World Soils Book Series

Rachel Creamer
Lilian O'Sullivan *Editors*

The Soils of Ireland

Springer

World Soils Book Series

Series editor

Prof. Alfred E. Hartemink
Department of Soil Science, FD Hole Soils Laboratory
University of Wisconsin–Madison
Madison,
USA

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The *World Soils Book Series* brings together soil information and soil knowledge of a particular country in a concise and reader-friendly way. The books include sections on soil research history, geomorphology, major soil types, soil maps, soil properties, soil classification, soil fertility, land use and vegetation, soil management, and soils and humans.

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Rachel Creamer · Lilian O'Sullivan
Editors

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Springer

Editors
Rachel Creamer
Wageningen University and Research
Atlas—Wageningen Campus
Wageningen
The Netherlands

Lilian O'Sullivan
Teagasc Agriculture and Food Development
Authority
Johnstown Castle Environment Research
Centre
Wexford
Ireland

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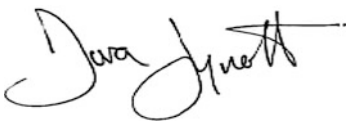
Foreword, Undersigned and Dated

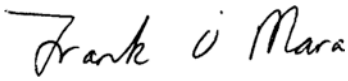
Our soil is an irreplaceable natural resource that has a critical role in food and feed production, as well as in services such as water purification, the provision of a home for biodiversity and as a major store of carbon. However, our soils are threatened by: soil degradation from agriculture and forestry; sealing from urban sprawl and contamination from industrial activities. As pressure to intensify soil use continues, we must balance the variety of demands on our soils in a sustainable manner. This relies, in the first instance, on a comprehensive knowledge of soil and its properties.

There is a proud history of mapping soils in Ireland. Indeed, An Foras Talúntais undertook the first soil survey in the 1970s, which mapped the soils of approximately half of the country. This book builds upon and completes this historic data by including the Irish Soil Information System, funded by the EPA Research Programme and co-funded by Teagasc.

This book will help us understand how this natural and national resource can be managed sustainably, how it is impacted by our decisions and how we can respond collectively to the most significant challenges of our time. It is intended that this book will be a rich resource for students, educators and researchers and the Environmental Protection Agency and Teagasc are delighted to support its authors in its completion.



Director
April 2017



Director of Research
April 2017

Preface

The range of soil related themes covered in this volume reminds us of the connective nature of the soil, between the lithosphere, biosphere, atmosphere and geosphere. Although soil only accounts for a small portion of the Earth's surface, it has enormous importance in terms of the functions that it performs particularly in overall ecosystem functioning that is critical to sustain life on earth.

In the process of developing this book, the collaboration of many researchers and organisations across Ireland has been an important aspect of the work and one which we believe adds value to the manuscript. It is our aspiration that this book will represent an important educational resource and to that end, the book has been written and developed with that goal in mind. Equally, the collaborative nature of this book can therefore be considered to support and add value with respect to addressing the needs of Irish students to those with an interest in Irish soils alike. The demand for soils knowledge is driven by the global challenges of the day, such as food security, climate change, energy and water security as soil fulfils a direct role in responding to these challenges. We recognise the role of soils in implementing the Global Sustainable Developments Goals which include goals that specifically cite soil, reflective of the growing recognition of the importance of the soil resource. We hope that the work contained in this book will help to stimulate interest in Irish soils and that it will help to broaden understanding and interest in this vital natural resource.

In an effort to understand where we are now, we open this volume of the World Soils Book Series, with a visit to the past. We provide a brief overview of soil related research in Ireland with an emphasis on soil pedology. This is followed with an introduction to soil formation, followed by soil classification and soil mapping in Ireland. In our chapter on soil formation, expertise from Geological Survey Ireland and Met Éireann allow the geological origins of Irish soils and the climatology of the country to be described. The completion of the 3rd Edition National Soil Map of Ireland, i.e. the development of a harmonised legend for Irish soils for the first time, was an important advancement in relation to classification and mapping in Ireland. Considerable attention has been paid to this part of the book as it largely informs subsequent chapters and forms the basis for the descriptions of the soils across the landscapes presented. In relation to this, it is important to acknowledge the work and efforts of those who have gone before. The content of this book relies in no small part on their efforts. Development of the Irish Soil Information Systems, while embracing the opportunities of new technologies and affording new possibilities through open online access, respectfully builds upon the legacy work such as that conducted by An Foras Talúntais and the National Soil Survey.

Unlike other volumes in this series, Ireland being a relatively small island, coupled with an emphatic influence in relation to glaciation means that soils here do not so readily divide into regional distributions. However, we have endeavoured to describe landscapes in natural groupings that best represent our landscapes largely based on elevation, and by parent material in the lowlands. While peatlands have a dedicated chapter, they appear repeatedly throughout the book reflective of their importance, not only in relation to their prevalence but also for the important societal benefits that they provide. Mountain landscapes represent only a small portion of the Irish landscape, much lower than landscapes of similar geological origin in

Great Britain or Scandinavia. The lowland landscapes are described separately based on their parent materials. The drumlin belt of the north midlands of Ireland that stretches across parts of Northern Ireland into the Republic of Ireland is one of the most extensive drumlin belts in Europe (described in Chap. 11). Finally, the landscape chapters conclude with a description of urban soils (Chap. 12). These soils tend to be underrepresented in soil surveys generally, leading to information gaps. Urbanisation has been rapid in Ireland in the period 2000–2006 and so attention must be paid to the impact that this represents both directly and indirectly for the soil resource.

Research in Ireland is responding to the failure to ratify the Soil Framework Directive and nowadays soil research, whilst acknowledging threats to soil quality adopts a more optimistic approach to soils, focusing on the functionality of soils and how to optimise soil quality. The latter chapters delve more into the capacity of Irish soils to function in the delivery of important soil based ecosystem services. Ireland is traditionally an agrarian society and this remains the major use of the land base today. Excess soil moisture is a major constraint in Irish soils from a productivity and environmental perspective. Here, we describe the current land based agricultural activities and provide a history of land drainage schemes for Ireland. The fertility and nutrient cycling of Irish soils is described as are some best management practices to support the nutrient cycling process. This naturally leads on to the role of soil in water quality followed by the potential of Irish soils to store carbon. Thereafter, the living soil is described with an overview of the role and extent of biodiversity in our soils. The final chapters in this section explore our archaeological soils and the options for sustainable spatial planning. Finally, the book concludes with an overview of the current policy context and the potential future role of soils in policy.

The Soils of Ireland book was generously co-funded by the Irish Environmental Protection Agency and Teagasc. The project was led by Teagasc and included the participation of researchers from other research and academic institutes as well as other stakeholders across Ireland. We are very grateful to have had this opportunity to contribute, work and collaborate on such an important topic.

Wageningen, The Netherlands — Rachel Creamer
Wexford, Ireland — Lilian O'Sullivan

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Editors and Contributors

About the Editors

Prof. Rachel Creamer is chair of Soil Biology and Biological Soil Quality at Wageningen University and Research. She is an author and co-author of over 50 scientific papers and the lead scientist on a number of national and European projects. Prof. Creamer has a background in pedology and soil quality, with research experience in the UK, Ireland and now the Netherlands. She was the lead scientist of the Teagasc Soil Quality and Classification sub-programme in Johnstown Castle from 2008 to 2016, where she led the development of the 3rd edition soil map of Ireland and associated soil information system.

Lilian O'Sullivan was awarded a Research Fellowship from the Irish Environmental Protection Agency to coordinate the Irish contribution to the World Soils Book Series contained here. She is based at Teagasc, Environment Research Centre in Co. Wexford where she has worked formerly as part of the Soil Quality Assessment Research project. Her research interests and work include soils and sustainability, agricultural development, food security and food policy.

Contributors

Tom Bolger UCD School of Biology and Environmental Science, University College Dublin, Belfield, Dublin 4, Ireland

Fiona Brennan Teagasc Environment, Soils and Land-Use Department, Johnstown Castle, County Wexford, Ireland

Kenneth A. Byrne Department of Biological Sciences, School of Natural Sciences, University of Limerick, Limerick, Ireland

James F. Collins University College Dublin, Dublin 4, Ireland

Rachel Creamer Wageningen University and ResearchAtlas—Wageningen Campus, Wageningen, The Netherlands; Teagasc Agriculture and Food Development Authority, Johnstown Castle Environment Research Centre, Wexford, Ireland

Thomas Cummins UCD School of Agriculture and Food Science, University College Dublin, Dublin 4, Ireland

Karen Daly Teagasc Environment Research Centre, Johnstown Castle, County Wexford, Ireland

Stephen Davis UCD School of Archaeology, University College Dublin, Belfield, Dublin 4, Ireland

Alan D. W. Dobson School of Microbiology and Environmental Research Institute, University College Cork, Cork, Ireland

Reamonn Fealy Teagasc, Rural Economy and Development Programme, Ashtown, Dublin, Ireland

Owen Fenton Teagasc Environment Research Centre, Johnstown Castle, Wexford, County Wexford, Ireland

Rochelle Fritch UCD School of Agriculture and Food Science, University College Dublin, Dublin 4, Ireland

Vincent Gallagher Department of Communications, Climate Action and Environment, Geological Survey Ireland, Dublin 4, Ireland

Mairéad Glennon Department of Communications, Climate Action and Environment, Geological Survey Ireland, Dublin 4, Ireland

Maryann Harris UCD School of Biology and Environmental Science, University College Dublin, Dublin 4, Ireland; Parks and Landscape Services Division, Dublin City Council, Dublin, Ireland

Phil Jordan Geography and Environmental Sciences, Ulster University, Coleraine, Northern Ireland, UK

Hendrik Van Der Kamp School of Transport Engineering, Environment and Planning, Dublin Institute of Technology, Dublin, Ireland

Gary Lanigan Teagasc Environment Research Centre, Johnstown Castle, Wexford, County Wexford, Ireland

Helen Lewis UCD School of Archaeology, University College Dublin, Belfield, Dublin 4, Ireland

Brian McConnell Department of Communications, Climate Action and Environment, Geological Survey of Ireland, Dublin 4, Ireland

Michael J. McLaughlin Soil Science, School of Agriculture, Food and Wine, The University of Adelaide, CSIRO Land and Water, Glen Osmond, Australia

Per-Erik Mellander Teagasc Environment Research Centre, Johnstown Castle, Wexford, County Wexford, Ireland

Franc Myles Archaeology and Built Heritage, Dublin, Ireland

Clíodhna Ní Lionáin Devenish Nutrition, Belfast, Ireland

Daire Ó hUallacháin Teagasc Environment Research Centre, Johnstown Castle, Wexford, County Wexford, Ireland

Lilian O'Sullivan Teagasc Agriculture and Food Development Authority, Johnstown Castle Environment Research Centre, Wexford, Ireland; Irish Environmental Protection Agency, Johnstown Castle, County Wexford, Ireland

Brian Reidy Teagasc Moorepark, Animal and Grassland Research and Innovation Centre, Fermoy, County Cork, Ireland

Florence Renou-Wilson School of Biology and Environmental Science, University College Dublin, Dublin, Ireland

Karl Richards Teagasc Environment Research Centre, Johnstown Castle, Wexford, County Wexford, Ireland

Ray Scanlon Department of Communications, Climate Action and Environment, Geological Survey of Ireland, Dublin 4, Ireland

Olaf Schmidt UCD School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4, Ireland

Rogier Schulte Teagasc, Environment Research Centre, Johnstown Castle, County Wexford, Ireland; Wageningen University and Research, Wageningen, The Netherlands

Sophie Sheriff School of the Environment, University of Dundee, Dundee, Scotland

Iolanda Simo Smart Soil & Land, Lleida, Spain

Brian Tobin UCD Forestry, School of Agriculture and Food Science, University College Dublin, Dublin 4, Ireland

Pat Tuohy Moorepark, Animal and Grassland Research and Innovation Centre, Teagasc, Fermoy, County Cork, Ireland

Sara E. Vero Agricultural Catchments Programme, Teagasc, Wexford, County Wexford, Ireland

David P. Wall Teagasc, Environment Research Centre, Johnstown Castle, County Wexford, Ireland

Séamus Walsh Met Éireann, the Irish Meteorological Service, Dublin 9, Ireland

Author Biographies

Tom Bolger is Professor and Chair of Zoology at University College Dublin. His primary research interests are in the effects of global change on biodiversity and nutrient dynamics in soil systems and in the evaluation of the status of and changes in that biodiversity. He is subject editor of several journals including Soil Biology and Biochemistry.

Fiona Brennan, Ph.D. is a Research Officer in Teagasc, Johnstown Castle and an Adjunct Lecturer in NUI Galway. She leads a research group on Soil and Environmental Microbiology whose main research focus is on the soil microbiome, functional microbial communities involved in nutrient cycling, plant–soil–microbial interactions, microbial adaptation to the environment and the fate of enteropathogens in soil.

Kenneth A. Byrne teaches soil science and agricultural science at the Department of Biological Sciences, School of Natural Sciences, University of Limerick. His main research interests are soil carbon stocks and greenhouse gas emissions, carbon storage in wood products and peatland management.

James F. Collins, M Agr Sc, Ph.D. is a retired soil scientist whose main research interests are in pedology and in relationships between Irish soils and climate. He has authored/coauthored over 100 publications (including 'Quickening the earth: soil minding and mending in Ireland', 2008) and currently writes on aspects of local history. He was Secretary/Treasurer of the Soil Science Society of Ireland from 1976 to 2000.

Thomas Cummins teaches soil science at University College Dublin. His research is in anthropogenic soils and long-term forest monitoring.

Karen Daly, M.Sc., Ph.D. is a Research Officer with Teagasc, the Irish Agriculture and Food Authority. Her main research interests include nutrient cycling in soil, soil biogeochemical processes and water quality modelling at catchment scale.

Stephen Davis, Ph.D. is a Lecturer in archaeology at University College Dublin who specialises in environmental archaeology (insect remains, pollen, and testate amoebae) and remote sensing. He has led projects in the Boyne Valley in Ireland, specifically within the Brú na Bóinne World Heritage Site, Co. Meath.

Alan D. W. Dobson studied biochemistry at the National University of Ireland, Galway and following his Ph.D., worked as a Postdoc at Baylor College of Medicine in Houston, in the area of eukaryotic gene regulation. He then moved to the School of Microbiology at University College Cork, where he is Professor of Environmental Microbiology. His group

employs both genomic- and metagenomic-based approaches to exploit the microbiota associated with marine and terrestrial environments with the goal of identifying novel bioactive compounds with potential biopharmaceutical applications.

Reamonn Fealy is a Senior Researcher at the Spatial Analysis Unit in Teagasc. While his research portfolio spans a broad range of agri-environmental issues, he has spent a large part of his career working on the development and improvement of soil mapping and informatics in Ireland.

Prof. Dr. Owen Fenton is a researcher with Teagasc in Ireland. Research focuses on soil hydrology and the source, fate and transformation/ remediation of nutrients along with all surface and subsurface pathways in agricultural catchments.

Rochelle Fritch, Ph.D. is an Ecologist in UCD School of Agriculture and Food Science.Her main research topics are grassland ecology and ecosystem functioning, specifically plant and invertebrate ecology, and their interactions with the environment in agricultural systems.

Vincent Gallagher, Ph.D. has since 1987 worked mainly for Geological Survey Ireland as a geochemist on various topics including ore deposit research, radon, mineral exploration and contaminated land. He is currently Project Geochemist for the Tellus project, Geological Survey Ireland's national geochemical and geophysical mapping project.

Mairéad Glennon manages the Tellus programme at Geological Survey Ireland which undertakes nationwide airborne geophysical and ground-based geochemical mapping. Her background is in geography and hydrogeology and she has previously worked in the private sector on contaminated land projects. She is a Non-executive Director of the Institute of Geologists of Ireland.

Maryann Harris is a landscape architect and ecologist with experience in managing biodiversity of urban ecosystems at Dublin City Council in Ireland. She is currently a Doctoral Research Fellow in environmental science at University College Dublin researching the structure of urban green spaces to support biodiversity in Dublin Bay UNESCO Biosphere.

Phil Jordan is Professor of Catchment Science, School of Geography and Environmental Sciences, Ulster University, Coleraine (N. Ireland). His research areas relate to the dynamics and fate of nutrients and sediments in river and lake catchments, high-resolution spatio-temporal water quality observation/analysis and agri-environmental policy evaluation.

Hendrik van der Kamp is the Head of the School of Transport Engineering, Environment and Planning in Dublin Institute of Technology. As well as providing planning advice to community groups, architects, consultants and private developers, he has given advice and acted as an expert evaluator to a range of public sector bodies including Government Departments and the European Commission. He is a member of the Executive Committee of the European Council of Spatial Planners (www.ectp-ceu.eu) and is currently Vice-President.

Dr. Gary Lanigan is a Principal Research Officer in Teagasc. He heads up the Greenhouse Gas and Climate Change sub-programme at Johnstown Castle Environmental Research Centre, having previously held positions at Trinity College Dublin and Cambridge University. His main interests are carbon and nitrogen biogeochemical cycling.

Helen Lewis, Ph.D. is an Associate Professor at University College Dublin School of Archaeology. Her research areas include geoarchaeology, landscape archaeology, and cave archaeology.

Dr. Brian McConnell is a Senior Geologist at Geological Survey Ireland, where he manages the onshore bedrock and sub-soils mapping programme.

Michael J. McLaughlin is a Professor in Soil Science at the University of Adelaide, Australia and is a Fellow of the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). His main research interests are soil and fertiliser chemistry, crop nutrition and soil contamination.

Per-Erik Mellander, Ph.D. is a Research Officer in Catchment science, Department of Environment, Soils and Landuse, Teagasc. He has a Ph.D. in Environmental Assessment from the Swedish University of Agricultural Sciences in Upssala, Sweden. His research focuses on the understanding of influences of climate and human impact on ecosystem processes and he is the author or co-author of 40 published scientific papers.

Franc Myles is Principal of a Dublin-based consultancy, Archaeology and Built Heritage. His research interests include the post-mediaeval expansion of Dublin and early island monasticism on the western seaboard.

Dr. Clíodhna Ní Lionáin is a licenced archaeologist with considerable commercial and research field experience in Ireland and Iberia and is employed by Devenish as Project Archaeologist for the Lands at Dowth. Her research interests include prehistoric archaeology, rock art, photogrammetry, and Community Archaeology.

Dr. Daire Ó hUallacháin is a Functional Ecologist with the Environment, Soils and Land-Use Department in Teagasc (Ireland). He has over 20 years of research experience in agri-ecology, terrestrial & aquatic Ecology, Water Quality and Sediment Dynamics.

Brian Reidy, Ph.D. is a soil ecology consultant. His research has focussed primarily on soil carbon, sequestration and land use change. In recent years, soil taxonomy and classification, coupled with extensive soil survey and correlation to WRB, have become areas of importance. Current research is in hydrology, drainage and soil/river catchment interaction.

Florence Renou-Wilson, Ph.D. teaches at University College Dublin (Ireland) where she is also the Director of the Masters of Science in Global Change: Ecosystem Science and Policy. She investigates peatlands in an integrative way at the crossroads of ecology, forestry, agriculture, climate change and sustainable management.

Karl Richards is a Principle Research Officer in Teagasc Johnstown Castle. He is author and co-author of over 85 peer-reviewed papers. His research focuses on understanding the fate,

transport and mitigation of pollutants through soils to water and the atmosphere from agricultural sources.

Ray Scanlon is a Principal Geologist in the Geological Survey of Ireland. He holds a B.Sc. in Geology and an M.Sc. in Geochemistry, both from University College Dublin. His research interests include applications of soil geochemical and geophysical data to environmental, mineralogical and for radon prediction and the development of policy in these areas.

Olaf Schmidt, Ph.D. is Associate Professor at the School of Agriculture and Food Science, and a member of the UCD Earth Institute, University College Dublin, Ireland. His main research interests are in the biology, ecology and biochemistry of soils, the management of invertebrate crop pests and the application of stable isotope ratio analysis in food authentication.

Prof. Rogier Schulte worked at Teagasc as leader in Translational Research on Sustainable Food Production, which meant that he worked closely with policymakers in Ireland and the EU. He developed the concept of Functional Land Management and is currently extending and applying this framework in projects across five continents. More recently, he has moved to Wageningen University and Research in the Netherlands, to take up the position of Chair of the Farming Systems Ecology group.

Sophie Sheriff, Ph.D. is a Postdoctoral Research Associate at the University of Dundee, Scotland. Her primary research interests are catchment-scale soil erosion, sediment and hydrology dynamics, food and water security, water–food–energy nexus and future water resources projections to support water quality and quantity management.

Iolanda Simo, Ph.D. is an independent Research Associate at Smart Soil & Land (Spain). She has expertise in soil science, environmental science, agronomy, drainage and GIS. Her main research topics include soil quality, carbon in soils, desertification, soil cartography and soil classification.

Brian Tobin, Ph.D. works for UCD Forestry in the School of Agriculture and Food Science in University College Dublin (Ireland). His research interests include forest ecosystem carbon sequestration, silviculture and tree species productivity and biomass allocation as well as above- and belowground woody decomposition.

Pat Tuohy, Ph.D. is a Research Officer on the Heavy Soils Programme at the Teagasc, Animal and Grassland Research and Innovation Centre. His main research interests are the design, installation and characterisation of land drainage systems, soil physical and hydrological characterisation and the optimisation and management of poorly drained grassland soils.

Sara E. Vero, Ph.D. is a researcher in the Teagasc Agricultural Catchments Programme, based in the Environmental Research Centre, Johnstown Castle, Co. Wexford. Her main research topics include hydrochemistry, nutrient transport, soil physics, numerical modelling and vadose zone instrumentation. She is also part of an on-going collaboration which is developing a conceptual model for the hydrology of American prairie landscapes.

David P. Wall is a Biogeochemist and leader of the Nutrient Efficiency Research Programme at Teagasc—the Irish Agriculture and Food Development Authority. He is Editor of the national soil fertility advice 'Major and Minor Nutrients for Productive Agricultural Crops' in Ireland, and his research interests relate to better understanding of nutrient cycling in agricultural landscapes.

Séamus Walsh is Head of the Climatology and Observations Division of Met Éireann. He previously worked as a weather forecaster and in the provision of climate services to the agricultural and environmental sectors.His main areas of interest are past data analysis, observation networks and generation of long term datasets for Ireland. He has contributed to various publications on the climate of Ireland.

A History of Soil Research with Emphasis on Pedology

1

Lilian O'Sullivan, James F. Collins, Thomas Cummins, Reamonn Fealy, and Rachel Creamer

Abstract

While commentary on the productivity of Irish pastures can be dated as far back as 55 BC, direct references to the different kinds of soil only begin in the eighth century AD. Early scientific information on Irish soils typically came from the endeavours of geologists or other professionals who studied rock and outcropping patterns. The Geological Survey of Ireland, a constituent of the Geological Survey of Great Britain and Ireland, developed small-scale county soil maps, largely for the southern counties in the mid-1800s. In relation to pedology, John Hodges, an Irish soil analyst described soil profiles in the 1850s in terms identical with those dated to the Dokuchaev School in 1880s Russia. Soil science in Ireland has typically been delivered with agricultural and environmental science at University level. Agricultural extension dates back to 1731 through the Dublin Society employment of itinerant instructors. The soil test, pioneered by P H Gallagher in the 1930s became the single most important tool for the advisory service. In their essays on the characteristics of Irish soil types he, together with Dr. Tom Walsh, laid the groundwork for future classification and mapping. In 1945, the Department of Agriculture established a research centre at Johnstown Castle, Co. Wexford. The soil division of An Foras Talúntais was headquartered there and the National Soil Survey of Ireland established. In 1980 the second edition, General Soil Map of Ireland, was published. This survey was discontinued in 1988. In 1998, the Spatial Analysis Unit was established in Teagasc a key output of which was the first nationally complete digital subsoil and indicative soil map in 2009. Not long after, the 3rd Edition National Soil Map of Ireland was launched in 2014, through the collaboration of the Spatial Analysis Unit and Teagasc Johnstown Castle.

Keywords

Geology • Soil testing • Pedology • Johnstown Castle Soil survey

L. O'Sullivan (✉) · R. Creamer
Teagasc Agriculture and Food Development Authority, Johnstown Castle Environment Research Centre, Wexford, Ireland
e-mail: Lilian.OSullivan@teagasc.ie

L. O'Sullivan
Irish Environmental Protection Agency, Johnstown Castle, County Wexford, Ireland

J. F. Collins
University College Dublin, Belfield, Dublin 4, Ireland

T. Cummins
UCD School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4, Ireland

R. Fealy
Teagasc, Rural Economy and Development Programme, Ashtown, Dublin 15, Ireland

R. Creamer
Wageningen University and Research, Atlas—Wageningen Campus, Droevendaalsesteeg 4, Building 104, 6708 PB Wageningen, The Netherlands

1.1 In the Past…

Favourable comments on the productivity of Irish pastures can be dated as far back as 55 BC (Murphy 2015) but direct comments or narratives on the different kinds of soil begin only in the eighth century AD. Using early Irish Law tracts, Kelly (1997) deduced that three classes of arable land and three classes of rough land were recognised. The main distinguishing criteria being vegetation (trees, shrubs..), access to water/wetness, and stoniness/shallowness. Stock-carrying capacity was rated in numbers of *milch* (24, 20, 16) or dry (16, 12, 8) cows per *cumal.* Some centuries later, Gerald of Wales (*ca.* 1183) noted soil diversity: '… *soil soft and watery… rather sandy than rocky… fruitful and rich in its soils'. 'In some places a blackish earth, in others clay and in many parts a mix of both together, as likewise there are sandy places where the ground is mixed earth and sand,*

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sand and clay, gravel and clay or earth… The plains are well clothed with grass, and the haggards are bursting with straw'. Dealing with manorial centres in the 1250/1350 period, Murphy (2015) listed some of the details in manorial extents (a description and valuation of all the items on the manor). This included the principal types of land-use: arable, meadow, pasture and wood. Many English sources wrote effusively about Irish soil in the late sixteenth century including Stanihurst who described …*so rich a kingdom, the Pastures are greene [in winter]*…; Payne …*soil for the most part fertil, and apte for wheat, rye, barley*… and Dymmock who found that …*the land lyeth very low and therefore very waterish and full of marishes*… A comprehensive account of agriculture was written by Boate (1652) ranging over many aspects including soils, crops, animals manures, burning lime and procuring sea-sand and shells. Subsequently, William Petty in the 1660s who confined himself to what was visible over-ground assigned Irish land to two groups: 'profitable' and 'unprofitable' (Simington 1931–61). The former group included arable, pasture, meadow and timberland, while the latter consisted of shrubby wood, rocky land, red bog and mountain. For some counties, Petty's commentary contained many references to agricultural practices such as liming, sanding and gravelling, aimed at increasing productivity (Simington 1931–61).

1.2 Geology and Geological Origins of Soil Research

Much of the early scientific information on Irish soils came from the endeavours of geologists or those other professionals who studied local rocks and their outcropping patterns. Boate (1652) may have pointed the way, having referenced the qualities of the Clare/Galway limestone-based mould, soils of various textures and 'in some places a blackish earth'. In his treatises, Smith noted the contrasts between the soils and agriculture of the Devonian and Carboniferous sandstones in Co. Waterford (1746); the potential value of a soil map in Co Cork (1750) and soils in Co. Kerry (1756). Later that century, Young (1780) commented on the rockiness of Irish soilscapes: '…*but the rocks here are clothed in verdure…the softest and most beautiful mould imaginable*…' In Co. Longford, Young noticed that even a two-inch thick layer of blue clay was sufficient to induce water retention. In a recent assessment of the roles of geology and soil in supporting cattle rearing, the contributions of Kirwan 1793, Meade 1806, Newenham 1809, Radcliffe 1814; and Shaw-Mason 1814–18, were noted (Collins 2016). Rock types and their associated soils were common themes in many of the (Royal) Dublin Society statistical surveys of the early 1800s, those of Fraser (1801, Wicklow), Sampson (1802, Londonderry), Tighe (1802, Kilkenny) and Townsend, (1810, Cork,) being particularly informative. The last-mentioned, Townsend, should be credited with introducing the pedologists' term, 'parent material', into the literature. Referring to the east/west valleys in Co. Cork, where sandstone debris from the mountains partially covers the limestone, he wrote: '*The limestone is certainly not the parent of the soil which is found over it… the earth incumbent on the limestone owes its birth to another parent*' (Townsend 1810). While the primary objective was bog reclamation, the reports of the Bog Commissioners, 1814–18, (which included R Griffith, geologist) alerted many to a range of calcareous materials suitable for neutralising the growing problem of soil acidity.

The Geological Survey of Great Britain and Ireland, instituted in 1845, conducted geological surveys and research across the UK and Ireland. The Geological Survey of Ireland (GSI) was a constituent part and survey work in Ireland was conducted under its local director, Henry James (Herries Davies 1983, 1995). The early results, largely from southern counties, were presented in small-scale county maps. These were superseded by one-inch maps based upon the field survey work conducted between 1857 and 1890 (Kilroe 1907). Early geological mapping was motivated by the search for economic minerals with the examination of soils and subsoils being an integral part of the mission. Du Noyer was the chief collector of samples taken across Cork, Waterford and Kilkenny. The GSI Memoir Series accompanying map sheets for a greater part of the country contain references to the use and availability of a range of soil amendments, mostly calcareous sands, gravels and marls, as well as locations of limestone rock suitable for burning to lime. As the survey proceeded through the 1870s/80s the emphasis on pedological matters lessened and in parts of the sandstone areas of South Munster the drift (till) was so thin that commentary on the soil was not worthwhile. However, George Kinahan highlighted the case of soils in his many publications (Kinahan 1878, 1885/9, 1908a, 1908b) especially in his 1908 booklet: 'Soils'.

1.3 Pedology, Agriculture, Education and Advisory

The recognition of the soil profile as the basic unit in soil survey has been dated to the 1880s in Russia (Dokuchaev 1883), but some decades previously, John Hodges, an Irish academic, soil analyst and author, described two soils in terms identical with those of the Dokuchaev School. In 1855/6, Hodges published compositional and descriptive data for the soils and subsoils of the Albert (Glasnevin) and Munster (Cork) Model Farms, together with advice on draining, trenching, crop selection and fertilisation reflecting the interwoven nature of the above-named disciplines in the 1850s.

Hodges' site, descriptive, compositional and commentary data were assessed and his work placed in context with the agricultural and educational developments of the period (Collins 2008). His interest and writings captured legacies and student progression that ascended from the Model Agricultural School system and transitioned to the Albert College and on to the Queen's universities. Other eminent persons of the period include Robert Kane, Edmund Murphy and Wm Sullivan. Writing on pedological themes, Antisell (1845, 46) reviewed the works of Griffith, Hamilton, Oldham, Mallet, Wilkinson and Kane, and having discussed weathering (1845, Chap. 3), addressed the contribution of various Irish rock types to soil formation. The pioneering work and writings of James Murray on soil phosphorus during these decades deserves special mention (Cooper and Davis 2004).

Irish agriculture was also well-served during the 1800s by a wide range of agricultural societies, many publishing journals, pamphlets and gazettes. The nature and properties of soils featured regularly in most of them, the subsoil getting the most notice in those articles dealing with drainage, trenching and ridge-and-furrow construction. The most impressive tome was the 1280-page first issue of the *Irish Farmer's Journal* in 1845; it included articles and notes on virtually every agricultural topic of the time including one entitled '*On the application of geology to agriculture*' (p. 213). One of the most influential and prolific agricultural educators of the 1800s was Martin Doyle, co-editor with Edmund Murphy of *Irish Farmers' and Gardeners' Magazine and Register of Rural Affairs* in the 1830s. Between 1830 and 1834, no fewer than a dozen books and pamphlets, including a two-volume collected works, were published under the Martin Doyle pseudonym (Cadogan 1989). Cadogan concluded '*…at a time when organic farming and self-sufficiency are enjoying a new vogue, his essays are as topical as when they first saw the light of day over 150 years ago…*'

As a discipline, soil science in Ireland has typically been delivered with agricultural and environmental science at University level. Agricultural extension in Ireland dates back to the establishment of the Dublin Society (later Royal Dublin Society) in 1731 and its employment of 'itinerant instructors'. State employment of instructors commenced with the establishment of the Department of Agriculture and Technical Instruction (DATI) in 1900. It is acknowledged that the soil testing, pioneered by P H Gallagher of UCD in the 1930s, became the single most important tool for the advisory service, leading to the transformation of Irish agriculture (Kirley 2008). Although the uptake of advisory services declined somewhat in the late 1980s, policy changes such as the Common Agricultural Policy (CAP) Reforms, the Rural Environment Protection Scheme (REPS) and the Green, Low-Carbon, Agri-Environment Scheme (GLAS) have seen an increased demand for advisory services. As well as Teagasc Agriculture and Food Development Authority, many private sector entities currently compete in the area of advisory service provision in Ireland.

1.4 Official Pedology, Pedogenic Investigations and Surveys

The establishment of DATI brought together diverse educational, scientific and administrative institutions including the Royal College of Science (a successor to the Museum of Irish Industry) and the County Committees of Agriculture (subsets of County Councils, established in 1898). One of its first commissioned publications, '*Ireland, industrial and agricultural*' (Coyne 1902), included an eight-page article '*The soils of Ireland*' by J R Kilroe; this was a forerunner for a much larger tome, '*A description of the Soil-Geology of Ireland*' by Kilroe in 1907. The Geological Survey, under Grenvile Cole, joined in 1905 (Herries Davies 1995), turning its attention to soils and employing Timothy Hallissy as a soil physicist. The soils of the new Agricultural College farms at Athenry, Ballyhaise and Clonakilty and a Forestry School at Avondale, Co. Wicklow, were studied. Unacquainted with the new thinking from Russia or from USA, Hallissy and co-authors drew heavily on their geological experiences. Their map of the 800-acre Ballyhaise Farm, showing the spatial distribution of seven soil types (scale 1:5280) attracted widespread approval. Surveyed by Hallissy and Kilroe, their map was colour-printed in 1909 and was awarded a Grand Prix Diploma. A few years later the GSI undertook a soil survey of Clare Island, Co Mayo, the findings of which were published by the Royal Irish Academy (Hallissy 1914) and in a special Survey Memoir (Cole et al. 1914). Hallissy may have been echoing the thoughts of many when he asserted that 'the soils occur in such a variety that a complete description of them is impossible, and were it possible, the labour necessary for full investigation of their properties would not be justified by the results'.

The study of both edaphology and pedology and, indeed, education/advisory to farmers, progressed significantly following the appointment of P H Gallagher at UCD, in 1928 (See Collins 2008, pp 462–7 and bibliography). While soil fertility and mineral nutritional considerations were addressed during the 1930s, it was Gallagher's research into the characteristics of Irish soil types that gained most prominence. Co-authored with T Walsh, their essay laid the groundwork on which future mapping and classification was to progress. In a 1944 paper ('The Soil'), Gallagher criticised those who would be satisfied with classifications such as 'Arable No.1', 'Arable No. 2', etc. and he outlined his scheme of using colour indicator dyes to aid soil advisory work (Gallagher 1944). On joining the State Department of Agriculture (Soils division), Walsh's position on the staff of the Faculty of Agriculture, UCD, was taken by W D (Bill) Brickley. Most of those who followed a career in

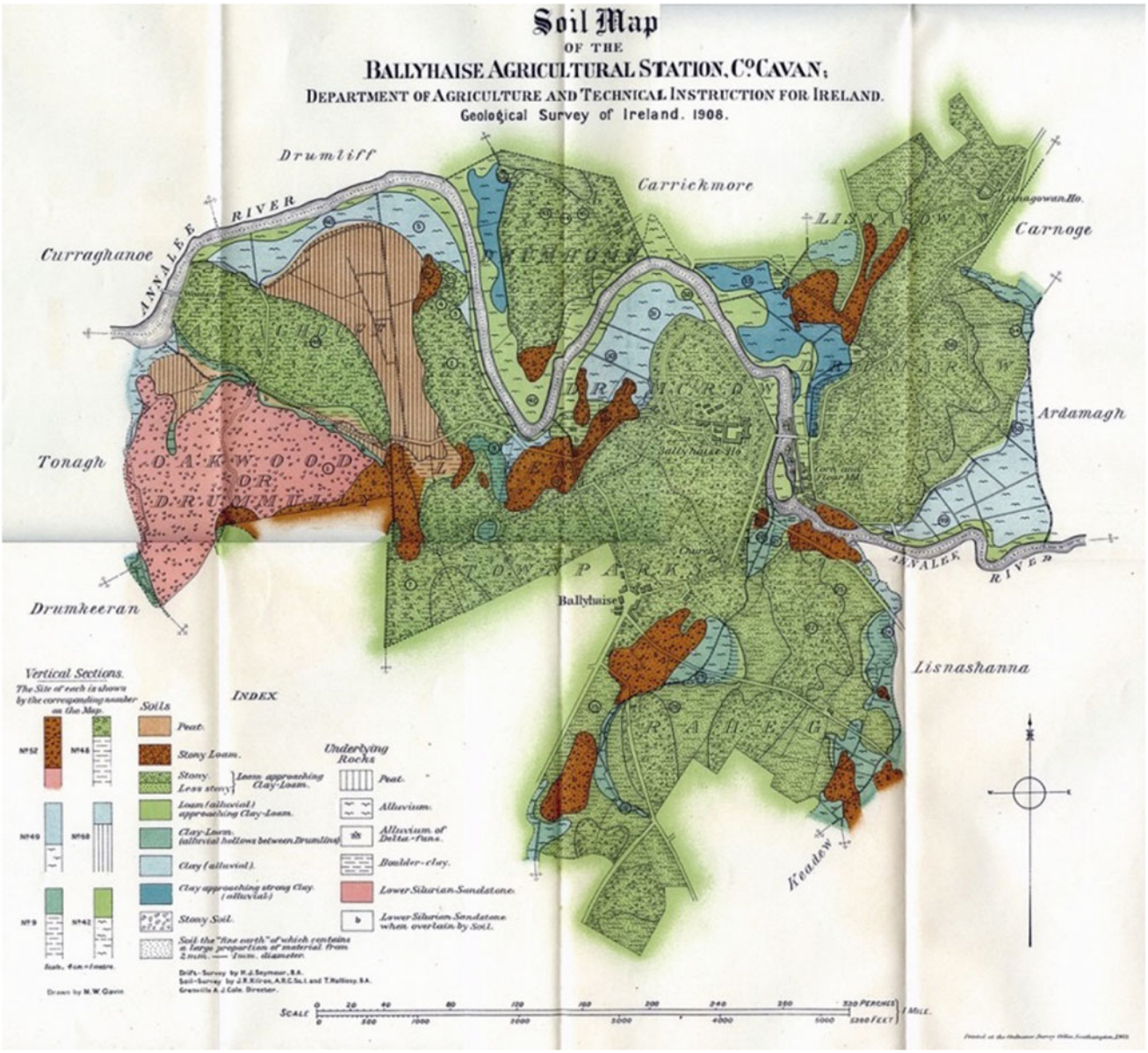

Fig. 1.1 Soil map of Ballyhaise Agricultural College, Co. Cavan. This map won a prize at a French conference in 1916, and a copy remains framed on the wall at Ballyhaise, which continues to be an agricultural education and training centre today

soil science from the 1950s onwards studied under Gallagher, Walsh and/or Brickley. Gallagher's paper was not published but readers of the proceedings would have noted Bishop's statistic and would have made a mental calculation spanning many centuries: '*…the loss of tricalcium phosphate to this country mainly through the export of cattle during the past few years has been somewhere between 20,000 and 30,000 tons per year*' (Bishop 1944). Much of the pedogenic research emanating from the Faculty of Agriculture, UCD, has been carried out on projects associated with the National Soil Survey (Fig. 1.1).

In 1945, the Department of Agriculture established a research centre at Johnstown Castle, Co. Wexford (Fig. 1.2). Prior to this, some soil testing had been initiated at Ballyhaise Agricultural College from 1943. By 1958, Johnstown Castle had already established its name in soil fertility and grassland research, carried out in conjunction with research trials to improve grassland productivity. Fertiliser compounds were developed based on the research of that time (Miley 2008b). The post-war European Recovery Plan or Marshall Plan was established in 1947 to rebuild Europe after World War II with money from the United States of America. Ireland was neutral during the war but was eligible for funding due to its role as a food exporter to the UK (Miley 2008a). Joesph Carrigan, head of the Economic Co-operation Administration in Dublin, first proposed the development of a research institute in 1949. In

Fig. 1.2 Johnstown Castle near Wexford town, where the Department of Agriculture established a research centre in 1945. The later An Foras Talúntais, the Agricultural Institute, and its descendant Teagasc were headquartered on this campus. Photo: Brian Murphy

late 1958 an institute for agricultural research, *An Foras Talúntais* (AFT), was established. In 1988, Teagasc Agriculture and Food Development Authority succeeded both AFT and *An Chomhairle Oiliúna Talmhaíochta,* the Agricultural Training Council (ACOT) which was the division responsible for education and advisory services. For over 50 years, AFT, ACOT and Teagasc have occupied a central role in research, advisory and training related to soil research in Ireland.

In the post-war period, soils in Ireland were significantly deficient in fertility. According to G A Holmes, a New Zealand government's agricultural attaché in London, it was a miracle that grass was found to grow, given the economic and political instability coupled with the limited use of fertiliser inputs (Miley 2008b). In 1950, research by Walsh et al. (1950) found that over 90% of soil samples were either 'very' or 'moderately' deficient in phosphorus (P), over 50% were deficient in potassium (K) and fewer than 50% were satisfactory for lime. Setting up its Soil Division headquarters at Johnstown Castle, AFT established the National Soil Survey of Ireland, under the guidance of Pierce Ryan. Amongst its other programmes, most urgent was the correction of soil acidity, mainly with ground limestone, and the avoidance of mineral nutrient deficiencies.

On joining the European Economic Community (EEC) in 1973, the role of agriculture as a major growth area for the Irish economy was widely recognised. Adequate knowledge of the land resource was considered essential for agricultural development and was a major driver of the soil survey (Gardiner and Radford 1980). In 1980, the second edition, General Soil Map of Ireland (Scale 1:575,000) and an accompanying bulletin by Gardiner and Radford (1980) were published (Fig. 1.3). The explanatory bulletin, No 36, included a description of the major soil types and assessed their land-use potential. Covering approximately 44% of the country, the soils of ten full counties were mapped and published: Wexford, Carlow, Limerick, Clare, Westmeath, Meath, Laois, Kildare, Leitrim and Offaly. Partial county surveys are published for west Mayo, west Donegal, Tipperary North Riding and West Cork. The National Soil Survey was discontinued in 1988, even though 'Soils of Co. Waterford' was published as Soil Survey Bulletin No 44, in 2011 (Diamond and Sills 2011). In the 1990s, environmental concerns, such as potential loss of nutrients from land, risking eutrophication of freshwaters, changed the emphasis of soil studies, moving away from agricultural production toward ecosystem science.

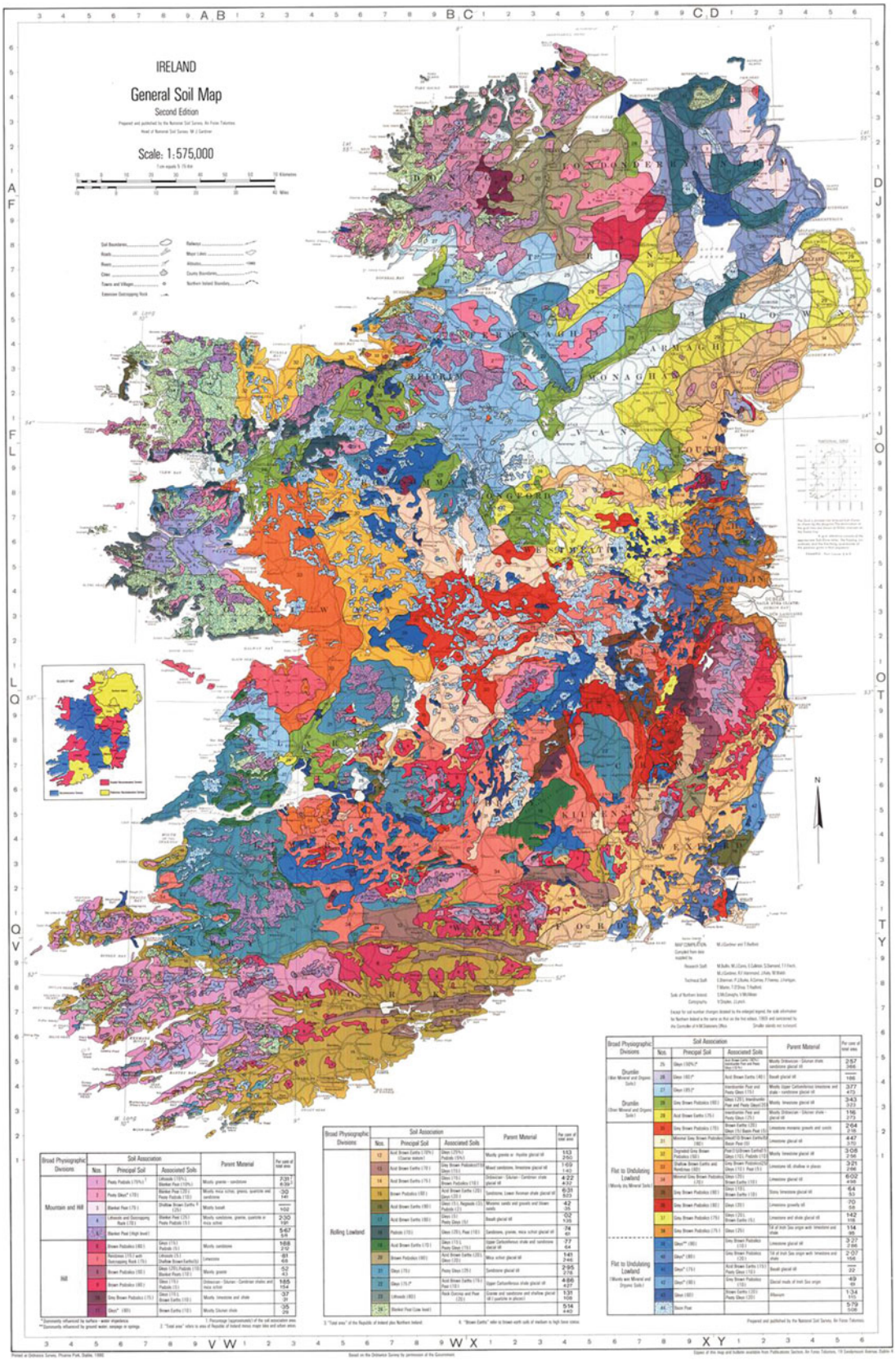

Fig. 1.3 The second edition national soil map of Ireland published by an Foras Talúnais in 1980, to accompany Gardiner and Radford's *Soil Associations of Ireland and their Land Use Potential*

Fig. 1.4 Dr. Tom Walsh, Director of An Foras Talúntais for its first 22 years (1958–1980) during which time he firmly established AFT as a leading centre in soil science research

Dr. Thomas Walsh (1914–1988) MAgrSc, DSc, PhD, LLD, ScD, MRIA (Fig. 1.4).

Born in Piercestown, Co. Wexford, Dr. Walsh graduated from University College Dublin (UCD) in 1937 with an honours degree in Agricultural Science. The following year he completed his master's degree in the same subject, his Ph.D. in 1941, and he was awarded a DSc for his published work in 1947. During his time at UCD (1938–1945), Dr. Walsh lectured in soil science, after which he worked as Soil Advisory Officer in the Department of Agriculture (1945–1954) and it was he who led the campaign on tacking the issue of soil fertility (O'Dwyer 2008). Dr. Walsh is considered the single most influential figure in the development of the internationally renowned agricultural and soil research infrastructure in Ireland which shaped the agriculture and food industry of today (O'Dwyer 2008).
During his lifetime, Dr. Walsh was very active in a large number of scientific organisations. He was elected a member of the Royal Irish Academy (MRIA) in 1956 where he served on the Council, as Senior Vice-President, as Science Secretary and as Secretary. He was a member of the Science Committee of the Royal Dublin Society and in 1969 was awarded the Society's Boyle Medal, for outstanding contribution to science in Ireland. He served on the Commission for Higher Education and was Chairman of the National Council for Educational Awards (NCEA) during the 1970s. He was appointed Director of An Comhairle Oiliúna Talmhaiochta (ACOT, the national farm advisory body) in 1980. He retired from public life in 1983.

In 1998, the Spatial Analysis Unit (SAU) was established in Teagasc to conduct work on the Irish Forest Soils project (FIPS-IFS). At the outset of the FIPS-IFS project, less than half of the country's soils had been surveyed and published at detailed reconnaissance (1:126,720) scale. The FIPS-IFS project resulted in a methodology to create an indicative soil classification and map for those areas not previously surveyed by the National Soil Survey, using satellite and aerial remote sensing and Geographical Information Systems (GIS). Inherent in this was the production of a soil parent material map. The SAU extended these efforts through the Environmental Protection Agency (EPA)/Teagasc Soil and Subsoil Mapping project leading to the first nationally complete digital subsoil and indicative soil maps created by a unified methodology (Fealy et al. 2009).

Notwithstanding the range of soil research and mapping undertaken since the 1950s, a comprehensive inventory by Daly and Fealy (2007) found that soil data coverage of Ireland was incomplete in both detail and extent. Shortly afterwards, the Irish Soil Information Systems (SIS) project was established in 2008, jointly funded by the EPA and Teagasc. A third edition National Soil Map of Ireland (Creamer et al. 2014) was developed using a combination of traditional soil survey methods and new GIS predictive mapping methods (see Chaps. 3 and 4). The 3rd Edition map also incorporated the legacy data generated in the earlier soil surveys and developed a harmonised legend for the soils of Ireland. This map and its soil database were launched in September 2014, coinciding with the centenary year of Dr. Walsh's birth.

The Joint Working Group on Applied Agricultural Meteorology (AGMET) has published soil relevant works including *Climate, Weather and Irish Agriculture* (Keane and Collins (1986), *Agro-Meteorological Modelling—Principles, Data and Applications* (Holden 2001, Chap. 4: Terestrial Data) and the *Agroclimatic Atlas of Ireland* (Collins and Cummins 1996). In '*Quickening the Earth—Soil Minding and Mending in Ireland*' Collins (2008) provides an account of agriculturalists' interaction with, and management of, land and soil over many centuries. The Soil Science Society of Ireland, formed in 1977, promotes the knowledge

and use of, Irish soils. The members are professionally active in research, teaching, administration, consultancy, advisory services, state agencies, civil service and industry (SSSI 2016). The Irish Quaternary Association, Irish Peatland Conservation Council, and member organisations of the Irish Geoscience Network all continue to work to improve understanding of soils and the integration of soil knowledge into other disciplines.

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Soil Formation

2

Lilian O'Sullivan, Brian McConnell, Ray Scanlon, Séamus Walsh, and Rachel Creamer

Abstract

Parent material, topography, organisms and climate represent the key soil forming factors that interact over a timespan of millennia to produce soil. These soil forming factors produce soil through physical, chemical and biological weathering occurring overtime. The relative influence of the individual factors is responsible for differences found in soils. Soils in Ireland are relatively young, having formed since the retreat of the last ice age approximately 15,000 years ago. Parent materials in Ireland are broadly categorised into solid bedrock geology and bedrock derived glacial geology, with the latter accounting for the majority of parent materials across the Irish landscape. The Irish climate is strongly influenced by its position on the eastern side of the Atlantic Ocean and on the western fringes of continental Europe resulting in a mild maritime climate with prevailing south-westerly winds. The high rainfall rates in Ireland are a dominant driver of soil genesis with leaching and gleying as the two main processes driving soil development.

Keywords

Parent material • Weathering • Topography
Time • Climate • Organisms • Soil profile
Soil horizon

2.1 Soil Forming Factors

Soils are formed as a result of the interplay of several factors that underpin soil formation across a timeline spanning millennia, dating back to the oldest rocks found on earth from 4.03 billion years ago. To understand the soils of Ireland requires an examination of the soil forming factors and the key events that occurred in Ireland over time, to arrive at the soil and landscape, as we know it today. In 1941, Hans Jenny published 'Factors of Soil Formation a System of Quantitative Pedology', which is a useful resource for assessing how soils are formed. In it, he proposes the key soil forming factors (Fig. 2.1) as parent material, topography, time, climate and organisms (Jenny 1941) and today, these remain the cornerstones of investigation when seeking to assess soil formation anywhere. These soil forming factors produce soil through physical, chemical and biological weathering occurring over time, and in response to climatic factors and landscape position.

Parent material represents an important factor of soil formation, the majority of which is of geological origin. There are many different soil types and some of the differences in soil are due to the wide variety of rocks from which the soils are formed. Rocks contain minerals and it is the weathering of rocks that determines the mineralogy of soil. Weathering refers to the process by which rocks get broken down into smaller pieces. Three main types of weathering occur; physical, chemical and biological:

- **Physical weathering** refers to the mechanical breakdown of rocks into smaller pieces. Physical weathering occurs due to changes in temperature, freeze/thaw action,

L. O'Sullivan (✉) · R. Creamer
Teagasc Agriculture and Food Development Authority, Johnstown Castle Environment Research Centre, Wexford, Ireland
e-mail: Lilian.OSullivan@teagasc.ie

L. O'Sullivan
Irish Environmental Protection Agency, Johnstown Castle, County Wexford, Ireland

B. McConnell · R. Scanlon
Department of Communications, Climate Action and Environment, Geological Survey of Ireland, Beggars Bush, Haddington Road, Dublin 4, Ireland

S. Walsh
Met Éireann, the Irish Meteorological Service, Glasnevin Hill, Dublin 9, Ireland

R. Creamer
Wageningen University and Research Atlas—Wageningen Campus, Wageningen, The Netherlands

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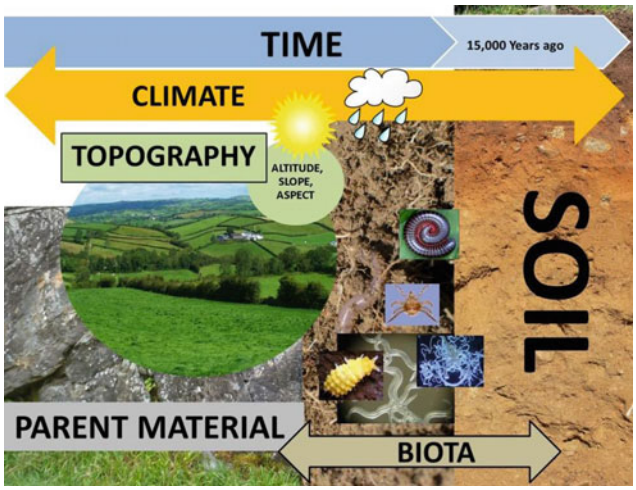

Fig. 2.1 Soil forming factors presented with background images taken during the Irish Soil Information System field campaign

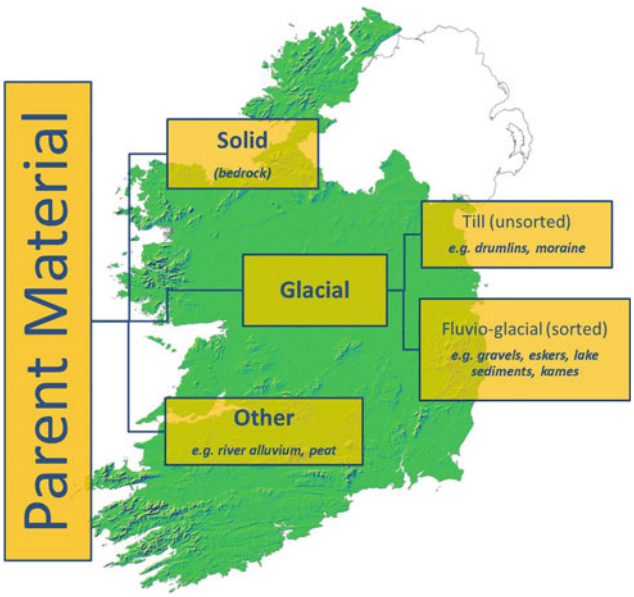

Fig. 2.2 Parent material types in Ireland

wetting, drying and erosion by wind, water and ice. Physical weathering does not significantly alter the mineral composition of the rocks.

- **Chemical weathering** refers to the breakdown of materials through chemical reactions. Carbon dioxide (CO_2) in the air dissolves in rainwater to form a weak carbonic acid (H_2CO_3) solution. When this acid solution comes into contact with rocks, it wears them down over time. Rainwater is, therefore, a primary weathering agent as it contains ions from the atmosphere and from the soil through which it moves. Unlike physical weathering, chemical weathering alters the mineral composition of rocks into secondary minerals such as clays. Physical and chemical weathering processes are complementary. Physical weathering increases the surface area of exposed rock, which in turn increases the areas susceptible to chemical weathering.
- **Biological weathering** occurs when organisms break down materials both physically and chemically. Physically, plant roots penetrate cracks in rocks thereby extending the exposed cracked surface area. Chemically, plants produce CO_2 that combines with rainwater to produce H_2CO_3. Organisms catalyse chemical reactions and also biologically mix (bioturbation) the structure of the parent material. This can increase the pathways for water flow, facilitating weathering to occur through the soil.

The nature and properties of parent material will influence important soil characteristics including the texture and the mineral composition, which in turn, defines other aspects of the soil such as the movement of water through the soil profile and soil fertility. Parent material also determines the content and type of clay present in the soil. Clay content is important as soils with higher clay content are more fertile. This is because the negatively charged clay surfaces adsorb and hold on to positively charged cations such as magnesium (Mg), potassium (K) and calcium (Ca) which are important for plant productivity.

In Ireland, parent materials are broadly grouped into two main types, solid geology and drift geology. Solid geology refers to weathered materials overlying the consolidated bedrock. Drift geology refers to unconsolidated deposits or loose sediments transported by ice, water, wind or gravity largely derived from the underlying solid geology (Fig. 2.2). Drift parent material accounts for the majority of parent materials across the Irish landscape. Geology is described in more detail in Sect. 2.2.

Topography is essentially created from geological activity and Ireland records a very dynamic geology associated with lithospheric plate tectonic movements. Topography refers to the shape of the landscape and includes macro- and microrelief dimensions. Macrorelief includes: altitude which is the height above sea level; the aspect, which refers to the direction of the site and whether it is south or north facing, and slope which refers to steepness. Microrelief refers to smaller localised variations, such as the height of the water table (Fig. 2.3). These attributes will determine the interaction between the site and climatic factors, such as solar radiation or precipitation. South-facing slopes in Ireland will receive more solar radiation and are consequently warmer and dryer with higher levels of evapotranspiration than slopes of a north-facing aspect. In Ireland, it is estimated that a 10° north-facing slope receives 40% less solar radiation than a similar south-facing slope (Collins et al. 2004). Relief determines the extent to which gravity influences the movement of water, soil and parent

material to different parts of the landscape (Graham 2006). Undulating topography and slope gradient will greatly influence the movement of parent material and soil downslope, with steeper slopes encouraging natural erosion of the surface layers. Soils found at higher elevations will differ significantly compared to soils downslope. In this sense, Brady (1974) indicates that topography is not only a modifier of climatic and vegetative effects but often acts as a major control in local areas. The speed of water movement across the landscape is also determined by relief, with flatter landscapes more likely to produce uniform weathering. Topography can therefore, speed up or delay the force with which these factors interact, affecting soil formation.

In Ireland, the majority of the mountain or hill areas (>500 m) are found along the western seaboard but mountain areas can also be found in Wicklow, Waterford and Tipperary. Elsewhere, hill (150–500 m) and drumlin landscapes, while not reaching a significant altitude, may sustain slopes in excess of 12° (Gardiner and Radford 1980). These slopes are likely to be subjected to gravitational forces sufficient to influence the movement of soil and water across the landscape. Topography also influences land use and management, as slopes with a gradient greater than 12° make tractor operations difficult (Mockler et al. 2013). This can determine anthropogenic factors that influence soil development, such as cultivation or fertilisation.

Climate represents a major influence in soil formation, in particular temperature and precipitation. Climate is a major determinant of vegetation which further influences soil formation. Temperature is important in chemical reactions and according to Van't Hoff's temperature rule, every 10 °C rise in temperature increases the velocity of chemical reactions by a factor of two to three (Jenny 1941). Soil temperatures in Ireland are higher in winter compared to most other parts of the world at the same latitude due to the moderating effect of the Gulf Stream (Gardiner and Radford 1980). Overall, soil moisture related to precipitation represents the dominant climatic factor affecting soil formation in Ireland. Water impacts soil formation in a number of ways, it can contribute to mechanical weathering through freeze/thaw action increasing the surface area exposed to weathering. Also, water is essential for chemical weathering (Duchaufour 1982; Shoji et al. 2006). Water performs a vital role in dissolution and transportation, acting as a medium for acids produced by living organisms that breakdown minerals into secondary minerals including clay, along with facilitating the growth of vegetation that acts on soil formation (Buol et al. 1997). In Ireland, precipitation exceeds evaporation and as a result, water movement down the soil profile is one of the dominant soil forming processes (Gardiner and Radford 1980). This results in leaching, where clay particles and nutrients are dissolved and moved down the profile, a process that accelerates with rainfall, however it is dependent on the texture of the soil. Most free-draining soils in Ireland are likely to require a continuous renewal of soil nutrients and lime above that which is removed via herbage and crop production alone (Gardiner and Radford 1980). A more detailed description of the Irish climate is presented in Sect. 2.3.

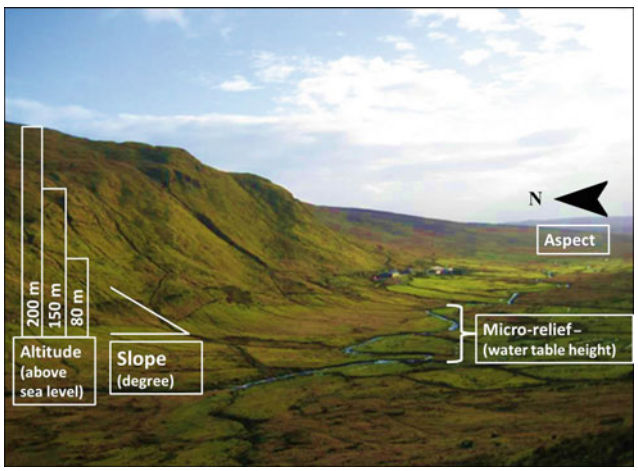

Fig. 2.3 Topographical features that affect soil formation shown across an Irish landscape. *Photo* Rogier Schulte

Soil biota includes a wide diversity of living organisms from microorganisms such as bacteria, fungi and algae to soil animals, including protozoa, nematodes, arthropods, insects and earthworms to higher animals and plants. Living organisms play a major role in profile development as they are necessary for organic matter accumulation, profile mixing, nutrient cycling and structural stability (Brady 1974). Soil biology alters the physical conditions of the soil through bioturbation and creates a range of chemical reactions. For example, soil biota may accelerate the rate of mineral weathering through the production of organic acids facilitating mineral solubilisation (Killham 1994), increasing nutrients in the soil solution. Living organisms play a vital role in the decomposition of organic matter with noticeable differences related to vegetation.

Soil profile development differs also in relation to vegetation. Exposed mineral material is gradually colonised by vegetation creating stable aggregates and soil structure (Duchaufour 1982). Gradually, the soil thickens and stabilises with the succession of plant communities (Duchaufour 1982). Soils under grassland systems have a large root biomass which contributes soil organic matter into the soil developing dark surface horizons (Brady 1974). In contrast, organic matter accumulation under forestry creates a shallow surface organic layer made up of leaf and woody litter. Vegetation present can define the cycling of nutrients, for instance, coniferous forestry is likely to remove a lot of base nutrients from the soil while the litter returned tends to be very acidic, low in cations, thereby increasing the potential for soil acidity. This affects soil organisms in relation to