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Impacts of climate change on the fate and behaviour of pesticides in surface and groundwater—a UK perspective

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Abstract

Over the last two decades significant effort has been dedicated to understanding the fate and transport of pesticides in surface water and groundwater and to use this understanding in the development of environmental policy and regulation. However, there have been few studies that have investigated the relationships between pesticides and climate change, and where this work has been undertaken it has principally been in relation to the impacts of climate change on agricultural production rather than in the context of environmental protection. This study addresses that gap by reviewing how climate change may impact the fate and transport of pesticides in surface and groundwaters as a pre-cursor to quantitative studies. In order to structure the review, we have adopted a source–pathway–receptor approach where climate sensitivities of pesticide source terms, environmental pathways and receptors are reviewed. The main climate drivers for changing pesticide fate and behaviour are thought to be changes in rainfall seasonality and intensity and increased temperatures, but the effect of climate change on pesticide fate and transport is likely to be very variable and difficult to predict. In the long-term, indirect impacts, such as land-use change driven by changes in climate, may have a more significant effect on pesticides in surface and groundwaters than the direct impacts of climate change on pesticide fate and transport. The review focuses on climate change scenarios and case studies from the UK; however, the general conclusions can be applied more widely.

Keywords: Pesticides; Climate change; Groundwater; Surface water; Source–pathway–receptor

1. Introduction

Significant research effort has been dedicated to understanding the fate and transport of pesticides in the environment, and the relationships between pesticide fate and transport and specific environmental parameters such as organic carbon and pH in soils are generally understood at least qualitatively (Bolvin et al., 2005; Johnson et al., 2004; Wauchope et al., 2002; Worrall et al., 2001). However, although there is an extensive peer-reviewed literature on the environmental impacts of climate change, particularly ecological impacts, there have been few studies investigating the relationships between pesticides and climate change, and where this work has been undertaken it has principally been in relation to the impacts of climate change on agricultural production, particularly in the United States of America (e.g., Reilly et al., 2003), or in the context of multi-sectoral studies (Holman and Loveland, 2002). To date there have been no studies published in the peer-reviewed literature that have

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specifically considered the impacts of climate change on pesticide fate and transport in the context of environmental protection. As there is now convincing evidence that the world's climate is changing and that these changes are not part of natural processes or cycles (IPCC, 2001; King, 2004), how could changes in the climate and predicted future variations impact on pesticide fate and transport?

Following the tiered approach to the assessment of climate change adaptation strategies recommended by UKCIP (2003), this study reviews how climate change may impact the fate and transport of pesticides in surface and groundwaters as a pre-cursor to quantitative studies (equivalent to Stage 3–Tier 1 of the UKCIP, 2003, methodology, to characterise the nature of the risks posed by climate change and to provide qualitative estimates of those risks). The review uses examples from the UK and so presents a UK-based perspective. However, the proposed framework and general conclusions can be applied more widely. A central question to be addressed by the study is how can relatively poorly constrained changes in future climates be used in any meaningful way to predict possible changes in the complex relationships between pesticide fate and transport and the many, often interrelated, factors that affect the behaviour of pesticides in the environment? One way to address this problem is to look at components of the system rather that the system as a whole. We have used this approach for the present study and have adopted the commonly used source–pathway–receptor approach where climate sensitivities of pesticide source terms, environmental pathways and receptors are considered and the potential impacts of future climate change on pesticide fate and transport are assessed to try and address this question.

Following a brief overview of climate change scenarios and of general possible impacts on agriculture in the UK, we present the source–pathway–receptor analysis. The results of the analysis are then discussed and considered in a broader socio-economic perspective. Although it is possible to identify the main climate drivers for changing pesticide fate and transport behaviour, as well as some of the important source, pathway and receptor responses, it appears that long-term land-use change driven by changes in climate may have a more significant effect on pesticides in the environment than the direct impacts of climate change on specific pesticide fate and transport processes.

2. Climate change scenarios and impacts on agriculture—a UK perspective

Climate change scenarios are coherent, internally consistent and plausible images of possible future climate that can be used as tools to analyse how possible future changes may affect the environment and the social, economic or institutional fabric of society. Climate change scenarios are developed using greenhouse gas emissions scenarios and global climate models. A number of climate change scenarios are available for the UK. Perhaps the most widely used scenarios in UK impact studies are those developed by the UK Climate Impacts Programme (UKCIP). Their most recent scenarios are known as the UKCIP02 scenarios (Hulme et al., 2002; http://www.ukcip.org.uk/). Based on the UKCIP02 scenarios a number of statements can be made about likely climate change in the UK (summarised in Table 1). For example, winters are expected to generally get wetter, while summers are expected to get drier, i.e., rainfall is expected to become more seasonal, and high-intensity rainfall events are likely to be greater in winter. Other changes predicted by the scenarios include an increase in overall temperatures and a longer thermal growing season. The present study uses the predicted changes in climate summarised in Table 1 as the starting point for the source–pathway–receptor analysis.

The most detailed analysis of the potential impacts of climate change on UK agriculture published to date is a report summarising the results of 7 years of research up to 2000 (MAFF, 2000). In the MAFF report, climate change impacts were considered with respect to crop and soil processes, crops, arable weeds, pests and diseases, and grassland and livestock (note that the MAFF report used UKCIP98 scenarios that predicted climate changes broadly similar to those for the more recent UKCIP02 scenarios). Although the report does not directly address the impact of climate change on the fate and behaviour of pesticides in the environment, it provides important context for the present study, the key observations of which are summarised below.

- arable production may increase by 20–30% by 2080
- arable crops could be produced further north in the UK and at higher altitudes
- conditions in southern England may become more suitable for crops such as grain maize and sunflower
- increased winter rainfall may stimulate disease, requiring greater use of pesticides
- it is likely that soil organic matter levels will be lower with increased average temperatures
- there will be enhanced potential for soil erosion with increased rates of movement of water and organic and inorganic chemicals through the unsaturated zone
- there will be increases in the capacity of the soil to store and cycle carbon
- there will be increases in the size and frequency of crack formation in soils as well as development of