads of the study rivers has been obtained by comparing the geochemical properties of the sediment transported by the two rivers during the study period with those of sediment mobilized from maize fields.

7.4 Analysis of Sediment Properties

Twenty four samples of surface soil were collected randomly from a representative selection of individual stubble maize fields within the Culm and Tone catchments, in order to compare the properties of suspended sediment and surface soil from the maize fields and thereby assess the likely contribution of maize fields to the sediment loads of the study rivers. In the case of suspended sediment, 5 bulk samples from both catchments were analysed. The procedures employed are explained in Section 3.2.3.

As detailed in Chapter 3, a suite of geochemical properties has been used to characterize the sediment mobilized from eroding maize fields and the suspended sediment transported by the two study rivers. These properties include heavy metals, base cations, total organic carbon and nitrogen, and total phosphorus. The Mann-Whitney U–test was applied to each parameter to identify the link between surface soil samples and suspended sediment samples. The test involves assessing whether the differentiation between the mean values of each individual parameter for surface soils from maize fields and suspended sediment samples are statistically significant. The distinguishing process was based on the critical probability value of $P<0.05$. If the probability value for a given parameter is below than critical value, the assumption has been made that this parameter shows no link between surface soils and suspended sediment samples collected from the rivers.

Table 7.4 presents the results from the Mann-Whitney U-test for each parameter for both the Rivers Culm and Tone. The results confirm that not all parameters provide evidence of a link between surface soil collected from bare maize fields and suspended sediment in the river. The total carbon (C), nitrogen (N) and sodium (Na) concentrations provide no evidence of a link between surface soils and suspended sediment. However, the P (inorganic and organic) values for the River Tone suggested that a significant proportion of the suspended sediment could be contributed from bare maize fields within the catchment. Six metals (Cr, Cu, Fe, Pb-206, Pb-207, Pb-208) also showed a statistically significant link between the concentrations associated with surface soil from maize fields and with suspended sediment from the two study rivers. This indicates that these metals show strong connectivity between surface soils and suspended sediment. The chemical analysis results of suspended sediment in the Rivers Culm and Tone demonstrates that Fe, and Pb-206, 207, and 208 could be useful tracers when considering the link between eroded surface soils from bare maize fields and suspended sediment in the winter period. However, the results for C, N, Na, Zn, Sr and Al do not demonstrate a direct link between the eroding maize fields and the sediment load transported by the study rivers.

Table 7.4: Mann-Whitney U-test results for a comparison of the geochemical properties of surface soils from eroding maize fields and suspended sediment collected in the Culm and Tone basins

Chemical property	Surface soil mean		Suspended sediment mean		Probability value	
	Culm	Tone	Culm	Tone	Culm	Tone
N (%)	6.50	6.58	17.00	16.89	0.001	0.001
C (%)	6.50	6.58	17.00	16.89	0.001	0.001
P (inorganic)	6.50	6.67	17.00	16.78	0.001	0.102
P (organic)	7.08	9.08	16.22	13.56	0.001	0.105
Al	13.92	14.17	7.11	6.78	0.012	0.005
As	8.75	8.17	14.00	14.78	0.058	0.013
Cd	7.67	8.25	15.44	14.67	0.003	0.015
Co	8.17	8.83	14.78	13.89	0.015	0.062
Cr	11.75	12.67	10.00	8.78	0.530	0.163
Cu	9.75	9.17	12.67	13.44	0.306	0.121
Fe	10.42	11.67	11.78	10.11	0.645	0.591
Mn	8.75	6.92	14.00	16.44	0.058	0.001
Ni	8.42	9.25	14.44	13.33	0.029	0.148
Pb-206	11.58	12.21	10.22	9.39	0.642	0.304
Pb-207	11.38	12.00	10.50	9.67	0.757	0.410
Pb-208	11.42	12.00	10.44	9.67	0.733	0.410
Sb	10.08	8.83	12.22	13.89	0.461	0.064
Sr	7.00	8.42	16.33	14.44	0.001	0.024
Zn	6.50	8.08	17.00	14.89	0.001	0.009
K	9.96	13.75	12.39	7.33	0.388	0.016
Mg	8.33	10.33	14.56	11.89	0.020	0.587
Na	6.50	6.67	17.00	16.78	0.001	0.001
^{137}Cs	7.95	11.08	6.67	7.51	0.660	0.501
^{210}Pb	11.22	28.98	66.51	51.54	0.001	0.031

Critical probability = $P<0.05$

The results presented above are complicated by contrasts in particle size composition and organic matter content between the source material and sediment samples (e.g. Collins *et al*., 1997; Ankers *et al*., 2003). This precludes detailed comparison of source material and sediment properties, unless the comparison can be based on detailed comparison of specific size fraction or organic fractions, which was beyond the scope of this investigation. Furthermore, it is known that sediment properties will reflect a range of local factors such as the underlying geology, soil type etc. which further complicate many direct comparisons between the properties of the sediment eroded from maize fields and those of the sediment transported by the rivers.

Overall, therefore, the geochemical results cannot be used to provide definitive conclusions. They neither confirm nor refute the hypothesis that the properties of the sediment transported by the river are closely linked to the properties of the sediment mobilized from the eroding maize fields. In this context the results obtained from this comparison of soil and sediment properties are broadly consistent with the results presented above regarding the likely contribution of the eroding maize fields to the sediment loads of the two rivers based on the measured erosion rates in maize fields and an estimate of the efficiency of sediment conveyance from those fields to the stream network. Both lines of evidence point to the maize fields providing a significant proportion of the suspended sediment loads transported by the two study rivers.

7.5 Conclusion

This chapter presents findings for river monitoring and sediment investigations undertaken in the Rivers Culm and Tone. The river monitoring and sediment investigation programme were undertaken during winter period between November 2004 and March 2005. Although not definitive, the results obtained from the river monitoring suggest that eroding maize fields are an important source of the fine sediment transported by the Rivers Culm and Tone. The results suggest that as much as 50% of the suspended sediment loads of the two rivers could be contributed by the eroding maize fields. However, the results obtained from the comparison of the geochemical properties of suspended sediment and soil from eroding maize fields was less conclusive, but were nevertheless broadly consistent with a substantial proportion of the suspended sediment being derived from eroding maize fields. Further work to take account of contrasts in grain size and organic matter content between soil and sediment samples is, however, needed to explore the geochemical evidence further.

CHAPTER 8: THE ENVIRONMENTAL IMPACT OF MAIZE CULTIVATION IN ENGLAND

8.1 Introduction

The area of maize cultivation in England has expanded greatly, particularly in the 1990s. Around 1995, maize cultivation experienced its greatest expansion in terms of the area involved and many areas in the Southwest region were cultivated for silage maize. Other areas, where maize is also important, included the Southeast, the Eastern England and the West Midlands. Maize is currently being grown in all regions in England. The expansion of maize cultivation has contributed to several environmental problems, particularly soil erosion and the diffuse pollution of rivers. These environmental impacts are closely related to poor land management practises during and after harvest, and particularly during winter if maize fields are left bare without any surface cover.

This chapter aims to provide a general assessment of the environmental impact of maize cultivation linked to available information on the expansion of maize cultivation in England. This is achieved by reviewing relevant information related to the physical characteristics of the land devoted to fodder maize cultivation and current agricultural practises. The information on the efficiency of sediment delivery from agricultural land provided by McHugh *et al*. (2002), in map format, will be used to link the spatial distribution of maize cultivation in England with information on sediment delivery efficiency as represented by the connectivity index and connectivity ratio maps presented by McHugh *et al*. (2002). However, before considering further the relationship between the spatial distribution of maize cultivation and sediment delivery efficiency, it is important to provide a general overview of the soil factors that are important in understanding the relationship between soil erosion and soil type. In addition, maps of the risk of diffuse water pollution produced by DEFRA (2004a) will be used to explore further possible link between maize cultivation and diffuse source pollution in England.

8.2 Soil Erosion Associated with Maize Cultivation

As indicated in Chapter 1, the growing of maize in England begins in spring, with the sowing of the crop around April and May. The harvest takes place in autumn, around mid-September and October. In the case of England, the risk of soil erosion associated with maize cultivation becomes very important after harvest. This is related to the practise of leaving the field, that is frequently damaged during harvest, bare and unprotected from rainfall impact during the wet seasons. This can result in surface runoff which encourages soil erosion, and the transport of sediment to watercourses.

In terms of on-site impacts, the rate of soil erosion varies, depending on various factors, mostly related to the physical characteristic of the area. The discussion on this matter was described in Chapter 6. At the general level, the rate of soil erosion can be related to the intensity and quantity of rainfall, soil erodibility, and the length and steepness of the slope. In terms of anthropogenic factors, these will be related to crop management and erosion control practises. These factors can be used to predict the rate of soil erosion. In the case of maize cultivation, beside the influence of these generic physical controls, improper management of maize fields after harvest could also be the most important factor that promotes surface erosion and transport of sediment to the rivers.

The rainfall factor (known as the R factor in the USLE equation), is related to intensity and quantity of rainfall. In general, the rate of soil erosion will be high if the intensity and amount of the rainfall are also high. This is related to both the effect of rainsplash in dislodging soil particles and the capacity for rainfall intensity and amount to control the amount of surface runoff. In a study located near Ilminster in Somerset, Clements and Lavender (2004) showed that treatment plots with bare stubble and late harvest treatment were characterized by significantly increased surface water runoff between November 2003 and March 2004. Total rainfall and runoff were significantly correlated $r = 0.892$, with d.f. = 9, and $P < 0.001$. The highest runoff occurred on 19 January 2003 following 68.0 mm of rainfall in the previous fortnight. The use of chisel ploughing, in attempt to reduce surface runoff, was shown to be highly effective, reducing total surface water runoff to 36 m^3/ha compared with 283 m^3/ha for bare stubble plots, whereas late harvest treatment increased surface water runoff to some 762 m^3/ha.

In the case of England, the amount of rainfall received varies over the year, as shown in Figure 8.1. Most of the high rainfall occurs after maize has been harvested and the maize fields are left bare, usually from October to March. The conditions can promote soil erosion, as the amount of rainfall during these periods is sufficient to promote splash erosion and to create erosive runoff on bare stubble maize fields. In addition, as discussed in Chapter 4, maize cultivation in England is mostly found in the Southwest, the Southeast and the West Midlands. According to rainfall data, as presented in Figure 8.2, significant erosion and transport of sediments from bare maize fields to the river networks can be expected during the winter months.

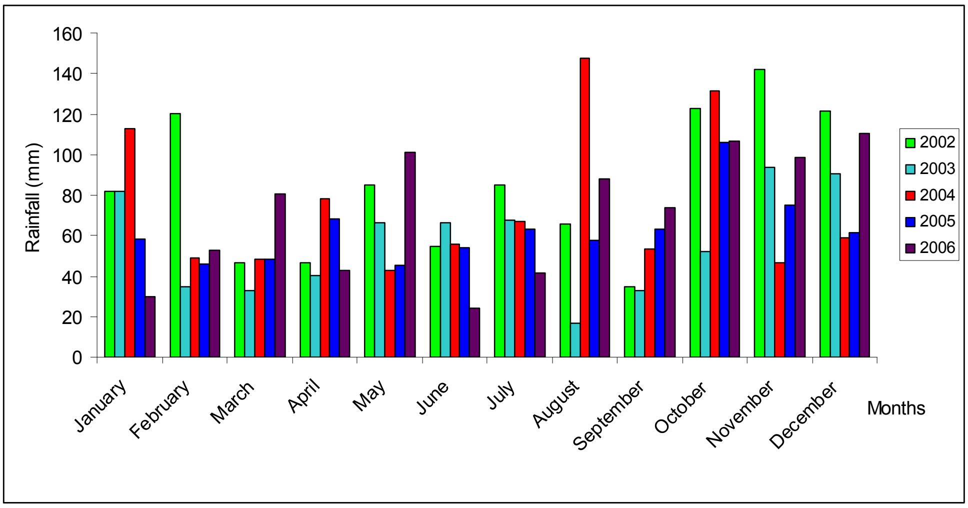


Figure 8.1: Monthly rainfall in England between 2002 and 2006

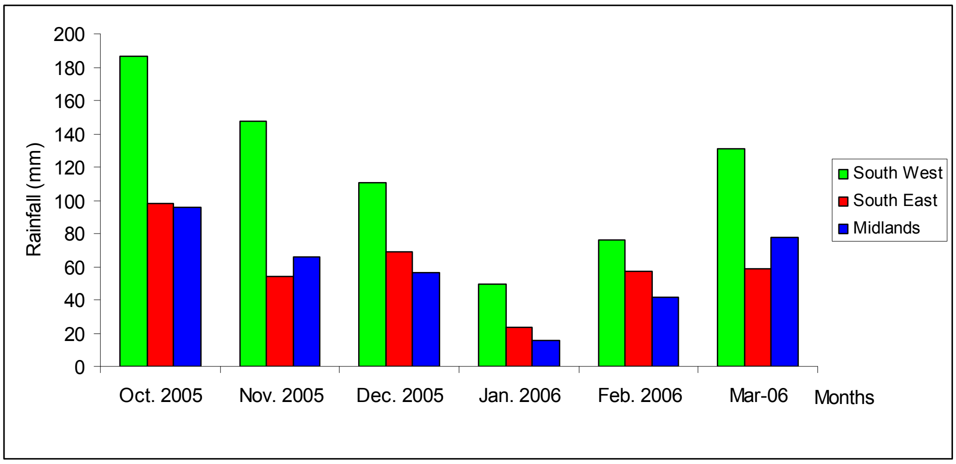


Figure 8.2: The distribution of rainfall in the Southwest, the Southeast and West Midlands between October 2005 and March 2006

In addition, the map of the spatial distribution of maize cultivation in England in 2000 can be linked to maps of erosion vulnerability and potential sediment delivery. It is important to note that the erosion vulnerability and potential sediment delivery maps were produced by McHugh *et al*. (2002) to determine sediment delivery from various land uses, especially from arable land, grassland and upland pasture. Thus maps are useful in this study, in terms of exploring potential increases in sediment delivery to rivers, resulting from maize cultivation. It is also important to stress that the predictions of sediment delivery from various land uses were originally based on the analyses of connectivity index and connectivity ratio.

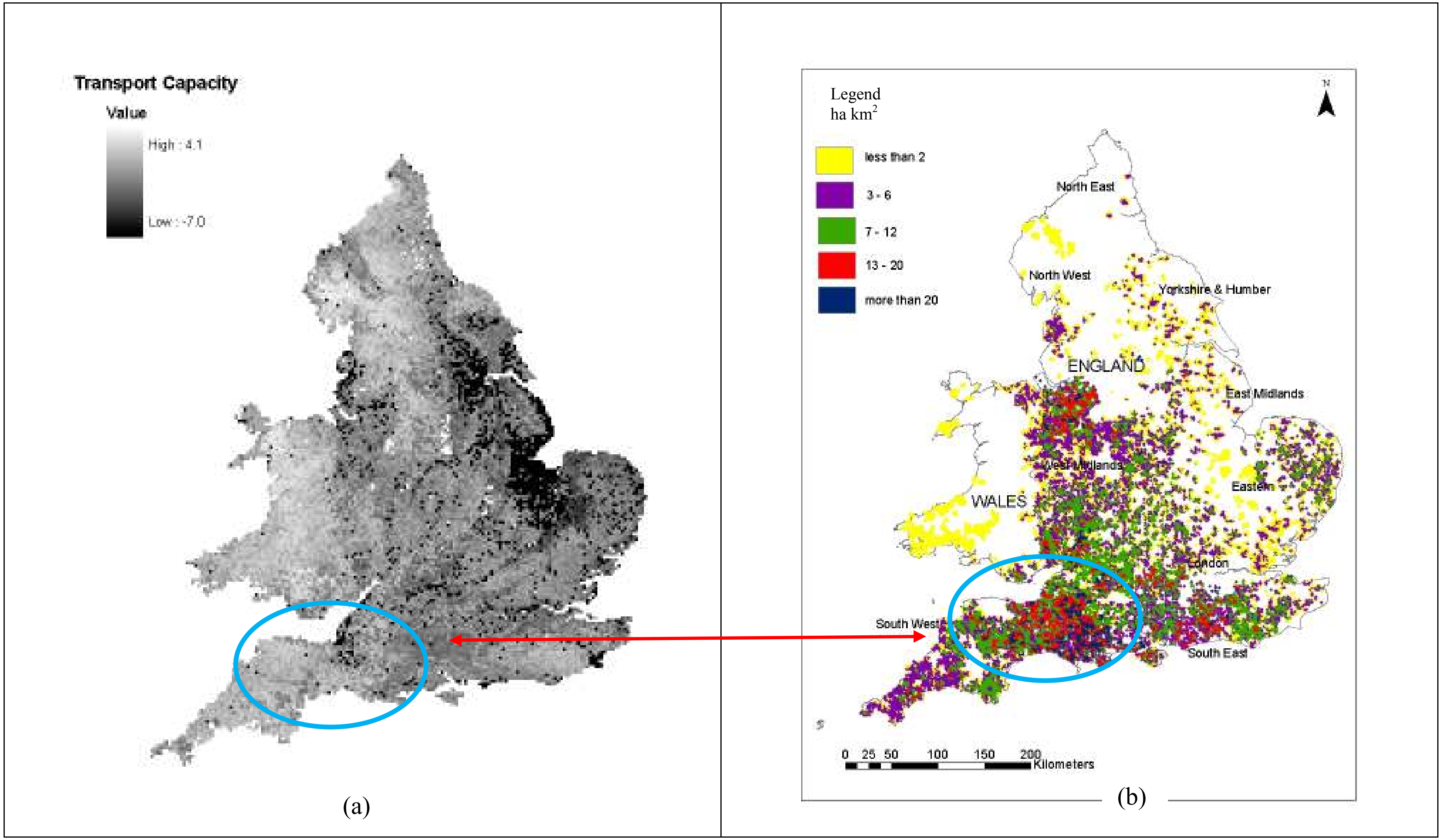
The connectivity index is a qualitative analysis that represents the likely relative efficiency of sediment transfer. The connectivity ratio provides a quantitative measure of the efficiency of sediment transfer from land surface to stream networks (McHugh *et al*. 2002). Prediction of the connectivity index and the connectivity ratio involves consideration of six factors, namely; (i) runoff potential, (ii) slope steepness, (iii) slope shape, (iv) drainage pattern, (v) the sediment characteristics, and (vi) land use.

The runoff potential factor considers the influences of rainfall characteristics, surface condition and soil properties on runoff generation. The slope steepness factor is related to the slope gradient associated with overland flow and sediment transport capacity, whereas the slope shape factor is related to the efficiency of surface form, in terms of convex or concave slopes, associated with either erosion or deposition. The drainage pattern factor is related to the drainage density and spatial distribution of drainage that can influence sediment transfer distance and concentration of sediment in the river network. In terms of mobilization and transportation of sediment, the sediment characteristic factor represents the particle size composition of eroding soil, and is very important in controlling the efficiency of sediment delivery. Lastly, a dynamic land use factor is also important in sediment delivery in terms of the overall effect of land use associated with surface roughness. A detailed explanation of each factor used in deriving the connectivity index and connectivity ratio can be found in McHugh *et al.* (2002).

Figure 8.3 shows that there is a relationship between sediment transport capacity and the spatial distribution of maize cultivation. The sediment transport capacity is influenced and determined by surface runoff magnitude, slope gradient, surface roughness and sediment particle size. Clearly, the areas where the sediment transport capacity is higher, the maize cultivation is also denser.

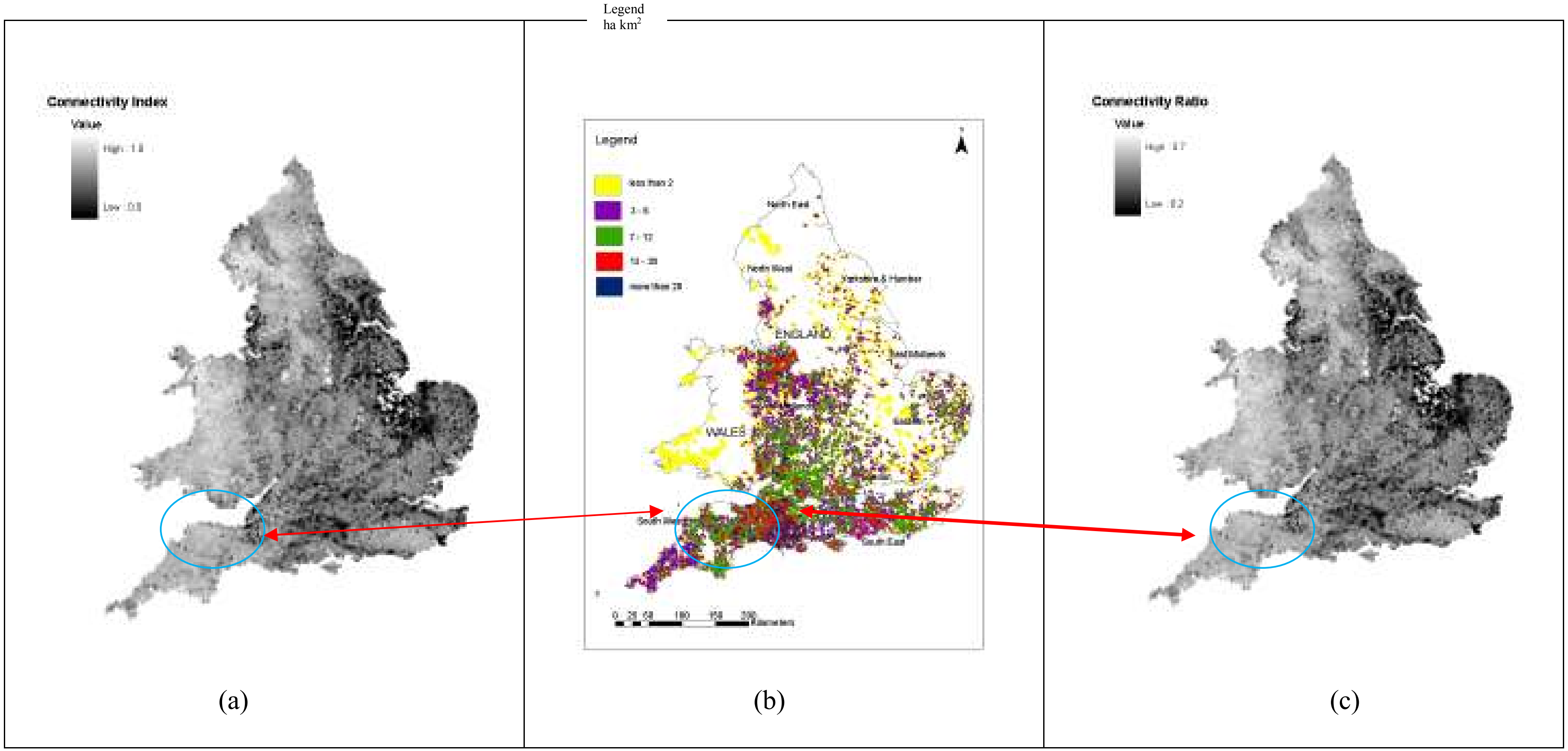
Derivation of the connectivity index involves combining information on sediment transport capacity with the drainage pattern and slope shape factors, and the result is used to derive the connectivity ratio. As shown in Figure 8.4, most areas of maize cultivation in England coincide with areas with a significant risk of sediment transfer. Furthermore, based on the erosion vulnerability map (Figure 8.5), most areas of maize cultivation in the southern and central parts of the Southwest, the eastern part of Eastern England, and the central part of the West Midlands occurs on the erodible area with a net soil loss of 0.013–0.023 m^3 ha^{-1} yr^{-1} for a 1-in-1 year erosion event. In addition, other areas of maize cultivation such as in the eastern area of the Southwest, the southern part of the West Midlands, and the western and central parts of Eastern England also coincide with areas that can be considered risky in terms of erosion vulnerability.

In terms of 1-in-10 year erosion events, it should be noted that the western part of the Eastern region is among the most vulnerable areas for erosion. The potential erosion vulnerability for this area is 0.5–1.0 m^3 ha^{-1} yr^{-1}. Other areas of land where the amount of land under maize cultivation is high, for example in Devon and the eastern part of Somerset in the Southwest region are also high in terms of erosion vulnerability, with values in the range 0.1-1.5 m^3 ha^{-1} yr^{-1}.



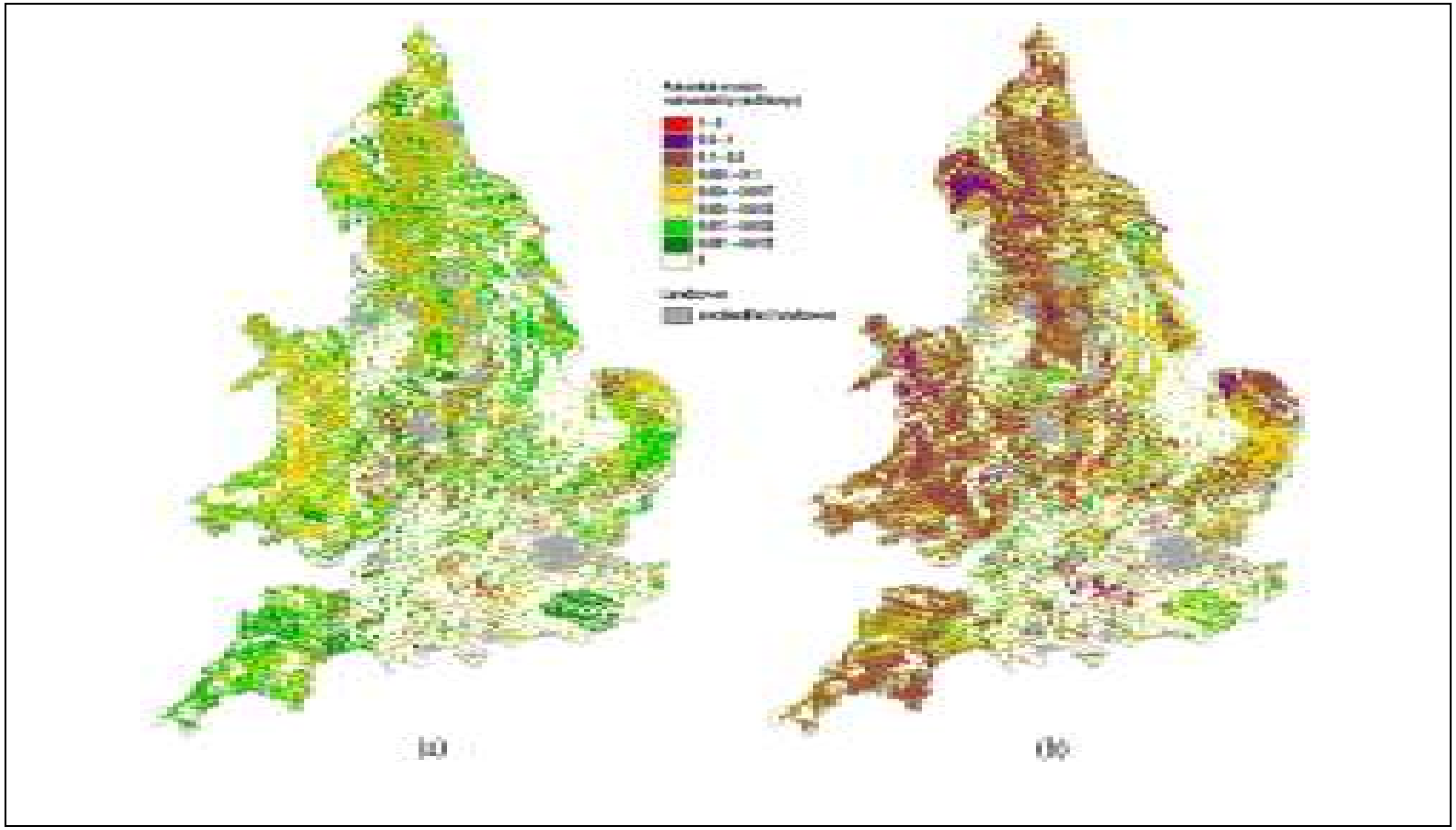
Source: (a) McHugh *et al*. (2002) and (b) the spatial distribution of maize cultivation in England in 2000

Figure 8.3: Comparison between the spatial distribution of sediment transport capacity of overland flow



Source: (a) and (c), McHugh *et al*. (2002)
(b) The Edinburgh Library data (2000)

Figure 8.4: Comparison between (a) the connectivity index, (b) spatial distribution of maize cultivation in England in 2000, and (c) connectivity ratio



Source: McHugh *et al*. (2002)

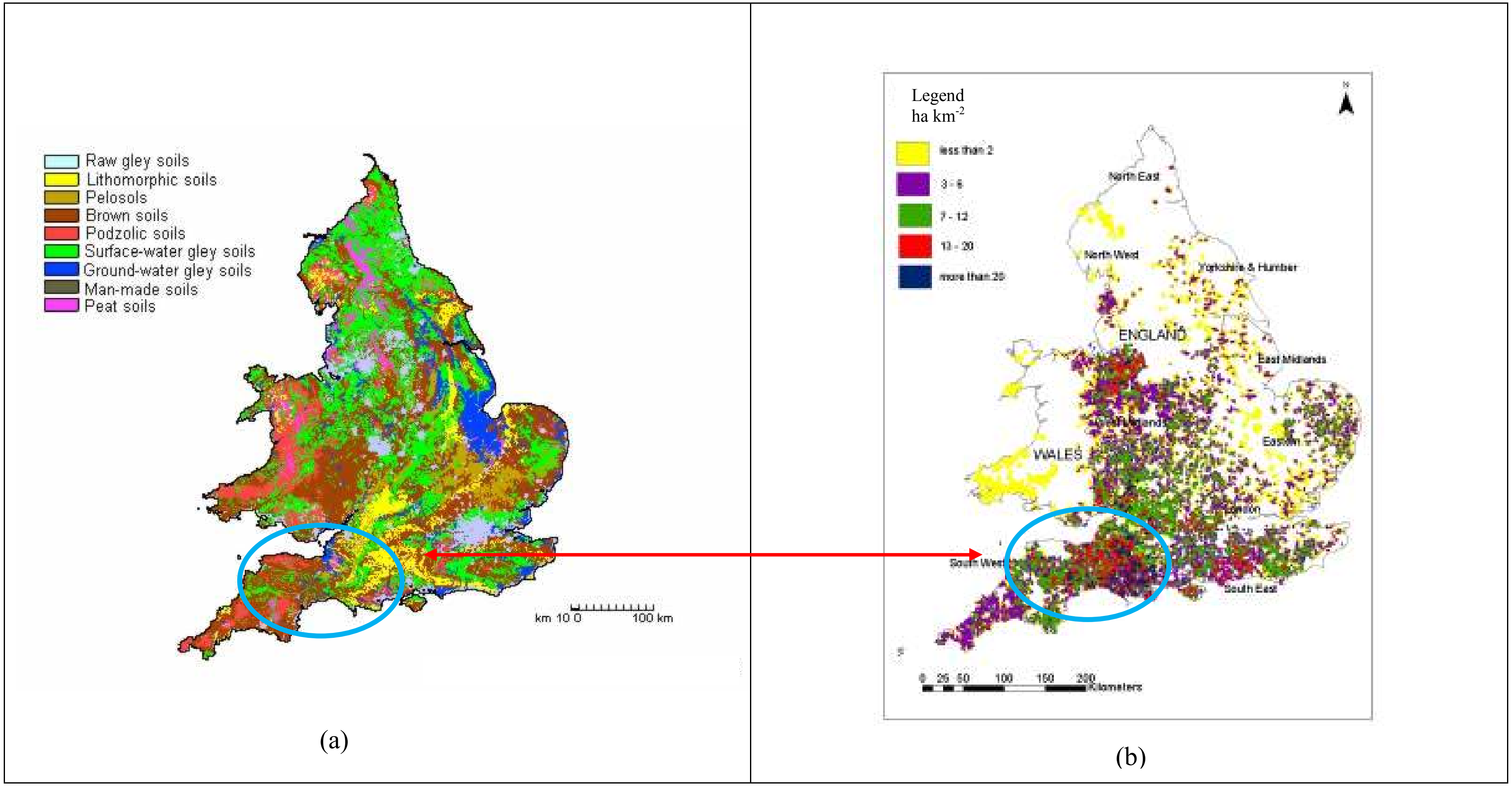
Figure 8.5: Erosion vulnerability for (a) 1-in-1 year erosion events, and (b) for 1-in-10 year erosion events

8.3 Soil Types and the Distribution of Maize Cultivation

For the purpose of this study, with regard to soil types in England, the author has used the soil classification map produced by the National Soil Resources Institute. According to Figure 8.6, most of the area of maize cultivation in the central part of the Southwest and the West Midlands is underlain by brown and podzolic soils. In the case of the north-eastern part of the Southwest, Eastern, and Northwest England, the East Midlands and the Southeast regions, the area of maize cultivation is underlain primarily by lithormorphic and gley soils. As discussed in Chapter 4, the Southwest, the Southeast, and the West Midlands, are the greatest areas of maize cultivation.

Brown soils in England are mostly in agricultural use. There are well-drained and can be divided to eight groups. However, the brown calcareous sands, brown calcareous alluvial soils, brown sands and brown alluvial soils are the groups in the brown soil types that are most susceptible to erosion by rainfall. The lithormorphic soils, especially sand-rankers, rendzinas and sand-pararendzinas are the groups of soils that are also fragile. The surface-water gley soils can be divided into two groups; (1) stagnogley soils, which occur widely in the lowlands, and (2) stagnohumic gley soils which are found mainly in the uplands. Both groups are also vulnerable to soil erosion caused by rainfall. Based on the above explanation, it can be concluded that most of the maize cultivation in England is found on fragile soils. In addition, the brown soils also contain more sands and loams, for which the rate of soil erosion has been shown to be high (Morgan, 1985; Fullen *et al*., 1996).

As shown in Figure 8.6, a high density of maize growing occurs on the brown soils especially in the southern and eastern parts of England. The trend of maize cultivation can be expected to be increasing in this area. If environmentally friendly practises are



Source: (a) National Soil Resources Institute

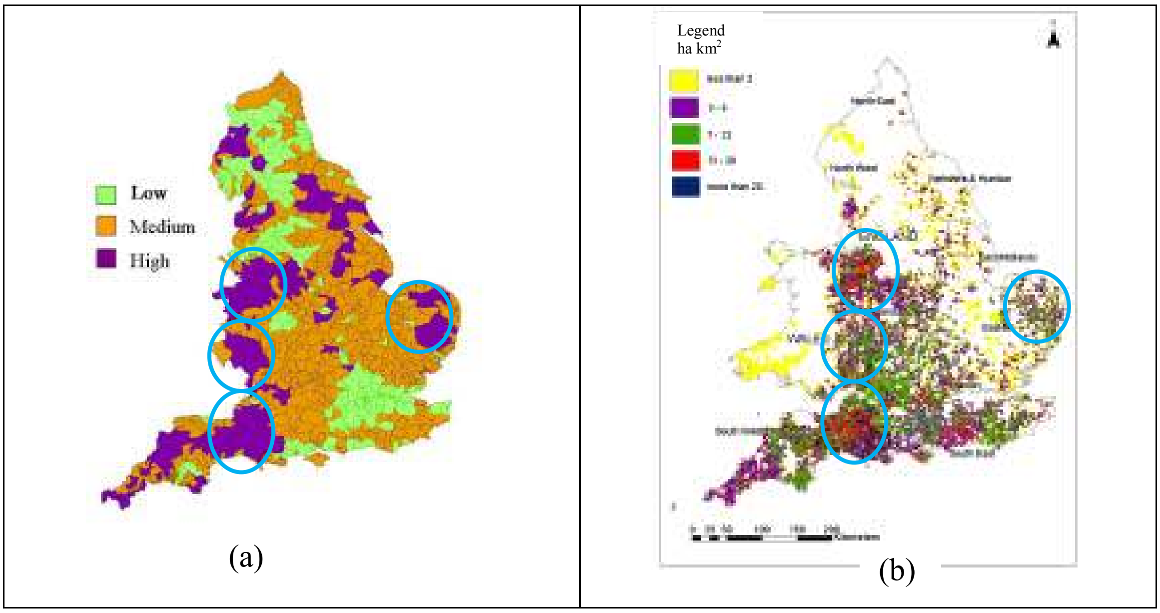
Figure 8.6: Comparison between (a) soil types and (b) the spatial distribution of maize cultivation in England in 2000

not implemented in the area of maize cultivation, especially in the area of high density of maize growing, serious soil erosion on brown soils can be expected and more sediment could be transported to nearby watercourses.

8.4 Diffuse Pollution Associated with Maize Cultivation

The previous section reviewed and discussed the links between the location of the main areas of maize cultivation and erosion vulnerability and the potential for delivery of mobilized sediment from maize fields to the stream network. This section focuses on possible links between diffuse pollution of water courses in England and maize cultivation. For this purpose, use will be made of several maps produced by DEFRA (2004) which provide an overview of diffuse pollution in England and thus a basis for exploring possible links with maize cultivation. Attention will be directed to the risk of phosphorus pollution and the designation of catchments at risk from agricultural diffuse pollution.

As indicated in the previous chapter, maize fields are highly likely to be a significant contributor to increased phosphorus loading in rivers. Figure 8.7 indicates that areas with the highest risk of phosphorus loss are closely linked with areas of intensive maize cultivation. However, the area of high risk of phosphorus loss does not only coincide with areas of denser maize cultivation, since some of the areas with high risk of phosphorus loss are found in areas with limited maize cultivation, such as in the northern part of the West Midlands and the eastern part of Eastern England. However, it is also important to note that such areas are actively cultivated and this condition should be taken into consideration when attempting to explore the possible links between phosphorus loss and maize cultivation. However, it is known that the areas in the northern part of the West Midlands and the eastern part of Eastern England are important for vegetable growing (e.g. in Yorkshire and Nottinghamshire) and that dairy farming is important in the South West (e.g. in Cornwall, Devon, Somerset, Dorset, Wilsthire), and such activities could also be greater contributors of phosphorus in the rivers (DEFRA, 2004).



Source: DEFRA (2004)

Figure 8.7: (a) Areas at risk of phosphorus pollution and
(b) the distribution of maize cultivation in 2000

Figure 8.8 shows that many catchments in England are at high risk from agricultural diffuse pollution. DEFRA (2004) stated that at least 70% of the country is at medium to high risk from agricultural diffuse pollution. However, the precise role of maize cultivation in contributing to this pollution was not specified in the report. Figure 8.8 clearly shows that many of the catchments designated as being at risk from diffuse source pollution are also areas with a higher density of maize cultivation, especially in Dorset, Devon and Somerset in the Southwest, and northern part of the West Midlands.

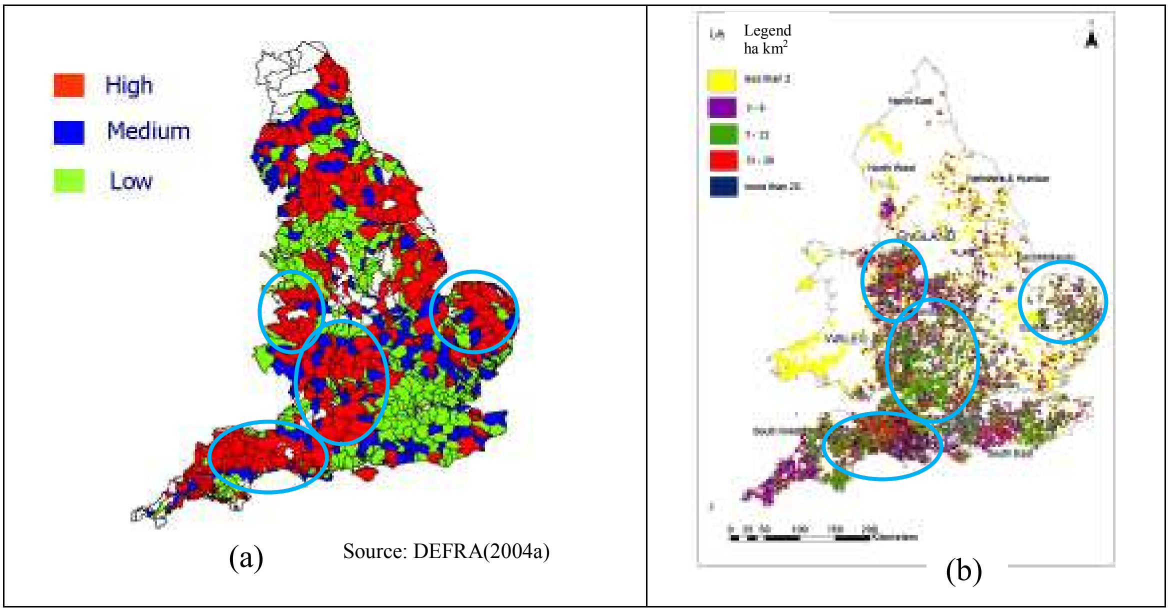


Figure 8.8: (a) Catchments at risk from diffuse agricultural pollution and
(b) the distribution of maize cultivation in 2000

8.5 Conclusion

This chapter attempts to provide a broad-based national-scale assessment of the environmental impact of maize cultivation in England, in terms of soil erosion risk and potential sediment delivery from maize fields to watercourses. The amount of rainfall received during wet periods (November to February) is considered sufficient to promote soil erosion (splash erosion and surface wash) on bare maize fields after harvest. In addition, most of the area of maize cultivation in England occurs on fragile brown soils which are vulnerable to soil erosion. The combination of rainfall amount and fragile soil can promote serious soil erosion on bare stubble maize fields, and mobilize and transfer sediment to the river network.

A detailed assessment of the spatial distribution of maize and potential sediment delivery to water courses indicates that most of the denser area of maize cultivation occurs in areas where sediment transport capacity is also higher. This could lead to significant risk of sediment transfer from bare stubble maize fields to the river network. Furthermore, determination of diffuse pollution, in terms of the risk of phosphorus pollution, show that the highest risk of phosphorus loss seems to show a link with not only areas of denser maize cultivation but also with low density areas.

To generalize the discussion in this chapter, it is clear that maize cultivation in England is significant in promoting soil erosion during wet months, and potentially contributes to diffuse pollution to the rivers by mobilizing and transferring sediment from bare stubble maize fields to watercourses. Therefore, there is a need to control the impact of soil erosion associated with maize cultivation in order to reduce sediment input to rivers. The next chapter will review several agricultural policies to promote environmentally friendly practises that could be implemented to reduce on- and off-site impacts associated with maize cultivation in England.

CHAPTER 9 : MAIZE CULTIVATION MANAGEMENT

9.1 Introduction

The on-site and off-site impacts of maize cultivation, associated with increased soil erosion, have been discussed in Chapters 6, 7 and 8, with reference to local, regional and national scales. It is clear that maize cultivation has significant negative on-site and off-site impacts on the environment. In the case of maize cultivation, the environmental damage can be related to poor soil and land management practises. This is due to improper management of maize fields during harvest and the ensuing winter by farmers and harvest contractors.

In this chapter, the literature on erosion control associated with maize cultivation will be reviewed. In addition, current policy associated with agricultural land management in general, and maize cultivation in England in particular, will be reviewed. This necessitates consideration of the Common Agricultural Policy (CAP) and the Water Framework Directive (WFD), as such legislation has implications for the promoting of sustainable and environmentally friendly farming aimed at reducing both the on-site and off-site impacts of farming activities. The Diffuse Water Pollution from Agriculture (DWPA) and Agri-Environment Scheme (AES) guidelines will also be reviewed, in the context of the Code of Good Agricultural Practise (COGAP), and the environmental impact of maize cultivation. More specifically, the three main drivers that are likely to represent key influences on maize cultivation, in terms of reducing on-site and off-site impacts, namely, the Single Farm Payment Scheme (SFPS), the Environmental Stewardship Scheme (ESS), and Catchment Sensitive Farming (CSF) initiative, will also be reviewed and discussed in this chapter. Figure 9.1 shows the links between the various policies, schemes and initiatives as mentioned above.

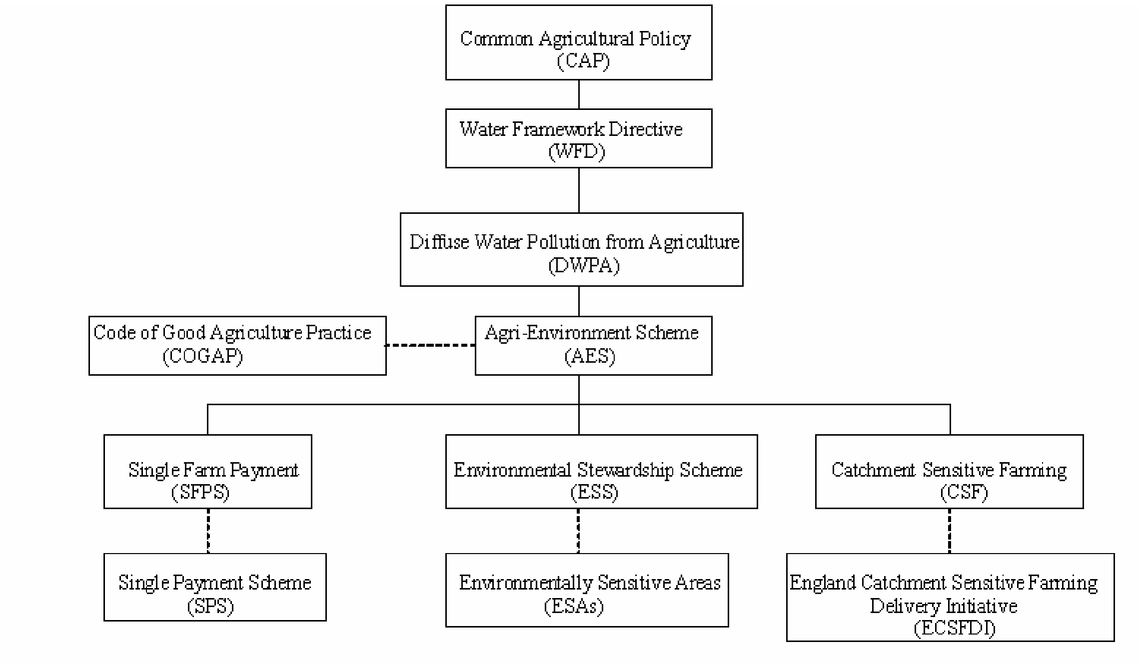


Figure 9.1: The links between the various policies, schemes and initiatives which influence farming practises in England

9.2 Erosion Control Associated with Maize Cultivation

Growing maize as a fodder crop has become more popular in the Europe, and maize has become an important source of cattle fodder in the United Kingdom, especially in England. As shown in Chapter 4 (Sections 4.2 and 4.4), the area cultivated with silage maize within the continent of Europe cover an area of *ca.* 3.86 million ha. In the case of England, in 2004, the area under maize cultivation occupied an area of ca. 107.4 thousand ha of arable land.

The growing of maize as a fodder crop to support diary farming in England has given rise to significant on-site and off-site problems related to increased soil erosion. Existing reviews of soil erosion control practises on maize field show that most of the studies covered three distinct periods i.e. (i) the seed sowing to growing period, (ii) the growing period to mature period, and (iii) the post harvest period where fields are left bare with stubble.

Clements and Donaldson (2002) worked on soil erosion control on maize field based on a series of field experiments undertaken between 1998 and 2001 at IACR Long Ashton (Institute of Arable Crops Research), and between 1999 and 2001 at IGER North Wyke (Institute of Grassland and Environmental Research). Their studies showed that chisel ploughing effectively limits soil compaction, but that it is only effective when soil conditions allow shattering of the soil. Surface runoff from compacted soil shattered by chisel ploughing was typically only 10 m^3/ha, whereas the runoff from compacted maize stubble averaged 433 m^3/ha. In addition, the experiments also demonstrated that an understorey of clover within the maize drilled across the slope was also effective in reducing runoff. As an example, the combination of a white clover understorey with drilling across the slope at Long Ashton experimental plot reduced runoff by nearly 90%. In the case of the North Wyke experimental plots, an understorey of grass was shown only reduce runoff by 40-60%.

Measurements of surface water runoff from maize stubble during the winter of 2003/04 in a Parrett Catchment area reported by Clements and Lavender (2004) support the findings of Clements and Donaldson (2002). In these measurements, chisel ploughing across the slope greatly reduced total surface water runoff by *ca.* 87% compared with bare stubble plots (283 m^3/ha). In addition, the cover crop and Italian ryegrass understorey had only a modest effect in limiting runoff, reducing this by *ca.* 41% and 8%, compared with bare stubble plots, respectively.

Studies undertaken in South Limburg (The Netherlands) have shown that soil tillage after maize harvest and sowing of winter ryegrass can greatly reduce surface runoff and soil loss during winter (Van Dijk *et al*. 1996a). Further investigations reported by Kwaad *et al*. (1998) support this finding, where winter runoff and erosion under continuous maize cropping were strongly reduced by autumn tillage. Their experiments undertaken in 1992 and 1993 showed that under various cropping systems, soil erosion was significantly reduced but did not effectively reduce runoff. The most effective cropping system was found to be direct drilling of maize in winter rye residue. This cropping system could reduce runoff by more than 90% in winter. In addition, the 'straw system' was shown to be an effective technique for reducing runoff on mulched surfaces.

A contour grass strip was shown to be an effective approach for erosion control in an investigation undertaken in Bedfordshire and reported by Melville and Morgan (2001). Their studies showed that two grass treatments involving *Festuca ovina* and *Poa pratensis* significantly ($P< 0.05$) lowered the runoff and soil loss compared to bare soil. However, despite differences in density, height and leaf size between the two grasses, there were no significant differences in their in controlling erosion. The grass strips could operate by ponding water upslope of the barriers which leads to particulate deposition, instead of acting as a filter with sedimentation within the barrier.

To support the above review, Table 9.1 summarise some other findings, which show that cover crops and soil tillage can be effective in dealing with erosion control in terms of reducing runoff and soil loss. In general, straw mulching and the growing of cover crops are effective and good practices for erosion control on stubble maize fields as they can significantly reduce runoff and soil loss.

Table 9.1: Summary of investigations aimed at controlling erosion associated with fodder maize cultivation

Methods and Result
• Cover crops that greatly reduced runoff and erosion
• Winter cover crops that reduced runoff by 88% compared with bare fallow
• Clover understorey greatly reduced runoff
• Winter rye, oil radish, spring or winter rape, or cocksfoot reduced soil loss, and therefore probably runoff, on maize field
• Soil tillage in autumn reduced runoff and soil erosion, and straw mulch effectively reduced runoff when used instead of winter rye as a cover crop
• Cover crops that reduce sediment production and runoff from crop land by intercepting the kinetic energy of rainfall, and by reducing the amount and velocity of runoff

Source: adaptation from Harris *et al*. (2004)

Beside studies focusing on controlling on-site impact of soil erosion associated with a mitigation approach to water runoff, studies have also been carried out to reduce the off-site impact caused by soil erosion. Hoang Fagerström *et al*. (2002) have shown that planting a hedgerow at the bottom of the slope can prevent transport of sediment directly to the river channel. The hedgerow can act as a trap by slowing the runoff and blocking the transfer of sediment to the river channel. In addition, their study also showed that the hedgerow species *Tephrosia* can improve nutrient cycling and prevent nutrient losses by erosion on slopes. Investigations reported by Chaowen *et al*. (2007) have also shows that hedgerows can significantly reduce runoff and sediment transfer. The reduction in sediment transfer associated with a one year old hedgerow was measured as *ca.* 82-86%, whilst the runoff reduction up to 63-71%.

Detention ponds have also been shown to be an effective technique for preventing sediment transfer to the drainage system. Investigations reported by Fiener *et al*. (2005) show that detention ponds effectively trapped sediment and reduced sediment movement by between 54% and 85%, or by between 1.0 and 15.3 t ha^{-1} yr^{-1}. The peak runoff rate, measured from the measured outflow rates and the inflow rates, was also reduced from 15.1 to 4.9 l s^{-1}, whilst the total outflow volume of 894 m^3 was reduced by 10%, based on integrated calculation of infiltration and evaporation rates.

Riparian buffer zones have also been identified as an effective practise for trapping sediments and pollutants in runoff before reaching the watercourses. Permanent vegetation such as grasses, shrubs and trees act as sponges to filter and absorb sediment and pollutants in runoff. A study reported by Mihara (2006) showed that a weed buffer of *Humulus scandens* Merrill and *Poa annua* L. was very effective in minimizing soil and nitrogen losses. The buffer captured 99.6% of the soil-sediment and stored 80% of the total nitrogen input. McKergow *et al*. (2003) reported that a riparian buffer zone reduced suspended sediment concentrations associated with a median event from 147 to 9.9 mg l. However, the riparian buffer zones did not alter significantly the P and TP concentrations after the riparian buffers were fenced and planted, probably associated with several reasons such as (i) P losses are dominated by FRP, and (ii) hydrological flowpaths affect the potential of riparian buffers for reducing nutrient export (McKergow *et al*. 2003).

Based on above reviews, regarding to on-site control of soil erosion, clearly that the most effective techniques for reducing runoff on bare stubble surface are chisel ploughing, winter ryegrass and understorey of clover within the maize drilled across the slope. In terms of mulched surfaces, the straw system seems to be the most effective technique. In addition, cover crop and Italian ryegrass understorey had a modest effect in limiting runoff. To summarize, all of these techniques can be applied on a bare stubble surface of maize for reducing and limiting runoff on various soil types and slope gradient.

In order to reduce sediment transfer from maize fields to nearby watercourses, hedgerow planting at the bottom of the slope and riparian buffer zones seems to be the most effective practises. Both of these approaches can act as a trap by slowing the runoff and trapping sediments and pollutants in runoff before reaching the river channel.

9.3 The Common Agricultural Policy (CAP) and Maize Cultivation

The Common Agricultural Policy (CAP) was established in 1961 and originally introduced in 1962 by the European Commission (EU) to promote intervention in the agricultural sector among European countries. Generally, the CAP promotes three major principles: (i) market unity, (ii) community preference, and (iii) financial solidarity; linked to what should be grown for maintaining prices for crops, and influencing how farming should be organized. Based on these basic principles, the CAP become an integrated system for controlling the agriculture sector within the EU, and more particularly, maintaining commodity price levels within the EU, based on three mechanisms: (i) import tariffs on specified goods imported into the EU, (ii) setting an internal intervention price, and (iii) subsidies to farmers for growing particular crops. In terms of cultivation of crops and particularly maize, the second and third mechanisms are crucial in the case of England since they promoted an expansion of the area of maize cultivation and thus an increase of its off-site impacts due to diffuse water pollution during winter.

According to the mid-term review of the CAP in 2003, the first CAP pillar (price and market policy) associated with direct payment has been separated from the second pillar (rural development and environment), which promotes more sustainable and environmentally sensitive land management. The first pillar represents a more consumer-focused policy, based on single farm payments, whilst the second pillar aims to maintain and enhance the landscape and wildlife by tackling pollution from agriculture land. This provides a clear framework for the EU agricultural policy by focusing on maintaining the environment and promoting sustainable rural development in more environmentally sensitive areas. In general, the first pillar is related to the Single Farm Payment Scheme (SFPS), and the second pillar with the Environmental Stewardship Scheme (ESS). Both pillars have affected the agriculture sectors in the UK, and more specifically England, by encouraging a larger area of land under arable farming and particularly maize cultivation. In more detail, in the case of England, the implementation of these pillars is connected to the Agri-Environment Scheme (AES) guidelines and Water Framework Directive (WFD) objectives, which aim to combat off-site impacts, especially from arable land and area of maize cultivation.

9.3.1 Single Farm Payment (SFP) scheme

Under the CAP reform in 2003, the SFP replaced 11 schemes[4] with one new single payment. This new scheme is based upon a standard regionalized area payment, modified to reflect historical subsidy receipts. In general, the SFP, managed by the Rural Payment Agency (RPA), requires farmers to follow the environmental standards of sustainable and environmentally friendly practises based on the AES and Code of Good Agriculture Practise (COGAP). In more detail, the SPS gives farmers freedom in

[4] These include (i) the Arable Area Payment Scheme, (ii) the Beef Special Premium, (iii) the Extensification Payment Scheme, (iv) the Sheep Annual Premium Scheme, (v) the Suckler Cow Premium Scheme, (vi) the Slaughter Premium Scheme, (vii) the Veal Calf Slaughter Premium Scheme, (viii) the Dairy Premium, (ix) the Dairy additional payment, (x) Hops Income Aid, and (xi) Seed Protection Aid (DEFRA, 2006a)

their choice of 'agricultural activity'[5] in response to consumer and market demands, but at the same time requires farmers' to meet a baseline standard when making their claims for payment. This requirement must meet the Good Agricultural and Environmental Condition (GAEC) (Table 9.2) and Statutory Management Requirements (SMRs) standards (Table 9.3). In other words, these requirements are described in the CAP as 'cross-compliance', where the SFP covers the whole agricultural area of a farm's holding, and the SPS involves the amount of land entered into SPS claims.

Table 9.2: Good Agricultural and Environmental Condition (GAEC) in use for cross-compliance guidance for the management of habitats and landscape features in 2005

GAEC 1	General requirements (soils)
GAEC 2	Post-harvest management of land after combinable crops
GAEC 3	Waterlogged soils
GAEC 4	Burning of crop residues
GAEC 5	Environmental Impact Assessment
GAEC 6	Sites of Special Scientific Interest
GAEC 7	Scheduled Monuments
GAEC 8	Public rights of way
GAEC 9	Overgrazing and unsuitable supplementary feeding
GAEC 10	Heather and grass burning
GAEC 11	Control of weeds
GAEC 12	Eligible land which is not in agricultural production
GAEC 13	Stone walls
GAEC 14	Protection of hedgerows and watercourses
GAEC 15	Hedgerows
GAEC 16	Feeling of trees
GAEC 17	Tree Preservation Orders (TPOs)

Source: DEFRA, 2006a

The cross-compliance that requires farmers to comply with GAEC and SMRs to receive the SFP and SPS involves two sets of requirements. These refer to (i) the maintenance of land/farms in accordance with the GAEC, and (ii) complying with a number of specified legal requirements of land/farms relating to the SMRs. In the case of maize

[5] 'Agricultural activity' is defined as the production, rearing or growing of agricultural products including harvesting, milking, breeding animals and keeping animals for farming purposes (Council Regulation (EC) No 1782/2003 (Article 2(c)) (DEFRA, 2006a)

Table 9.3: Statutory Management Requirements regimes

SMR 1	Wild Birds
SMR 2	Groundwater
SMR 3	Sewage sludge
SMR 4	Nitrate Vulnerable Zones (NVZs)
SMR 5	Habitats
SMR 6	Animal identification and registration - pigs
SMR 7 & 8	Cattle identification
SMR 8a	Animal identification and registration – sheep and goats
SMR 9	Restrictions on the use of plant protection products
SMR 10	Restrictions on the use of substances having hormonal or thyrostatic action and beta-agonists in farm animals
SMR 11	Food and feed law
SMR 12	Prevention and control of Transmissible Spongiform Encephalopathies (TSEs)
SMR 13	Control of Foot and Mouth Disease (FMD)
SMR 14	Control of certain animal diseases
SMR 15	Control of Bluetongue

Source: DEFRA, 2006b

cultivation, the GAEC 1 (General requirements-soils) requires farmers to fulfil the Soil Management Plan (SMP)[6] and Soil Protection Review (SPR)[7] to claim the SPS based on the cross-compliance basis under the ESS. In general, both soil requirements involve three basic environmental reviewing processes: (i) identifying soil issues, (ii) deciding on measures to manage and protect soils, and (iii) reviewing success. These requirements can be generalized to minimize and reduce the risk of damaging the environment from unsustainable farming practise.

According to the SMP, associated with maize cultivation as a specific case, all maize growers have to prepare an erosion risk map based on the risk of water erosion and runoff from a field. In order to establish this risk, maize growers are required to prepare

[6] The SMP is guidance for Entry Level (ELS) and Organic Entry Level (OELS) of the ESS, and is a voluntary option that contributes 3 points/ha towards ELS or OELS points targets.
[7] The SPR is guidance to manage and protect the soil based on GAEC standards. Details of these can be found in DEFRA (2006c).

a risk assessment based on three criteria: (i) soil texture, (ii) slope steepness, and (iii) frequency of flooding. Criteria (i) and (ii) are probably the most important aspects that maize growers in England have to take into account in the risk assessment. This involves two aspects of erosion risk. The first is water erosion where by maize growers have to identify signs of erosion based on four risk classes; (i) very high risk areas, (ii) high risk areas, (iii) moderate risk areas, and (iv) lower risk areas. This can be undertaken by referring to the guideline given in Table 9.4. The second is runoff, where maize growers need to identify the signs of runoff based on three risk classes; (i) high risk areas, (ii) moderate risk areas, and (iii) lower risk areas. This can be undertaken by referring to the guidelines given in Table 9.5. Regarding the erosion risk map, maize growers have to promote an environmentally friendly approach to minimizing and reducing both the on-site and off-site impacts of maize fields. According to the susceptible land use category, maize growers should be more aware that growing maize on Very High Risk and High Risk sites is highly likely to encourage erosion, unless suitable soil management precautions are taken, such as suggested in COGAP and GAEC. If maize must be grown in those areas, and in order to qualify the claimant under the SFPS and SPS, in addition to the COGAP and GAEC standards for preventing soil erosion in high risk situations, maize growers also have to prove that their SMP follows the EJ1[8] and EJ2[9] to gain necessary points.

[8] EJ1 refers to the Management of high erosion risk on cultivated land.
[9] EJ2 refers to the Management of maize crops to reduce soil erosion.

Table 9.4: Erosion risk category with regard to risk classes and soil types

Risk classes	Description
Very high risk areas	Rills are likely to form in most years and gullies may develop in very wet periods.
High risk areas	Rills are likely to develop in most seasons during wet periods.
Moderate risk areas	Sediment may be seen running to roads, ditches or watercourses and rills may develop in some seasons during very wet periods.
Lower risk areas	Sediment rarely seen to move but polluting runoff may enter ditches or watercourses.

Soils	Steep slopes (> 7^o)	Moderate slopes (3^o - 7^o)	Gentle slopes (2^o - 3^o)	Level ground (< 2^o)
Sandy and light silty soils	Very high	High	Moderate	lower
Medium and calcareous soils	High	Moderate	Lower	Lower
Heavy soils	Lower	Lower	Lower	Lower

Source: DEFRA, 2005a

Table 9.5: Sign of runoff risk with regard to risk classes and soil types

Risk classes	Description
High risk areas	Runoff seen in most years during wet periods.
Moderate risk areas	Runoff seen in some years during wet periods and in most years during very wet periods.
Lower risk areas	Runoff seen in some years during very wet periods.

Soils	Steep slopes (> 7^o)	Moderate slopes (3^o - 7^o)	Gentle slopes (2^o - 3^o)	Level ground (< 2^o)
All soils	High	Moderate	Lower	Lower

Source: DEFRA, 2005a

9.3.2 The Environmental Stewardship Scheme (ESS)

The ESS was also launched under the CAP reform in 2003, and this scheme works simultaneously with the SFPS and SPS. The ESS is an advanced scheme in terms of caring for the environment as a whole, and is superimposed on the Environmentally Sensitive Areas (EAS) and Countryside Stewardship (CS) schemes introduced by DEFRA. In general, the ESS is a reward scheme based on promoting good land management to address any environmental issues within and outside of the farm that could affect the wider countryside, including soil erosion, diffuse source pollution and the conservation of habitats. In more detail, this scheme intends to improve water quality and reduce soil erosion, improve conditions for farmland wildlife, maintain and enhance landscape character, and protect the historic environment of the English countryside.

The ESS has three elements that all farm and land owners and farmers have to take into account in order to qualify them as SFS claimants. The first is Entry Level Stewardship (ELS), which refers to a 'whole farm' scheme and provides a straightforward approach to support the good stewardship of the countryside. Under this scheme, farm owners or land managers have to prepare a Farm Environment Record (FER) to record all farm features. This requires them to identify where water erosion or runoff occurs, field-by-field. They will receive a payment of £30 per hectare per year for all the land they enter into the scheme[10]. In order to qualify, they have also to meet a 'points target' for the land they enter into the scheme. The points target they have to achieve is 30 points per hectare for all eligible land. However, for any land in the Less Favoured Area (LFA) in parcels of 15 ha or more, they will only need to achieve 8 points per hectare.

The second element is Organic Entry Level Stewardship (OELS), which is in many ways similar to the ELS but also has differences. The aim of OELS is to encourage organic farming across a wide area of farmland, in order to deliver simple effective environmental management. The potential for pollution and other environmental damage will be less, as organic farming avoids the use of artificial fertilizers and synthetic pesticides (DEFRA, 2005b). Under this scheme, the farm owners or land

[10] However, this excludes land within parcels of 15 hectares or more within the Less Favoured Area, (LFA) where farm owners or land managers receive £8 per hectare per year.

managers will receive £60 per ha per year for all OELS eligible land. They also need to prepare the FER for assessment. The point's target for the OELS is 60 points per ha. The OELS works simultaneously with ELS, but is more focused on organic farming and 'conversion' to organic farming. On top of the organic farming payments, farm owners or land managers may also apply for conversion aid top up payments on established fruit orchards[11].

In association with maize cultivation, both ELS and OELS require farm owners or land managers to manage their land, on a field-by-field basis, and to prepare the FER for assessment. The payments will be based on the SFPS. Under the management options[12] available for the ELS and OELS, maize growers have to give more attention to protecting soils by following the COGAP and GAEC 1 guidelines regarding TO management of maize fields during winter to reduce soil erosion risks. This also requires maize growers to mark in their FER the risk of soil erosion (on-site impact) and the risk of water pollution (off-site impact) associated with diffuse pollution from maize fields, and to promote good management of high erosion risks, if maize will be grow on risky land with a high risk, as mentioned in the SMP.

The third element of the ESS is the Higher Level Stewardship (HLS), which aims to deliver significant environmental benefits in high priority situations and areas[13]. This scheme is a combination scheme with ELS and OELS options. Under this scheme, on

[11] The conversion aid top-up payments rate is £600 per ha p.a. for the first three years of OELS agreement for areas of top fruit orchards (pears, plums, cherries and apples), and £174 per ha p.a. for the first years of OELS agreement for areas of improved land. Details can be found in DEFRA (2005b)

[12] The management options for ELS and OELS involve 10 options; (i) arable land, (ii) boundary features, (iii) buffer strips, (iv) encouraging a range of crop types, (v) LFA land, (vi) lowland grassland outside the LFA, (vii) management plans, (viii) protection of historic features, (ix) protection soils, and (x) trees and woodland (DEFRA, 2005b).

[13] The five primary objectives of HLS are: (i) wildlife conservation, (ii) maintenance and enhancement of landscape quality and character, (iii) natural resource protection, (iv) protection of the historic environment, and (v) promotion of public access and understanding of the countryside (DEFRA, 2005c)

top of the FER requirements, the farm owners also have to support their application with a Farm Environment Plan (FEP). The farm owners are required to identify features on their farm and their condition, and to provide a guide to the most appropriate management options, for the whole farm and field-by-field in their FEP. This involves a process of identifying historical features, wildlife, resource protection, access and landscape interest, and making an assessment of their condition. In order to claim the payment under this scheme, farm owners have to register related 'land'[14] to qualify for the payment under the SFPS.

In the case of maize growers, in addition to the FEP, they also have to provide a plan to protect the soil from water erosion and runoff, and a plan to prevent diffuse pollution of water courses. This can be achieved by following the guidelines for controlling soil erosion. In general, the guidelines suggest that maize growers should control soil erosion caused by water on susceptible soils by protecting the soil with vegetation cover after harvest, or by promoting surface retention to maintain water infiltration rates and to avoid the impact of rainfall. In more detail, maize growers are advised to avoid land of high erosion risk for growing maize. They are also advised to sow an early maturing variety of maize on all areas at risk of erosion, so that harvesting can be carried out early and before the end of autumn. In addition, they are also encouraged to reduce the post-harvest erosion risk by establishing a winter-cover crop or by rough ploughing immediately after harvest, to prevent overwinter runoff and erosion, and subsoiling along the contour to shatter the sub surface layer to improve soil infiltration and reduce runoff (DEFRA, 2005c).

[14] For the purpose of HLS, the 'land' refers to all land and associated boundaries registered on the Rural Land Register (RLR) which is farmed as one business enterprise, and which is included in a single application (DEFRA, 2005c)

The Environmentally Sensitive Areas (ESAs) scheme, which was introduced in 1987 to all farmers in England, is connected to the ESS. This scheme also offers incentives to farm owners and farmers to encourage them to adopt agricultural practises that are more environmentally friendly and that will 'safeguard and enhance parts of the country of particularly high landscape, wildlife or historic value' (DEFRA 2005d). However, with the introduction of the ESS, the scheme was closed to new applicants, but still applies for those already in the scheme before the ESS. The ESAs cover over 1.1 million hectares of land and involve 22 areas in England (Figure 9.2). This specific scheme, will only affect maize growers if they plan to cultivate maize within the ESAs, when they will have to follow the same requirements as given in the COGAP and GAEC related to preventing water erosion on the land and runoff to watercourses. The benefits of this scheme in terms of the payment vary for each area. For example, in the South Downs area, the payment for the land under TIER 4A category (winter stubble with undersowing) is £125 per ha, whilst in the West Penwith area, the payment for land under TIER 2 (winter stubbles) is £170 per ha.

9. 4 Catchment Sensitive Farming (CSF)

The Catchment Sensitive Farming (CSF) is a programme to reduce diffuse water pollution from agriculture in England and focuses on controlling phosphorus, faecal indicator organisms, sediments and nitrate pollution of any watercourse to meet the Water Framework Directive (WFD) water quality targets. It is already well accepted that the biggest threat of diffuse water pollution is from agricultural activity, especially in terms of increases in nutrient levels caused by fertilizers and manure, and turbid water caused by soil erosion. The CFS is a local scale programme that focuses on changing farmer behaviour and practise in farming (Table 9.6), such as protecting watercourses, nutrient and manure management, and land use and soil management.

Under this programme, farmers are encouraged to apply best practise in the use of fertilizer, manures and pesticides, simultaneously with managing good soil structure, to maximize infiltration of rainfall and minimize water erosion and runoff, protecting watercourses from faecal contamination and reducing sedimentation and pesticides.

The ESAs list which involves 22 areas and will be introduced in four stages;

Stage I
1. Broads
2. Pennine Dales
3. Somerset Levels & Moors
4. South Downs
5. West Penwith

Stage II
1. Breckland
2. Clun
3. North Peak
4. Suffolk River Valley
5. Test Valley

Stage III
1. Avon Valley
2. Exmoor
3. Lake District
4. North Kent Marshes
5. South Wessex Downs
6. South West Peak

Stage IV
1. Blackdown Hills
2. Cotswold Hills
3. Dartmoor
4. Essex Coast
5. Shropshire Hills
6. Upper Thames Tributaries

Source: DEFRA, 2006c

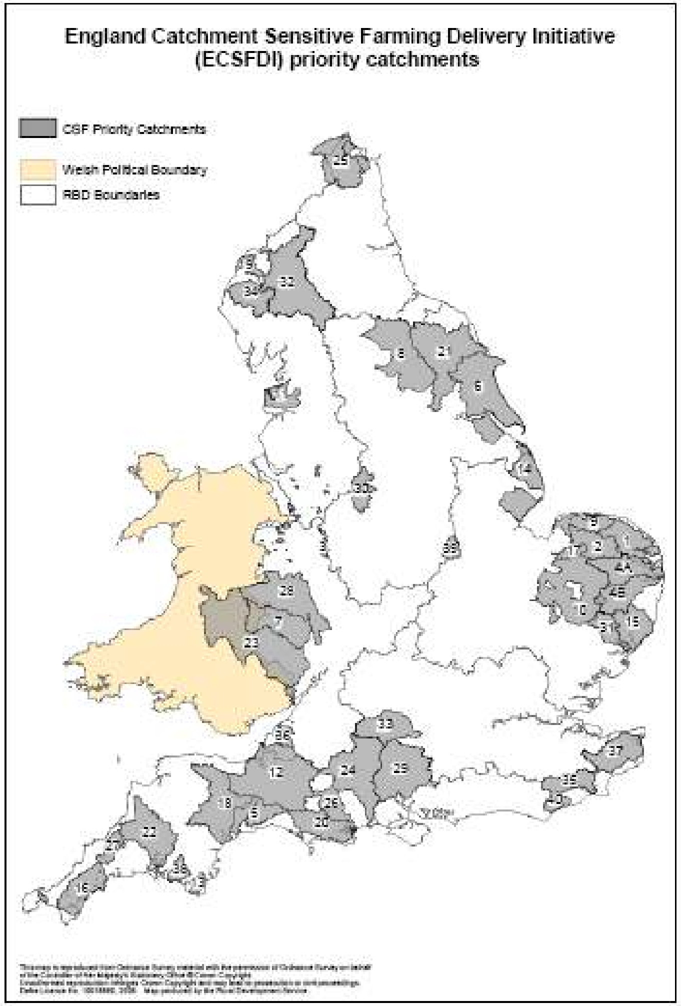
Figure 9.2: The location of the ESAs programme

In addition to the CSF, DEFRA also introduced the England Catchment Sensitive Farming Delivery Initiative (ECSFDI) as part of the CSF, focusing on England. As a sub-scheme of the CSF, the main ECSFDI target is to reduce diffuse water pollution from agriculture by encouraging CSF based on a catchment-specific approach. This approach includes the prioritization of catchments affected by diffuse water pollution from agriculture, the appointment of a network of dedicated Catchment Sensitive Farming Officers each assigned to a specific priority catchment, and the establishment of Catchment Steering Groups (DEFRA, 2008). Currently, forty catchments have been identified as priority areas for action under the ECSFDI, involving eight river basin districts (Figure 9.3), namely, (i) the South West river basins, (ii) the South East river basins, (iii) the Thames river basins, (iv) the Severn river basins, (v) the Anglia river basins, (vi) the Humber river basins, (vii) the North West river basins, and (viii) the Solway and Tweed river basins. In more detail, DEFRA and related members in the ECSFDI identify several environmental issues in each priority catchment via the catchment priority approach, and some of the issues related to maize cultivation. Table 9.7 shows some example of the environmental issues associated with maize cultivation identified by DEFRA and ECSFDI members, and provide a description and justification of the issue.

Table 9.6: List of farmer objectives and practises

Objective	Practices	
Protecting watercourses	• Establish riparian buffer strips • Trap silt and sediment	• Fence watercourses • Provide fording/crossing points for livestock
Livestock management	• Reduce stocking densities • Reduce grazing intensity • Avoid poaching	• Move feeders and troughs at regular intervals • Reduce N and P in livestock diets • Provide access to drinking water through pasture pumps and troughs
Manure management	• Adopt recognized manure management plan • Export surplus manure • Adopt batch storage of slurry and of solid manure • Compost solid manure • Change from slurry to solid manure handling system • Site solid manure heaps away from watecourses and field drains	• Site solid manure heaps on concrete and collect the effluent • Do not apply manure to high risk areas • Do not spread farmyard manure, slurry or poultry manure to fields at high-risk times • Incorporate into soil quality or inject • Test manure spreaders and re-calibrate as necessary
Nutrient management	• Adopt nutrient management plan • Use recognised fertilizer recommendation system • Test soils • Keep records of applications • Seek advice from FACTS qualified agronomists	• Integrate fertilizer and manure supply • Do not apply P fertilizer to high P index soils • Do not apply fertilizer to high risk areas • Avoid spreading fertilizers at high risk times • Test manure spreaders and re-calibrate as necessary
Land use / soil management	• Convert arable land to grassland • Adopt recognized soil management plan • Establish autumn cover crops • Cultivate in spring rather than autumn • Adopt minimal cultivation system • Check for and deal with sub-surface capping and compaction • Cultivate and drill across the slope and along contours	• Avoid winter tramlines • Leave autumn seedbeds rough • Establish in-field grass buffer strips • Reduce field size with new hedges and beetle banks • Introduce grass leys into arable rotations • Avoid high risk crops on high risk fields • Use forestry and set aside schemes to good effect
Crop protection	• Adopt recognized crop protection management plan • Test sprayers • Use registered operators	• Spray under optimum conditions • Handle and dispose of pesticides responsibly
Other	• Adopt phase feeding of livestock • Maintain and enhance soil organic matter levels • Incinerate poultry litter • Relocate gates • Provide adequate slurry and manure storage	• Separate clean from dirty water • Manage / treat dirty water • Allow field drainage to deteriorate • Establish wetland

Source: DEFRA, 2006c



Source: DEFRA, 2007

River basin district	Catchment
South West river basin district	5. River Axe 12. Somerset Levels and Moors 13. Slapton Ley 16. West Cornwall Catchments 18. Exe Estuary 20. The Frome 22. Tamar-Tavy Estuary 24. Hampshire Avon System 26. Dorset Stour 27. River Camel Valley 38. Yealm and Erme Estuaries
Anglia river basin district	1. Bure Ant and Muckfleet 2. River Wensum 4. Yare and Waveney 9. North Norfolk rivers 10. Little Ouse (Thetford area) 14. Lincolnshire Coast rivers 15. Deben, Alde & Ore 17. River Nar 31. Gipping and Orwell
Severn river basin district	3. West Midlands Meres 7. River Lugg 23. River Wye (Welsh side only) 28. River Teme 36. North Somerset Moors
Humber river basin district	6. East Riding of Yorkshire and North Lincs 8. Yorkshire Ouse, Nidd and Swale 21. Yorkshire Derwent 30. Peak District Dales of West Midlands and East Midlands 39. River Eye
South East river basin district	29. Rivers Test and Rivers Itchen 35. Eastern Rother 37. The Stour 40. Pevensey
Solway and Tweed river basin district	19. River Waver and Biglands Bog 25. Tweed Catchment rivers 32. River Eden and tributaries
Thames river basin district	33. Rivers Lambourn and Kennet of South West and South East

Figure 9.3: List and map of priority areas under the England Catchment Sensitive Farming Delivery Initiative (ECSFDI)

According to the catchment priority list in Table 9.7, many issues reported in the ECSFDI scheme associated with maize cultivation cover both on-site and off-site environmental problems. These include soil erosion and runoff problems from steep slopes and lighter soils with less or no surface cover due to heavy rainfall during winter. In addition, attention is direct to diffuse pollution in the watercourses, and especially phosphorus, nitrogen and sediment problems, which degrade the water quality. Furthermore, based on the justification of such problems, as well as slope gradient and soil type, the connectivity of most maize fields to watercourses is also identified as a main contributor to diffuse water pollution in some priority catchment priority areas. All of these factors should be taken into account by maize growers in order to prevent soil erosion and protect the river or other watercourses from diffuse pollution.

9.5 The Agri-Environment Scheme (AES) and Code of Good Agriculture Practise (COGAP)

The Agri-Environment Scheme (AES) was introduced in 1987 by the Ministry of Agriculture, Fisheries and Food (MAFF) as a voluntary scheme to enable farmers to protect and enhance the rural environment in terms of biodiversity, landscape and historic features, and to promote public access in designated areas of high environmental value. In addition to this scheme is the Countryside Stewardship Scheme (CSS), which involves a similar approach to the AES, but differs in that the CSS has no designated areas. The AES has been reviewed and is still working simultaneously with the ESS. The concern of the AES is for improved environmental management, rather than greater income from farming itself, but it rewards through a ‘positive incentive’ payment approach that promotes environmentally friendly practises in farming.

Table 9.7: Some examples of the environmental issues associated with maize cultivation in the ECSFDI scheme.

Priority problem/issue	Description	Justification
4. Waveney Soil erosion from steeper slopes/lighter soil arable fields along Waveney River terraces.	Relatively small areas of glacial sandy soil with slopes greater than 3^{o} particularly those with **maize** and root cropping.	Data analysis has highlighted these areas and soil risk assessment makes them high risk.
5. Rivers Axe and Otter (Upper Otter) Phosphates and sediment.	A steep, highly connected catchment dominated by soils with high clay and silt content. In association with high rainfall, this topography leads to poor drainage and high levels of runoff. Land use is dominated by dairy farms, some of which have manure, management and infrastructure problems. **Maize** is being increasingly grown for silage.	Although the RQO failure may not be as serious as it seems, this is the only stretch of river within the catchment that has failed RQO with diffuse pollution implicated as a source. This area of the catchment has received little landcare support in the past when compared to other parts and may benefit greatly from CSF interaction.
9. North Norfolk Rivers High risk crops for soil erosion including spring-sown cereals, field vegetables, sugar beet, **maize**, potatoes and pigs.	These crops are considered high risk due to the nature and timing of their operating, thus resulting in land being left bare during periods of high rainfall. This may result in soil erosion and runoff into watercourses, either through field drains, onto roads, and into fords, or directly into watercourses.	Anecdotal evidence and modelled data has identified this area as high risk due to soil types, slopes, connectivity to watercourses and land use. This problem can realistically be tackled within the scope of the CSF programme, through soil erosion workshops for farmers, one to one advice and the capital grants scheme.
10. Headwaters of Wissey and Little Ouse Sediment deposition is caused through soil erosion and soil wash from steeper slopes/lighter soil and areas of heavier soils in arable fields. Fen and sand blows occur when soils are dry and subject to a lack of crop cover.	Relatively small areas of sandy soils with slopes greater than 3^{o}, particularly those with **maize** and root cropping.	Data analysis has highlighted these areas and soil risk assessment makes them high risk.
17. River Nar and Great Cressingham Fen High risk crops for soil erosion including spring-sown cereals, field vegetables, sugar beet, **maize** and potatoes.	Site entering watercourses via runoff from fields / farm tracks to roads, and fords, and via under drains on heavier land. This is an issue throughout the target area.	Anecdotal evidence and modelled data has identified this area as high risk due to light soil types which are easily eroded, heavier soil types which are drained, steeper slope, high connectivity to watercourses, and high risk land uses. This problem can realistically be tackled within the scope of the CSF programme through soil erosion workshops for farmers, one to one advise and the capital grants scheme.

Continue in next page

19. River Waver and Wampool Increased popularity of **maize** growing across the catchment.	Maize growing has become increasingly popular over the last few years with improvements in varieties. The extent to which this is occurring across the catchment has not been recorded.	With improving varieties and potential to grow **maize** across the catchment, it may become more prevalent on increasingly inappropriate land. Note may need to be taken on the slopes and soil types on which **maize** is appearing.
20. South West (Upper Frome) Phosphorus and sediment.	A tributary much like the Hooke with more intensive agriculture, particularly higher concentration of **maize** and other arable.	Pollution situation in this rural catchment is uncomplicated, however there is a short and minor involvement of the Landcare programme in the past that should be built on before it becomes to old. There are existing contacts and support structures from the Landcare programme that can be built on.
21. Yorkshire Derwent (Helmsley and upper Rye catchment) Runoff and sediment.	Extensive areas of winter wheat, **maize**, potatoes and other arable crops establishment on a variety of gradients including steeply sloping land, and soil types including sandy loams and shallow lime rich soils.	High rainfall (837 to 1021 mm) combined with steep gradients and the soil types of the area can result in some agricultural land generating high runoff bringing very high volumes of sediment into the River Rye and the Derwent River system.
23. River Wye (excluding Lugg) Agricultural diffuse pollution from **maize** growing.	**Maize** is harvested in the autumn and land is left bare over the winter with just the stubble present, this land is often used as an area to dispose of slurry / muck in the winter months.	Improved management of **maize** ground could provide benefits with regards to less muck / slurry runoff and less soil erosion.
36. North Somerset Moors (Congressbury Yeo) Phosphate, sediments and nitrogen.	Steep slopes on the Mendip Hills and Broadfield Down. Areas of intensive dairy pigs, poultry and **maize** with the high conservation value Blagdon Lake SSSI.	This sub-catchment contributes sediments and nutrients to the catchment, eventually flowing into Blagdon Lake SSSI. This catchment is relatively rural with most pollution likely to arise from agriculture. However, there are many small villages and two STW's present. Presence of significant amounts of duckweed and algae indicate nutrient enrichment. This sub-catchment has received little targeted Diffuse Pollution advice in the past or present, so there is a real opportunity here to have an impact.

RQO – River Quality Objective

Source: DEFRA, 2006c

Basically, the AES requires farmers to meet the farming management and practices required by the Code of Good Agriculture Practice (COGAP). This code is designed to provide practical guidance to support farming activity in terms of avoiding landscape damage and pollution. It covers three components; (i) water, (ii) air, and (iii) soil. Farmers, agricultural contractors and land owners are required to be more aware of their responsibility in protecting these components from serious environmental damage and pollution. In addition, the codes describe the main risks of causing damage and pollution associated with different arable practises and promotes the adoption of good agricultural practises that minimize the risk of causing damage and pollution.

In the case of maize cultivation, the codes for water and soil are the most important to take into account in farm management and farming practices. The Code of Good Agricultural Practise for the Protection of Soil (COGAP-POS) is a practical guide to avoid causing long-term damage to the soils and it provides guidance to maintain and increase the ability of soil to support plant growth. This code covers six elements; (i) soil fertility, (ii) soil compaction, (iii) soil erosion, (iv) soil mixing, (v) soil contamination, and (vi) restoring disturbed soils. Table 9.8 summarizes some of the early action that farmers, contractors and farm owners have to take into account in managing their farm and arable land. In relation to maize cultivation, maize growers have to give more attention to the soil erosion and soil compaction elements to protect the soil from soil erosion impact and soil compaction damage. This includes avoiding growing maize on susceptible sites, such as steep slope and light soil, and reducing runoff by protecting bare ground after harvest with undersown cover crops or other practical measures[15].

[15] Details on soil erosion protection as suggested in COGAP-POS can be found in paragraph 63-75 from COGAP-POS guideline (MAFF, 1998a)

Table 9.8: A summary of the key elements in the Code of Good Agricultural Practise for the Protection of Soil (COGAP-POS)

Elements	Guidance
Soil fertility	• Maintain or enhance the chemical and physical fertility of the soil (Paragraphs 30-33, and 46-49) • Aware soil acidity and liming level (Paragraphs 34-45) • Aware soil nutrient contents (Paragraph 43)
Soil compaction	• Aware land capability and soil ability to cultivate (Paragraphs 51-52) • Avoid unsystematic harvesting practises (Paragraphs 53-54)
Soil erosion	• Consider possibility of soil erosion in farming processes (after ploughing, crops growing periods, after harvested) (Paragraphs 63-65) • Apply appropriate management to reduce the risk of water erosion and runoff (Paragraphs 66-75)
Soil mixing	• Avoid deep cultivation (Paragraphs 88-91) • Plan carefully for the disturbance soil (Paragraphs 92-93)
Soil contamination	• Recognize potential of contamination sources (organic and inorganic) (Paragraphs 96-101) • Get expert advice to manage contaminant soil (Paragraphs 102-112)
Restoring disturbed soils	• Action must be taken during agricultural after care (cropping, cultivations, lime and fertilizer, drainage, sub-soiling, grazing management and monitoring) (Paragraphs 181-201)

Source: MAFF, 1998a

The Code of Good Agricultural Practise for the Protection of Water (COGAP-POW) is a guideline to avoid causing water pollution from different agricultural and horticultural sources. This code covers 12 elements[16] but in the case of maize cultivation, they have to give more attention to the nitrate and phosphorus code, associated with soil erosion and diffuse pollution from maize fields.

[16] The 12 elements of the COGAP-POWs' are; (i) farm waste management planning, (ii) slurry, (iii) dirty water, (iv) solid manure, (v) silage effluent, (vi) fertilizer, (vii) fuel oil, (viii) sheep dip, (ix) pesticides, (x) disposing of animal carcases, (xi) nitrate and phosphorus, and (xii) specialized horticulture (MAFF, 1998b)

9.6 The Water Framework Directive (WFD) and Diffuse Water Pollution from Agriculture (DWPA)

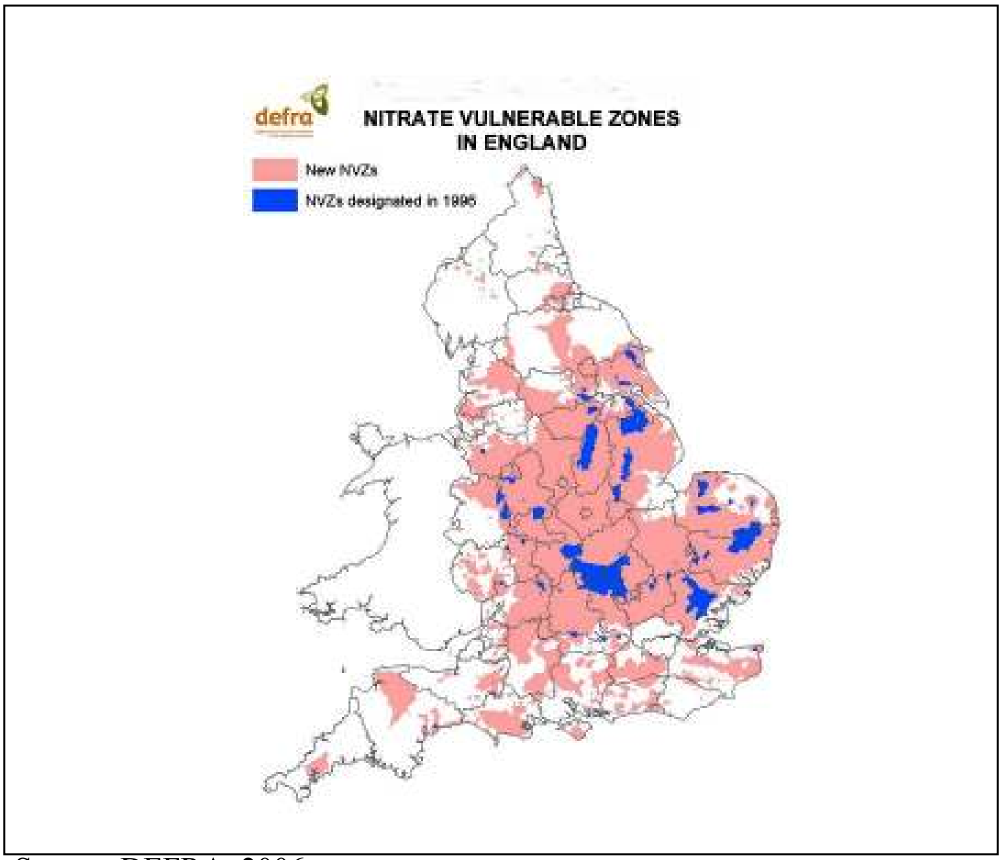
It is generally accepted that the agricultural sector is a major contributor to diffuse water pollution problems as a result of poor farm management practises. 'Diffuse water pollution from agriculture' differs from 'non-point pollution', and Silcock *et al.* (2004) defined it as "pollution arising from agricultural land-use activities that are dispersed across a cathcment, or sub catchment, and do not arise as a process effluent, municipal sewage effluent or effluent discharge from farm buildings." Based on the European Union Water Framework Directive (EUWFD), the United Kingdom WFD target is to have 'good ecological status'[17] by 2015 rather than just water quality targets based on chemistry indicators. Under the WFD, all water bodies, (rivers, lakes, transitional waters and coastal waters) have to satisfy certain chemical and hydromorphological criteria set in Annex V of the WFD. Four agencies are responsible for implementing the WFD in the UK, and DEFRA, in cooperating with the Environment Agency (EA) are responsible for England.[18]

The main water pollutants associated with agriculture that become targets in the WFD in the UK for achieving 'good ecological status' are; (i) nitrogen and phosphorus, (ii) siltation, (iii) organic waste, (iv) pesticides, (v) veterinary medicines, and (vi) micro-organisms. To support the WFD associated with DWPA, River Basin Management Plans (RBMPs) have been introduced and River Basin Planning Guidance (RBPG) can be use to guide actions needed to fulfil the WFD requirements. In addition, to support

[17] The 'good ecological status' of water quality is based on the ecological structure of natural systems, and the good ecological standards are set to the ecological conditions of **reference condition,** which ecological status standards and chemical standards of 'good status' vary between water bodies and regions or areas (MAFF, 1998b)

[18] Besides England, the implementing agency of the WFD in Scotland is the Scottish Executive co-operating with the Scottish Environment Protection Agency, the Welsh Assembly Government for Wales, co-operating with EA, and the Department of the Environment Northern Ireland co-operating with Environment and Heritage Service in Northern Ireland for Northern Ireland (Green and Fernández-Bilbao, 2006)

reducing DWPA associated with the nutrient problem (nitrogen and phosphorus), DEFRA also launched the Nitrate Vulnerable Zones (NVZ) in England, co-operating with the EA to monitor the level of nutrients in surface freshwater[19], groundwaters[20] and natural freshwater bodies[21]. In total, 55.0% of England was designated as a NVZ in 2002 and the area of the NVZ can be seen in Figure 9.4



Source: DEFRA, 2006c

Figure 9.4: Map shows the Nitrate Vulnerable Zones in England

In the context of maize cultivation, the primary concern of the WFD regarding the DWPA is pollution by atrazine. This pesticide is the mainstay of weed control in maize cultivation. The main problem caused by atrazine is the risk of contamination of groundwater. In addition, as discussed in a previous section of this chapter, most maize

[19] The concentration of nitrate in surface freshwaters should not be more than 50 mg/l.
[20] The concentration of nitrate in groundwaters should not be more than 50 mg/l.
[21] The indicator nitrates pollution in the natural freshwater is based on eutrophication.

fields are left bare during winter, and subject to the risk of water erosion and runoff, which can pollute watercourses with nutrients, pesticides and sediment. These pollutants are also of concern under the WFD to reduce the off-site impact of maize cultivation.

9.7 Discussion and Recommendation

Sections 9.2 to 9.6 review various environmentally friendly schemes in England designed to achieve the CAP and WFD objectives, and aimed more generally at achieving a better landscape and good ecological condition across the country. In general, the CAP and WFD targets and requirements involve interaction between human and physical aspects to maintain and enhance good environmental quality for both habitats and landscape. Agriculture has become a major sector in England, contributing to environmental problems in many ways and increasing the cost of conservation and rehabilitation.

The SFPS-SPS, ESS-ESAs, CSF-ECSFDI, and AES schemes should be seen as supporting schemes for the CAP and WFD targets. Each scheme is implemented simultaneously, and farm or land managers and farmers are advised to follow several guidelines in each scheme (GAEC, SMRs, SPR, SMP, FER, FEP, RBPG), which are also based on COGAP-POS and COGAP-POW, to qualify their payment claims. In the case of maize growers, all these guidelines and requirements should prove very useful in preventing water erosion and runoff from maize fields, and should reduce diffuse pollution to adjacent watercourses caused by soil erosion and transport of nutrients, pesticides, and sediment by runoff. These guidelines require maize growers to establish their cultivation plan before they start ploughing the land and sowing the seed, and to practice post-harvest planning to avoid environmental problems associated with soil erosion and diffuse pollution.

To summarize, maize growers have to avoid growing maize on fragile land susceptible to water erosion and runoff, especially in high risk areas. Fragile land refers to light soils, which are susceptible to soil detachment caused by rainfall impact and promotes soil erosion. In addition, they should avoid steep slopes as this encourages runoff, and transportation of sediments and nutrients to nearby watercourses. After harvest, maize growers are advised to cultivate winter crops or surface cover with grass to reduce the impact of raindrops. The risk assessment also requires maize growers to plan crop rotations and minimize exposure of bare land to the effects of rainfall by considering the type and timing of maize cultivation. Harvest contractors are advised to harvest maize based on strips across the slope to reduce runoff impact.

Soil compaction can readily occur on vulnerable fields and this can also increase runoff and soil erosion rates. In order to avoid this problem, maize growers are advised to choose early-maturing maize varieties to allow an early harvest. Some of the top quality early-maturing maize varieties are *Caruso, Target, Pernel, Diplomat, Meribel, Spartacus, Santiago, Kroesus, and Kwiss* (Huntseeds). Huntseeds Ltd. provides a guide to choosing the correct early-maturing varieties to meet the physical conditioning and harvest dates for several counties in England and Wales as shown in Table 9.9. In order to cover the bare surface after harvesting, maize growers frequently cover the surface with animal waste to encourage grass to grow. Based on the author observation during soil sampling, many farmers practised this method, which is a relatively easy and cheap approach to protecting the fields based on farmers' perception. However, this practise may contribute to diffuse pollution through movement of organic waste to watercourses when runoff occurs.

Table 9.9: An example of choosing correct early-maturing maize based on maturity score

What is your target harvest date?	Sept 15th to 22nd **3**	Sept 23rd to 30th **2**	Oct 1st to 7th **1**	Oct 8th to 15th **0**	
What is your target drilling date?	April before 10th **0**	April 10th to 20th **1**	April 21st to 30th **2**	May 1st to 10th **3**	May After 10th **4**
What is the altitude of the field?	Feet 0-149 **0**	Feet 150-299 **1**	Feet 300-449 **2**	Feet 450+ **3**	
What type of soil do you have?	Light Fine **0**	Medium Good **1**	Heavy Cloddy **2**	Very Heavy Very Cloddy **3**	
What is your annual rainfall?	Low 10" - 27" **0**	Medium 28" - 39" **1**	High 40" + **2**		

County	**Score**		**County**		**Score**
Berkshire	**0**		Lincolnshire		**1**
Buckinghamshire	**0**		Norfolk		**0**
Cambridgeshire	**-1**		Northamptonshire		**1**
Cheshire	**1**		Nottinghamshire		**1**
Cumbria	**2**		North & Mid Wales		**2**
North Devon/Cornwall	**2**		Oxfordshire		**0**
South Devon/Cornwall	**0**		Scotland		**3**
Derbyshire	**2**		Shropshire		**0**
Dorset	**0**		Somerset		**0**
Durham	**2**		Staffordshire		**1**
Essex	**-1**		South Wales		**1**
Gloucestershire	**0**		Suffolk		**0**
Glamorgan	**1**		Surrey		**0**
Gwent	**1**		Sussex		**-1**
Hampshire	**-1**		Warwickshire		**1**
Herefordshire	**0**		Wiltshire		**0**
Hertfordshire	**0**		Worcestershire		**1**
Kent	**-1**		Yorkshire (North)		**2**
Lancashire	**1**		Yorkshire (South)		**1**
Leicestershire	**1**			**County Score Here >**	
	Now add them up for your maturity group =				

Source: Huntseeds

All guidelines under the above schemes are clearly useful in promoting an environmentally friendly approach by maize growers to reduce on-site (soil erosion and runoff) and off-site (diffuse pollution) impacts. All these requirements are considered sufficiently environmentally friendly to conserve and rehabilitate the soil and watercourses from soil erosion and diffuse pollution caused by maize cultivation in England. 'Big rewards' are given to maize growers who participate in the AES. These guidelines can be an important incentive in the future to encourage them and other maize growers to take serious action in helping the country to promote sustainable landscape and habitats.

To ensure that maize growers are fully aware of their responsibility to support the national targets on environmentally friendly and sustainable development of both the landscape and habitats, there is a need to raise awareness of the issue among them. Farmers should have ready access to information regarding the environmental problems associated with maize cultivation, to permit them to develop a clearer understanding of these problems and potential approaches for reducing them. Based on the author's experience during a field programme of maize field mapping undertaken in 2004, many farmers complained of difficulties in obtaining access to information on guidelines, and beyond this there is a need to provide both consultation and advice, especially with regard to managing their land using environmentally friendly approaches as mentioned in the guidelines. Many farmers do not have access to the internet or probably do not want to use this technology, which can provide them with a free guidelines document. DEFRA and related agencies need to be more active in organizing meetings, probably at the parish or community level, and for farm associations, to provide relevant information and advice on following the guidelines. This must be seen as a first approach to disseminating the information from the top or from the decision maker level to farmers at the ground level.

In addition, maize growers need to assume greater environmental responsibility when planning to grow maize, particularly in terms of developing a strategy to protect the soil and reduce runoff, that suits the local soil type and slope steepness. Existing guidelines advise maize growers to protect the soil surface during winter by growing winter crops or grassing the surface. On top of this, with regard to winter cropping, they are recommended to undertake chisel ploughing, which can increase water infiltration, thereby reducing runoff, and retaining nutrients. These approaches have already proved to be effective in reducing runoff and soil loss (Clements and Donaldson, 2002; Clements and Lavender, 2004).

In the case of growing grass as a surface cover, based on the author's observations and interviews with maize growers, many of them apply animal wastes (especially cow waste) in order to encourage grass to grow faster and as an early input of organic fertilizer in advance of the growing season in spring. However, this practise could increase pollution problems, as the waste could be transported by runoff to nearby watercourses. The existing guidelines do not incorporate this matter, except in advising farmers to apply appropriate amounts of fertilizer, including organic fertilizer, during crop growth. Maize growers should be advised to practice a similar approach to that which they are told to follow during the growing period. This would involve applying animal waste at an appropriate rate to each bare maize field for the purpose encouraging the growth of grass after harvesting. Farmers are also advised to apply ryegrass as demonstrated by Van Dijk *et al* (1996a), since it is effective in reducing surface runoff and soil loss during winter.

Based on the author's observations during field mapping, maize fields are often located in a sequence running from the top to the bottom of the slope, one below the other. Maize growers should avoid this practise when growing maize on steep slopes, because it could increase the volume of runoff and also promote channelization and thus increased flow velocity when runoff from upslope reaches the second field. This could increase surface erosion and transfer more sediment to adjacent watercourses. The author's observations also indicated that many maize growers plant maize from the top to the bottom edges of the field. At the bottom of the slope, especially for steep slopes, maize growers are advised to leave a strip of vegetation cover to act as a sediment trap. This natural trap can also slow down the runoff before it reaches a watercourse. Maize growers can also construct detention ponds between two fields to reduce runoff on the second field.

In order to reduce the impact of soil compaction on soil erosion caused by heavy harvest machinery, farmers are advised to deal with harvest contractors who to avoid the use of wheel tractors and employ rubber-tracked vehicles. Keller *et al*. (2002) demonstrated that rubber-tracked reduced subsoil compaction by reducing vertical stress and soil displacement. However, farmers are also advised to consult with their harvest contractor regarding use of rubber-tracked vehicles, in order to take account of the soil type and field conditions.

9.8 Conclusion

This chapter has reviewed and discussed current policy associated with maize cultivation management in England. The CAP and the WFD are considered to represent the key legislative drivers in terms of protecting soil from water erosion and runoff, and in reducing diffuse pollution into watercourses. In order to support both areas of legislation, various environmentally friendly schemes have been introduced under the agri-environment scheme. This scheme offers very big rewards, in terms of payment, for maize growers that can practise environmentally friendly approaches, as suggested in various schemes under the AES. However, the effectiveness of these schemes in preventing and protecting land and soil, and watercourses, especially rivers, from soil erosion and diffuse pollution associated with maize fields will be heavily dependent on the attitude of land managers, farmers and harvester contractors in understanding the targets of the CAP and the WFD, and co-operation within DEFRA, EA and other related agencies to support the AES. In addition, maize growers and harvesters also have to change their current unfriendly environmental practises in growing maize, as emphasised by the government and recommended by the author.

CHAPTER 10: CONCLUSION

10.1 Introduction

The main objective of this research was to investigate the soil erosion problem associated with maize cultivation in England. Maize cultivation, generally has been identified as a key cause of river pollution during the winter period and more particularly of increasing fine sediment loads which cause degradation of aquatic habitats and ecosystems. These problems are frequently linked to land mismanagement and environmentally unfriendly attitudes among farmers and harvest contractors. Growing maize as a fodder crop has expanded rapidly in England, especially between 1990 to 2000. Furthermore, maize cultivation is primarily undertaken to support dairy farming where maize silage is used to feed dairy cows.

Most of the areas of major expansion of maize cultivation and its intensive production during the 1970s to the early part of the 2000s were located in the Southwest and Southeast regions. Together, these regions accounted for ca. 61% of the area of maize cultivation in England in 2003. This study was also narrowed down to the catchment scale and analysed the spatial and temporal patterns of maize cultivation in the Culm Catchment in Devon and the Tone Catchment in Somerset, both in the Southwest Region. Spatially, most of the maize fields in the Culm and Tone catchments occurred in the middle and downstream parts of the catchments, and ca. 60% of the maize fields can be found located within 100 m from the river systems. This could in itself be a key factor in any investigation of the link between sediment input for maize fields and increased suspended sediment loads in the river systems.

In order to understand the soil erosion problems associated with maize cultivation in England, this research has attempt to quantify the magnitude of the soil erosion rates associated with maize cultivation. This investigation of soil erosion rates was at the field level using fallout radionuclide techniques. ^{7}Be measurements were used to obtain estimates of short-term erosion rates associated with previously harvested maize fields during the winter of 2004-5, and ^{137}Cs measurements were used to obtain estimates of longer-term (i.e. ca. 45 years) average rates of soil loss from the same fields under the more traditional land use of the past. Comparison of the two erosion rate estimates afforded a means of assessing the magnitude of the increase in erosion rates associated with maize cultivation. The study focused on six fields, with three located in the Culm catchment in Devon and three in the Tone Catchment in Somerset.

In addition, a further investigation of suspendent sediment problems in the River Culm and River Tone was undertaken, in order to assess the likely contribution of the sediment contribution from the maize fields in these two river basins to their suspended sediment loads. A river monitoring programme was undertaken at the outlets of the two study catchments during the winter period extending from November 2004 to March 2005. This monitoring programme provided further information on the likely role of maize cultivation in contributing to the suspended sediment loads of the Rivers Culm and Tone.

This final chapter aims to summarize the research findings of the study and their potential contribution to the agriculture sector, especially in England and the United Kingdom, in terms of management aspects associated with preventing soil erosion and reducing sediment inputs to river systems caused by maize cultivation. In addition, this chapter will discuss some recommendations which might be followed in the future to obtain an improved understanding of the impact of maize cultivation in England.

10.2 Maize Cultivation in England: Spatial and Temporal Characteristics and Trends

In this component of the study, spatial and temporal patterns of maize cultivation were analysed at the national and regional scales. Data on maize cultivation were obtained from the EDINA data centre at Edinburgh University, for selected years during the period extending from the 1970 to 2000 and these data were analysed using the Geographical Information System (GIS) of ArcMap, version 8.3, to characterize the spatial and temporal patterns of maize growing in England. For the analysis of temporal patterns, data were also obtained from the DEFRA website and were in Excel for trend analysis.

The results of the analysis undertaken showed that over the past *ca*. 15 years since 1990, the area under maize cultivation had increased by 223% by 2004. Compared to 1970, the increase in the area under maize had increased 10,640% by 2004. Several factors were identified as a major causes of expansion of the area under maize cultivation in England, however, the EU Common Agricultural Policy (CAP) appeared to be the most important. This can be related to market price support and aid in terms of income support, in the form of area payments under various schemes, such as the Arable Area Payments Scheme (AAPS) and the Single Payment Scheme (SPS). In addition, expansion of dairy farming in the United Kingdom, and also England, since the 1970s, was identified as a further cause of the expansion. This can be related to the increased demand for forage to support *ca*. 2 million dairy cows in the 1990s and *ca*. 1.5 million dairy cows in the early 2000s.

Although maize has been grown as a fodder crop in England since 1970, the area involved was initially small, covering an area of less than 10,000 ha. However, the area of maize cultivation expanded rapidly in the 1980s, 1990s and 2000s, with decadal increases of ca. 87%, 297% and 63%, respectively. It is also important to note that the area of maize cultivation in England evidenced very rapid expansion between 1990 and 1995, when all regions in England, with the exception of the eastern region, showed a greater than 100% increase in their area under maize cultivation. The Southwest, Southeast and West Midlands regions were identified as an important area of maize growing in England since the 1970s.

In the context of maize cultivation in the Southwest region, the counties of Somerset, Dorset and Devon had the largest areas cultivated with maize in the 1990s and 2000s. However, in the 1970s and 1980s, maize growing was only important in Somerset, Dorset and Wiltshire. By 2000, the area of maize cultivation in the Southwest region had expanded by 182%, when compared to 1990. In addition, the increase in the density of maize cultivation in the three most important counties in the 2000s, showed a similar trend to the increase in the number of dairy cows, which increased by ca. 3,587% between 1990 and 2000 (see Table 4.2).

10.3 Rates of Soil Loss Associated with Maize Cultivation in England

Fallout radionuclide measurements have been used to assess the magnitude of soil erosion rates associated with winter rainfall on bare post-harvest maize fields in six study fields located in the Culm and Tone catchments. Measurements of short-term rates of soil erosion have been undertaken using ^{7}Be fallout, whilst the ^{137}Cs measurements have provided estimates of longer-term (i.e. *ca*. 45 year) erosion rates associated with more traditional land use. Soil sampling was conducted on maize fields which had been used for maize cultivation for at least three years in a row since 2002. A profile distribution model was used to convert the ^{7}Be measurement into estimates of soil redistribution rates and a mass-balance model (Mass Balance Model 3 of Walling and He (1999)) was used to derive the estimates of longer-term erosion rates from the ^{137}Cs measurements. The findings suggested that on average maize cultivation caused the gross and net erosion rates to increase by *ca*. 4 and 8 times, respectively, with the associated sediment delivery ratio increasing by *ca*. 2 times (refer to Table 6.7). The increase in the sediment delivery ratio and thus the greater increase in net erosion rates is of particular significance in terms of increasing delivery of sediment to the stream channels. However, it is important to recognize that these results relate only to a specific year i.e. the winter of 2004-5. Both higher and lower values of soil loss could be found on the maize fields in other years, depending on the winter rainfall conditions. Conditions in 2004-5 were judged to be ‘average’ and the results are therefore seen to provide a worthwhile general indication of the rates of soil loss involved. Equally, it must be recognized that the estimates of longer-term soil loss associated with the ^{137}Cs measurements themselves include several recent years with increased soil loss resulting from maize cultivation and thus that the estimates of the degree to which maize cultivation has increased soil losses could be seen as underestimates. Overall, the results of this component of the study highlight the potentially high rates of soil loss associated with bare maize fields after harvest and thus their potential significance as a source of increased sediment input to stream channels.

In considering the wider implications of the results outlined above, it is important to consider key features of maize cultivation in England, which appear to increase the potential for high rates of soil loss and sediment delivery to stream channels. As noted in Chapter 8, most of the area of maize cultivation in England occurs on soils (e.g.

sandy loam types) that are particularly susceptible to erosion by rainfall. In addition, many maize fields are located relatively close to watercourses and are characterized by relatively steep and long slopes. These factors are likely to increase the erosion risk and the efficiency of sediment delivery to watercourses.

10.4 The Contribution of Maize Cultivation to the Suspended Sediment Loads of Local Rivers

An investigation of the suspended sediment loads transported by the Rivers Culm and Tone was conducted during the winter of 2004-5. The investigation attempted to provide an assessment of the likely importance of sediment inputs mobilized from eroding maize fields to the sediment loads exported during the winter period from the two catchments. This has been achieved by establishing a sediment monitoring and sampling programme at the downstream gauging station over the period November 2004 to March 2005.

The findings confirmed that values of suspended sediment concentration (SSC) and turbidity (T) are closely related for the River Culm and River Tone, with high r^2 values of *ca*. 0.98. Average values of SSC estimated for both rivers were *ca*. 30-50 mg l^{-1}, indicating that the rivers are relatively turbid and that they transport a considerable amount of suspended sediment during the winter period. The records of SSC obtained for both rivers were used to estimate the suspended sediment loads for the study period. These were in the range 2,600-3,200 tonnes, and therefore equivalent to suspended sediment yields of 14.2 t km^{-2} and 12.8 t km^{-2} for the catchments of the River Culm and Tone, respectively.

Any attempt to compare these estimates of the sediment load of the Culm and Tone catchments with the likely sediment input from the maize fields in the two catchments, based on the estimates of rates of net soil obtained from the ^{7}Be measurements must attempt to take account of both the conveyance losses associated with transfer of sediment from the field boundary to the stream and the reduction in the sediment load of the river due to conveyance losses associated with sediment deposition within its channel. By taking these losses into account and also by considering the relative magnitude of rates of net soil loss from the maize fields and fields under other land use in the study catchments, it was tentatively concluded that potentially *ca*. 50% of the suspended sediment loads transported by the Rivers Tone and Culm during the winter period could be contributed by eroding maize fields. However, further work is required to substantiate and refine these estimates and calculations.

In an attempt to confirm the above conclusions regarding the importance of maize fields as a source of the suspended sediment loads transported by the two study rivers, the geochemical properties of representative samples of surface soil collected from maize fields were compared with those of the suspended sediment transported by the two rivers. Problems of comparability associated with contrasts in grain size composition and organic matter content between the suspended sediment and source materials samples, as well as the limited number of geochemical properties that it was possible to consider, necessarily limited the degree to which any definitive conclusions could be drawn regarding the importance of sediment contributions from maize fields. The information on Cr, Cu, Fe, Pb-206, Pb-207 and Pb-208 concentrations, nevertheless, provided some evidence that the sediment transported by the two rivers could have been mobilized from the maize fields during the winter periods. Overall, the conclusions based on a comparison of the geochemical properties of sediment transported by the rivers and those of potential source material from the maize fields proved inconclusive, but equally the findings were generally consistent with a scenario where the maize fields were an important source.

10.5 The Environmental Impact of Maize Cultivation in England

This study also attempted to provide a general national-scale assessment of the environmental impact of maize cultivation in England, with particular emphasis on increased sediment inputs to rivers. This assessment was linked with the national-scale information on the efficiency of sediment delivery from agricultural land provided by McHugh *et al*. (2002). Based on the national scale maps of connectivity index and connectivity ratio, it was clear that there is a clear link between those areas where the maize cultivation is denser, and those areas with a high sediment delivery efficiency and thus an increased risk of sediment transfer to watercourses. Similar analysis involving erosion vulnerability maps also demonstrated that most areas of maize cultivation in the Southwest, Eastern and West Midlands were located in areas with erodible soils that are accepted to be vulnerable to the risk of erosion.

Further analysis was conducted to analyse possible links between diffuse pollution of rivers and maize cultivation. The results indicated that, in general, the areas with the highest risk of phosphorus loss are also closely linked with areas of intensive maize cultivation and thus increased transfer of fine sediment to local watercourses. In the case of Southwest England, where dairy farming is important, the high concentration of phosphorus in the rivers could be, at least in part, directly related to maize cultivation.

10.6 Maize Cultivation Management in England

As demonstrated by the review of existing understanding and information and the results obtained from this study, it is clear that maize cultivation has significant negative impacts on the environment. This negative impact is associated with soil erosion problems at the field level and increased transport of suspended sediment by local rivers. The study therefore attempted to review current policy associated with agricultural land management in England, in general, and maize cultivation, in particular. This review focused on the Common Agricultural Policy (CAP) and the Water Framework Directive (WFD). These aim to promote sustainable and environmentally friendly approaches to land management, in order to reduce both the on-site and off-site impacts of farming activities and maintain good ecological status in rivers and aquatic ecosystems, rather than being specifically directed at maize cultivation.

Many schemes, such as the Single Farm Payment Scheme (SFPS), the Environmental Stewardship Scheme (ESS) and the Catchment Sensitive Agri-Environment Scheme (AES) are directed to achieving and supporting CAP and WFD targets. Thus specific schemes and environmentally friendly guidelines, such as the Good Agricultural and Environmental Condition (GAEC) and the Soil Protection Review (SPR) could prove very useful in preventing water erosion and runoff from maize fields and therefore reduce suspended sediment inputs to nearby watercourses.

10.7 The Wider Contribution of the Study

Although the general problem has been recognized for more than a decade, soil erosion and diffuse pollution of watercourses associated with maize cultivation in England has not been well documented, when compared with work on other crops. Only very few studies have been undertaken in England in order to understand the environmental impact of maize cultivation. These include the work reported by Walling et al. (1999a), Clements and Donaldson (2002), and Clements and Lavender (2004). The study by Walling *et al*. (1999a) was in many respects more advanced, since their study involved investigation of both on-site and off-site impacts of maize cultivation in Devon, whereas the studies by the other two authors focused primarily on on-site impact in terms of soil erosion control.

This study can be seen as providing additional scientific evidence and results to support previous findings by other researchers, in order to develop an improved understanding of the environmental problems caused by maize cultivation in England. As well as using the fallout radionuclide ^{137}Cs to provide estimates of longer-term erosion rates, this study also involved the use of ^{7}Be to estimate short-term erosion rates. Although others such as Blake *et al*. (1999) and Walling *et al*. (1999a) have used ^{7}Be to document short-term erosion rates associated with maize cultivation, that work involved only a single field and a short period of heavy rainfall. In this study, measurements were undertaken on six different fields located in the two study catchments and the timescale involved was longer, in order to capture the main period of heavy winter rainfall in December 2004 and January 2005. The increased number of study fields in this study provided a meaningful basis for obtaining representative information on likely gross and net erosion rates associated with post-harvest maize fields during the winter period, in the Culm and Tone catchments. The study has also provided further confirmation of the potential for using the short-lived cosmogenic fallout radionuclide, ^{7}Be, in soil erosion and sediment delivery investigations and particularly its conjunctive use with ^{137}Cs which is able to provide a longer-term perspective.

The findings from this study must be seen as important in terms of current land management agendas in England. As indicated in Chapter 9, the EU Common Agricultural Policy (CAP) and Water Framework Directive (WFD) are aimed at reducing both the on-site and off-site impacts of farming activities more generally, rather than maize cultivation in particular. However, in this wider context, the findings of this study clearly confirm the negative on-site and off-site impacts of maize cultivation in England and demonstrate the need for urgent action to avoid further environmental damage that could be caused by the poor land management practises of maize growers and harvest contractors. The various environmentally friendly schemes and guidelines that are being introduced in England should incorporate measures aimed specifically at reducing erosion on maize fields and thereby limiting the associated suspended sediment problems in river systems.

Furthermore, the findings of this study could also provide agricultural policy makers with clear evidence of the detrimental effects of maize cultivation in England on both soil erosion and diffuse source water pollution in river systems associated with maize cultivation in England. In general, the findings show that most of the areas of denser maize cultivation in England coincide spatially with soils that are susceptible to erosion and that maize fields are frequently located very close to watercourses. Since this study has demonstrated a close link between increased suspended sediment loads in rivers and sediment inputs from eroding maize fields, policy makers should recognize that there is an urgent need to ensure that farmers are actively advised not to grow maize too close to watercourses.

10.8 Recommendations for Future Work

Although this study is deemed to have fulfilled its original aims and objectives, it is also recognized that it has a number of limitations that could be addressed by additional work. Equally, the work undertaken has pointed to others areas of work related to the general topic and approach taken, which could usefully be developed. In these two contexts, some areas that could be addressed by future work include the following.

(1) The current detailed study of erosion rates and sediment transfer to rivers undertaken in the catchments of the River Culm and Tone is limited to a single winter. This represents an important limitation when viewed againts the natural variability of weather conditions from year to year. Further studies aimed at documenting additional years would provide more representative information on the magnitude of erosion rates associated with the exposure of bare post-harvest maize fields to heavy winter rainfall. In this context, it is important to consider both the conditions at the time of harvest, which will influence the degree of compaction and soil damage caused by harvesting machinery and the magnitude and timing of the subsequent winter rainfall.

(2) The quantitative assessment of erosion rates associated with eroding maize fields undertaken in this study was based on six fields. Although this number of fields was considerably greater than those involved in other work, it must nevertheless still be seen as limited. It was, however, not possible to increase the number of fields sampled within the constraints of the time and laboratory facilities available to the current study. However, provision of more resources, including both manpower and gamma counting facilities could in the future permit a greater number of fields to be studied. Investigation of a greater

number of fields would in turn provide more representative results. Furthermore, by covering a greater range of soil types, field sizes and topographic conditions it should be possible to develop a typology which could be used to extrapolate the findings to other fields and thereby obtain a more reliable assessment of the likely erosion rates associated with the entire area of maize cultivation within the study catchments. Furthermore, application of recent developments in the methodology for using ^{7}Be measurements to obtain estimates of rates of soil loss over longer periods, extending to several months (see Walling *et al*., 2009) would usefully provide information on soil loss for the entire winter period, rather than the main period of winter rain.

(3) It is accepted that the component of the study related to documenting the sediment loads of the two study rivers and attempting to link these to estimates of the sediment input to the river systems from maize fields involved a number of important limitations and uncertainties that precluded definitive conclusions. Further work is clearly required to expand the geochemical source fingerprinting component of the study that aimed to compare the properties of suspended sediment with those of source material collected from eroding maize fields. This should involve a greater range of source fingerprints, as well as greater attention to standardizing the grain size distribution and organic matter content between sediment and source material samples, in order to permit more definitive discrimination of maize fields as a potential sediment source. Equally, sampling of other potential sources would permit the use of a mixing model to provide quantitative estimates of the relative contribution of maize fields and other potential sources (e.g. Walling, 2005) and thus a more definitive assessment of the importance of eroding maize fields as a sediment

source. The uncertainties regarding the conveyance losses associated with field to river and in-channel/floodplain conveyance losses must similarly be seen as an important limitation of the current study. Further work could usefully attempt to establish a sediment budget for a small (e.g. 1 km^2) catchment in order to quantify the fields to channel conveyance losses for several maize fields. The information provided by the mapping of the location of the individual fields within the study catchments should also be incorporated into any assessment of field to channel conveyance losses, since these will clearly be influenced by the location of individual fields relative to the nearest water course.

(4) The work undertaken on the Culm and Tone Catchments is necessarily rather site specific and there is a needs to develop this further to use as a basis for a more general model of the contribution of eroding maize fields to catchment sediment yields for application within England. This modelling could usefully integrate new empirical field data on erosion rates associated with maize fields with existing information on the key controls of erosion rates (e.g. soil type, topography, annual rainfall etc.) to provide a basis for predicting rates of soil loss from eroding maize fields in different areas of the country. This could, in turn, be combined with an improved representation of slope-channel connectivity based on the empirical evidence assembled from further work in the study catchments. It should prove possible to substantially refine and improve the general approach adopted by McHugh *et al*. (2002) to take account of the particular conditions found in most maize growing areas and the magnitude of the potential soil losses. In their case, the estimation of conveyance loss was largely independent of the magnitude of the erosion rate.

(5) Although some suggestions for improved land management and erosion reduction measures have been made in this study, they are necessarily based primarily on a general appraisal of measures currently used across a range of land use types, although informed by some experimental work on maize fields (e.g. Clements and Donaldson, 2002; Clements and Lavender, 2004). However, if a strong case is to be made to implement such measures, it is important that clear empirical evidence of their efficacy should be made available. Farmers need proof that what they are asked to do will actually make a difference. Any future study could therefore usefully include some experimental work aimed at demonstrating the efficacy of various measures for reducing erosion and sediment delivery from maize fields.

10.9 Concluding Remarks

Maize cultivation has become one of the main causes of river pollution in England, in terms of increased sediment loads. This study has provided evidence of the high rates of both gross and net soil loss that can be associated with eroding maize fields and the links between such erosion and increased sediment loads in rivers. An eroding maize field caused by heavy rainfall during the winter period can lead to significant sediment inputs to the local river system and this increased sediment load can degrade the ecological status of the river. Because many of the areas of intensive maize cultivation in England coincide with areas of increased erosion risk, due the local soil type and of increased sediment delivery efficiency which increases the potential for eroded sediment to reach the river system, it is important that there should be a nationally coordinated strategy, underpinned by legislation, to control this important environmental problem.

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