

Soil Conditions and Plant Growth

TENTH EDITION

by E. WALTER RUSSELL
C.M.G., M.A., PH.D.

Emeritus Professor, University of Reading

FIRST TO SEVENTH EDITIONS

BY SIR E. JOHN RUSSELL
D.SC., F.R.S.



LONGMAN

LONGMAN GROUP LIMITED
London

*Associated companies, branches and representatives
throughout the world*

<i>First published (in Monographs in Biochemistry) by E. J. Russell</i>	<i>1912</i>
<i>Second Edition</i>	<i>1915</i>
<i>Third Edition</i>	<i>1917</i>
<i>Fourth Edition (in Rothamsted Monographs on Agricultural Science)</i>	<i>1921</i>
<i>Fifth Edition</i>	<i>1927</i>
<i>Sixth Edition</i>	<i>1932</i>
<i>Seventh Edition</i>	<i>1937</i>
<i>Eighth Edition rewritten and revised by E. W. Russell</i>	<i>1950</i>
<i>Ninth Edition</i>	<i>1961</i>
<i>Tenth Edition</i>	<i>1973</i>

ISBN 0582 44048 3

TENTH EDITION © E. W. RUSSELL 1973

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior permission of the copyright owner.

*Printed in Great Britain by
William Clowes & Sons, Limited,
London, Beccles and Colchester*

Preface to tenth edition

The importance of the inter-relations between soil and plant in determining plant growth is now so well accepted that very large resources all over the world are devoted to their study, with the consequence that rapid advances are being made in our understanding of them. These advances render the text of the previous edition of this book sufficiently out-of-date to necessitate a complete re-writing of most sections, to allow a proper discussion of the ideas and theories that are currently receiving most attention. It is also gratifying to see how rapidly the concepts of present-day physics and chemistry are being used to give an exact quantitative understanding of many factors relevant in soil-plant inter-relations, but these applications often require advanced mathematical techniques which are difficult for research workers unfamiliar with them to understand. I have attempted to give as accurate a description as I can of the physical and physico-chemical properties used in these studies, but have usually omitted any discussion of the basic mathematical techniques needed to obtain the final quantitative results.

One of the functions of this book has been to give a critical account of our present knowledge of the topics discussed, so wherever possible references are given for all the statements made. This has always been an essential feature of the book in the past, and I consider it should remain so in the future. But the amount of original work published each year is so enormous that I have made no attempt to be familiar with it all; instead I have been obliged to give references to work with which I am familiar, knowing that often the references given are neither the earliest nor the most suitable for the particular statement made or experimental result quoted. I hope any author whose work has been ignored but which is more relevant or earlier than work quoted will appreciate the reason for its omission.

I have taken the opportunity in this edition to convert all relevant experimental data into metric, and usually S.I., units, the principal exceptions being the results of experiments of purely historical interest. This means that many field experiment results given in this edition are not given in the original units, so the reader must be aware of the possibility of error creeping into the conversions.

It is again a very great pleasure to acknowledge the most generous help I have received from all of my colleagues whom I have consulted. They have supplied me with information, readily provided me with illustrations, and often read and commented on many of my drafts; and I trust they will forgive me if they find either that I have not always taken their advice or have failed to appreciate the significance of their suggestions. I cannot possibly make adequate acknowledgement to all of them, though I would like to make personal acknowledgement to Drs D. S. Jenkinson, G. E. G. Mattingly and H. L. Penman of Rothamsted, Mr B. W. Avery of the Soil Survey of England and Wales, Dr R. Scott Russell and some members of his staff, particularly Drs D. T. Clarkson and M. C. Drew, at the ARC Letcombe Laboratory, Mr P. H. Nye of the Soil Science Laboratory, Oxford University, Dr F. N. Ponnemperuma of the International Rice Research Institute, Emeritus Professor G. W. Leeper of Melbourne University, and Professor D. J. Greenland and his staff, particularly Drs P. J. Harris and C. J. M. Mott of the Department of Soil Science, Reading University. Finally I am once again greatly indebted to my wife for preparing the Author Index.

Department of Soil Science
University of Reading

E. W. RUSSELL

Contents

Preface to tenth edition	v
1 Historical and introductory	1
The search for the 'principle' of vegetation, 1630–1750	2
The search for plant nutrients	5
The phlogistic period, 1750–1800	5
The modern period, 1800–60	7
The foundation of plant physiology	7
The foundation of agricultural science	9
The beginnings of soil bacteriology	17
The rise of modern knowledge of the soil, and return to field studies	21
2 The food of plants	23
3 The individual nutrients needed by plants	31
Nitrogen	31
Phosphorus	37
Potassium	40
Other elements needed in moderate quantities	43
Trace elements in plant nutrition	45
Trace elements in animal nutrition	46
4 Quantitative studies on plant growth	49
The relation between growth and nutrient supply	50
The assumed relation between growth and nutrient supply	52
The interaction between nutrients	55
5 The composition of the soil	60
The size distribution of soil particles	61
Soil texture	65
The mineralogical composition of soil particles	67
Sand and silt fractions	67
The clay fraction	70
Other inorganic components	71

6	The constitution of clay minerals	76
	Isomorphous replacement	77
	The structure of the kaolin clay minerals	81
	The 2:1 group of clays	83
	Soil clays	85
	The surface area of clay particles	86
	The charge on soil clay particles	86
7	The cation and anion holding powers of soils	89
	Cation exchange	90
	The Ratio Law	90
	Relative strengths of cation adsorption by clays	92
	The quantitative laws of cation exchange	93
	The fixation of potassium by soils	101
	Acid clays	105
	The determination of the electrical charges on soil particles	111
	The behaviour of exchangeable aluminium ions in acid soils	115
	Cation exchange capacity of a soil	118
	The pH of a soil	121
	Anion adsorption by soils	128
8	The interaction of clay with water and organic compounds	134
	The swelling of clays	134
	The diffuse electrical double layer around clay particles	138
	Deflocculation and flocculation of clay suspensions and soils	142
	Adsorption of organic compounds by clays and soils	147
9	The physiology of the microbial population	150
	The microbial population of the soil	150
	The nutrition of the microflora: Autotrophic and heterotrophic organisms	153
	The respiration of the microflora: Aerobic and anaerobic organisms	156
	The byproducts of microbial metabolism: Microbial excretions	158
10	The organisms composing the population	160
	Bacteria and actinomycetes	160
	The number of bacteria in the soil	160
	The fluctuations in the number of soil bacteria	163
	The types of soil bacteria	164
	Adsorption of clay particles by bacteria	169
	Bacteriophages	169
	Actinomycetes	170
	Fungi	171
	Algae	177

Protozoa	180
Amoeboid and flagellate stages of other organisms	183
11 The soil fauna other than protozoa	185
Nematodes	194
Enchytraeid worms	195
Earthworms	196
Arthropods	206
Mesofauna	206
Larvae of beetles and dipterous flies	206
Ants and termites	207
Myriapods and Isopods	211
Gasteropods	212
The soil-inhabiting mammals	213
12 The general ecology of the soil population	214
The distribution of micro-organisms through the soil space	215
The effect of energy supply	219
Activity of the soil population	222
The effect of moisture content	222
The effect of temperature	224
Biochemical processes brought about by soil micro-organisms	225
Soil enzymes	228
Dissolution of soil minerals by microbial activity	229
The break-down of toxic chemicals in the soil	230
Symbiotic and antibiotic relations between the microflora	231
Interactions between the soil microflora and fauna	236
Effect of drying, heating or sterilising a soil	237
Partial sterilisation of soils	238
13 The association between plants and micro-organisms	241
The rhizosphere population	241
Association of fungi with plant roots	245
Root-rot fungi	246
The mycorrhizal association between fungi and plant roots	250
Mycorrhiza of forest trees	250
Endotrophic mycorrhiza	256
14 The decomposition of plant material	261
The plant constituents	261
The decomposition of plant residues	263
Composting	271
The products of microbial synthesis formed during decomposition	273
Green manuring	275

15	The composition of the soil organic matter	282
	The separation of humus from the soil particles	282
	The fractionation of the humus dispersion	283
	Constitution of humic colloids	285
	The soil polysaccharides	287
	The nitrogen compounds	289
	Organic phosphates	291
	The sulphur compounds	293
	Functional group analysis	293
	The humic acid core	300
	The elemental ratios in humus	302
	Interaction of humic acid with metallic ions	306
	The interaction of humus and clay	309
	The turnover of organic carbon in soils	313
	Humus formation	313
	Humus decomposition	314
	The level of organic matter in field soils	316
	Effect of organic manures	321
	Effect of grass leys	324
16	The nitrogen cycle in the soil	327
	The mineralisation of soil nitrogen	327
	The production of ammonia from organic matter	327
	Nitrification in the soil	328
	The organisms involved	328
	The biochemistry of nitrification	330
	Nitrification of ammonium salts in field soils	332
	The level of mineral nitrogen in field soils	335
	Nitrification in fallow soils	336
	Nitrification in arable soils	338
	Nitrification in grassland soils	340
	Nitrification in forest soils	342
	Losses of inorganic nitrogen from the soil	343
	Denitrification in soils	343
	Nitrogen losses from soils in the field	346
	Gains of nitrogen by the soil	349
	Non-symbiotic fixation of nitrogen	352
	The biochemistry of nitrogen fixation	355
	Symbiotic nitrogen fixation by non-leguminous plants	356
	Symbiotic nitrogen fixation in leguminous plants	357
	Conditions necessary for nitrogen fixation	361
	The nodule bacteria	363
	The formation and morphology of nodules	365
	The longevity of nodules	373

	The number of <i>Rhizobia</i> in the soil	374
	The inoculation of plants with <i>Rhizobia</i>	375
	The amount of nitrogen fixed by leguminous crops in the field	377
	The residual value of a leguminous crop	385
17	The temperature of the soil	388
	The control of bare soil temperatures in practice	395
	The influence of vegetation on soil temperature	398
	The effect of soil temperature on crop growth	401
18	The soil atmosphere	403
	The mechanisms of gaseous transfer	405
	The composition of the soil atmosphere	410
	Soil aeration and microbial activity	415
	Soil aeration and plant growth	416
19	The water in soils	420
	Where and how the water is held	420
	Suction and pF curves for soils	421
	The soil moisture-characteristic curve	424
	The movement of water in soils	429
	Entry of water into a soil	433
	Field capacity	437
	Drainage to a water-table	441
	Evaporation of water from a bare soil	441
	Soils with a water-table near the surface	446
	Evaporation of water from saline soils	446
20	Water and crop growth	448
	The water requirements of crops	448
	The use of the Penman equation in practice	455
	Effect of water shortage on transpiration	460
	The effect of water shortage on crop growth	469
	The available water content of a soil	473
	Effect of moisture stress on the quality of the crops	476
	The efficient use of water	477
21	Soil structure and soil tilth	479
	The stability of soil structure	487
	The creation of structural pores in undisturbed soils	491
	The stabilisation of structural pores	492
	The role of the clay fraction	492
	Stabilisation due to humus	493
	Soil conditioners	495
	Stabilisation by the decomposition of organic matter	495

The creation and protection of soil structure in arable soils	503
The stability of seedbed structure	508
Stabilising the structure of arable soils	511
Value of farmyard manure	513
Value of grass and lucerne leys	513
22 The development and functioning of plant roots in soil	520
The effect of pore sizes and soil strength	530
Depth of rooting in the field	532
The uptake of nutrients by roots	542
The sources from which plant roots extract nutrients	542
The soil solution	543
The movement of nutrients to the roots	545
The role of diffusion	546
The rate of uptake of ions	548
Selectivity in uptake	550
Root exudates	552
23 The sources of plant nutrients in the soil: Phosphate	555
The phosphates present in the soil	555
Organic phosphates	555
Calcium phosphates	556
Iron and aluminium phosphates	559
The solubility products of soil phosphates	560
The sorption processes operative in soils	565
The adsorption isotherm	568
Summary of the types of phosphate in soils	572
The source of phosphates in the soil used by crops	573
Phosphate dissolved in the soil solution	573
Plant-available phosphate in the soil	576
Phosphate fertilisers	580
The reaction between water-soluble phosphate fertilisers and the soil	582
Comparative value of different phosphate fertilisers	584
The movement of fertiliser phosphate in the soil	589
The uptake of fertiliser phosphate by crops	590
The residual value of phosphate fertilisers	594
Responsiveness of crops to phosphate fertilisers	602
24 The sources of plant nutrients in soils	604
Sodium, potassium, magnesium, calcium	604
The uptake by crops	606
The availability of soil potassium to crops	609
Potassium manuring of soils	615
The effect of leys on the potassium economy of soils	618

Nitrogen	619
Nitrogen fertilisers	624
Sulphur	629
Selenium	633
Silicon	634
Silicon and plant growth	636
Farmyard manure	639
Trace elements or minor elements	641
Iron	645
Manganese	647
Copper, zinc and cobalt	650
Boron	654
Molybdenum	657
The effect of soil acidity and alkalinity on plant growth	658
Lime requirements of soils	662
The effect of soil alkalinity and overliming	668
25 The chemistry of waterlogged soils	670
The reduction products from organic compounds	675
The changes taking place on waterlogging a dry soil	679
Effect of adding decomposable organic matter to waterlogged soils	683
Adaptation of plants to waterlogged soils	685
The soil conditions prevailing in a padi field	686
The management of rice soils	689
Drainage and water control in padi soils	690
The nutrition and manuring of padi rice	691
Salt marsh soils	694
26 The formation and classification of soils	696
The weathering of rocks	696
The chemical weathering of rock minerals	698
Weathering in the soil zone: Soil forming processes	703
Soil classification	705
Types and forms of humus in and on the soil surface	707
Well-drained soils	709
Podsoils and podsolisation	709
The process of lessivage: Brown earths, brown forest soils	717
The grassland soils: The prairie soils and chernozems	718
The effect of anaerobic conditions in the profile	722
Leached tropical soils	725
Types of laterite	729
Pan formation in soils	733
Effect of topography on soil formation: The soil association or catena	735
Saline soils	737

Alkali soils: The solonetz and solod	740
Land use capability classification	742
27 The management of irrigated saline and alkali soils	749
The effect of soluble salts on plant growth	749
The management of irrigated soils	753
Quality of irrigation water	753
Management for salt control	755
The control of exchangeable sodium	757
The control of alkalinity	761
The reclamation of salt and alkali affected soils	764
Reclamation of soils damaged by sea water	769
28 The general principles of soil management	771
The principles underlying the control of soil erosion	772
Wind erosion and soil drifting	772
Erosion by running water	778
Water conservation in semi-arid regions	784
Removal of excess water by drainage	793
Principles of soil cultivation	796
Mulches	802
Synthetic mulching materials	807
Appendix 1 Description of the Rothamsted and Woburn soils	808
Appendix 2 Conversion factors for units used in the text	811
Author Index	813
Subject Index	834

Plates

Frontispiece. A podsol under *Pinus sylvestris* in a fluvio-glacial gravel. Speymouth Forest, Morayshire. (D. G. Pyatt and Forestry Commission.)

PLATE	PAGE
1. The effect of nitrogen fertilisers on the yield of wheat on Broadbalk field, Rothamsted in 1943, after 100 years in wheat <i>Rothamsted Experimental Station</i>	35
2. Auto-radiographs of barley plants containing radio-active phosphorus <i>R. S. Russell, F. K. Sanders and O. N. Bishop</i>	38
3. Coatings on the surface of clay particles of Urrbrae loam soil: <i>D. J. Greenland and G. K. Wilkinson</i>	72
4. The structure of the oxygen and hydroxyl layers in clay minerals, and the structure of pyrophyllite <i>G. Nagelschmidt and Rothamsted Experimental Station</i>	78, 79
5. Electron microscope photographs of kaolinite and bentonite <i>English Clays Lovering Pochin & Co., St. Austell</i>	82
6. Dried pastes of a deflocculated and a flocculated sodium-saturated Lower Lias clay <i>E. W. Russell and Rothamsted Experimental Station</i>	146
7. Electron micrographs of soil bacteria: (a) <i>Nitrosococcus nitrosus</i> dividing <i>P. J. Dart, N. Walker, S. Soriano and M. Chandler and Rothamsted Experimental Station</i> (b) Rod-shaped bacteria with flagellae, gold shadowed <i>H. L. Nixon and Rothamsted Experimental Station</i> (c) Montmorillonite particles sorbed on to the surface of a bacterium <i>Esterichia coli</i> <i>M. M. Roper and K. C. Marshall</i>	168
8. and 9. Typical members of the soil fauna <i>F. Raw and Rothamsted Experimental Station</i>	189, 190
10. Micro-organisms in the soil: (a) Bacteria and actinomycetes (b) Fungal hyphae as displayed by Jones and Mollison's technique <i>P. C. O. Jones and J. E. Mollison, and Rothamsted Experimental Station</i> (c) Bacteria in the pore of a Kikuyu red loam crumb, thin soil section <i>D. Jones and E. Griffiths</i>	216

PLATE	PAGE
11. Electron microscope stereoscan photographs of bacteria, actinomycete mycelia and fungal mycelia, growing in a sandy soil enriched with chitin <i>T. R. G. Gray</i>	218
12. Part of the root system of Scots pine, showing mycorrhizas <i>M. C. Rayner and Faber and Faber Ltd.</i>	251
13. Part of the root system of the date palm, showing mycorrhizas Transverse section of a mycorrhiza of Scots pine <i>M. C. Rayner and Faber and Faber Ltd.</i>	252
14. Vesicles and arbuscules in strawberry rootlets <i>D. B. O'Brien and E. J. McNaughton, and the West of Scotland College of Agriculture</i> Vesicles and pelotons in autumn crocus roots <i>I. Gallaud, and Revue generale de Botanique</i>	257
15. <i>Endogene</i> mycorrhiza in an onion root showing arbuscules and thickened hyphae within the root, and mycelia outside the root <i>B. Mosse and Rothamsted Experimental Station</i>	258
16. Healthy nodules on lucerne rootlets <i>H. G. Thornton and Rothamsted Experimental Station</i>	358
17. A very young nodule on a lucerne rootlet, seen by transmitted light <i>H. G. Thornton and Rothamsted Experimental Station</i>	360
18. Transverse section of the meristematic end of a lucerne nodule <i>H. G. Thornton and Rothamsted Experimental Station</i> Infection threads in the root of subterranean clover with some rhizobia released into the cortical cells <i>P. J. Dart and Rothamsted Experimental Station</i>	366
19. Multiplication of rhizobia in the cortical cells of subterranean clover The bacteroid zone in subterranean clover <i>P. J. Dart and Rothamsted Experimental Station</i>	368
20. Bacteroids enclosed singly in their membrane envelopes in subterranean clover Groups of bacteroids enclosed within each membrane envelope in <i>Phaseolus vulgaris</i> <i>P. J. Dart and Rothamsted Experimental Station</i>	369
21. Nodules formed by an ineffective and an effective strain of nodule bacteria on red clover roots <i>H. G. Thornton and Rothamsted Experimental Station</i>	373
22. The profile of the Rothamsted clay-with-flints soil <i>Rothamsted Experimental Station</i>	481
23. Fine blocky soil structure <i>C. C. Nikiforoff</i>	482
24. Fine prismatic soil structure <i>C. C. Nikiforoff</i>	483

PLATE	PAGE
25. Rounded and flat tops of prismatic aggregates <i>C. C. Nikiforoff</i>	484
26. Electron micrograph of a replica of a fracture surface of a clay core of Willalooka illite <i>L. A. G. Aylmore and J. P. Quirk</i>	486
27. The effect of microbial action on soil structure The break-up of the water-stable aggregates built up by the mycelia of the fungus <i>Aspergillus nidulans</i> after it had been heat-killed, and the soil inoculated with other organisms <i>R. J. Swaby and Rothamsted Experimental Station</i>	497
28(a) The furrow slice of a Saxmundham chalky boulder clay soil after a three year lucerne ley <i>G. W. Cooke</i>	498
28(b) The furrow slice of a Saxmundham chalky boulder clay soil on old arable land <i>G. W. Cooke</i>	499
29. Electron microscope stereoscan photographs of the crumb surfaces of an old grassland and an old arable soil <i>P. R. Stuart and A. J. Low, and National Physical Laboratory</i>	502
30. Crust formation on a weakly-structured light sandy loam subjected to simulated rainfall <i>A. G. M. Bean and D. A. Wells, and National Institute for Agricultural Engineering</i>	508
31. Soil crumbs held together by grass roots <i>Rothamsted Experimental Station</i>	516
32. Root of Italian ryegrass growing in a sandy loam soil, showing development of root hairs <i>M. C. Drew</i>	522
33. Liquid droplets exuded from an apple root <i>G. C. Head and East Malling Research Station</i>	524
34. Distribution of ^{32}P in a sterile and non-sterile root of a three-week-old barley plant <i>D. A. Barber, J. Sanderson and R. S. Russell, and A.R.C. Letcombe Laboratory</i>	526
35. Apple tree roots growing in a silt loam, when 6, 25 and 35 days old <i>W. S. Rogers and East Malling Research Station</i> Pea root growing in a moderately compacted loam soil <i>K. P. Barley</i>	527
36. The root systems of plants in a typical short-grass prairie after a run of years with average rainfall and with drought <i>F. W. Albertson and Kansas State College</i>	536
37. The root systems of plants in the same area as Plate 36 after a run of drought years <i>F. W. Albertson and Kansas State College</i>	537

PLATE	PAGE
38. The effect of nutrients on the root development of eight-year-old gooseberry bushes in a sandy soil <i>W. S. Rogers and East Malling Research Station</i>	539
39. Podsol developed under <i>Calluna</i> heath in a Barton Sand contaminated with Plateau Gravel, in the New Forest <i>D. G. Pyatt and the Forestry Commission</i>	711
40. The profile and carbon content of a prairie and a hardwood forest soil on a silty loam in Iowa <i>R. W. Simonson and Iowa State College Agricultural Experiment Station</i>	720
41. A lump of vesicular laterite and of a re-cemented nodular laterite <i>R. L. Story, R. A. Pullan and Institute for Agricultural Research, Samarú</i>	731
42. A lump of cellular laterite <i>R. L. Story, R. A. Pullan and Institute of Agricultural Research, Samarú</i>	732
43. Salt soils in the Karun delta, Iran, showing salt efflorescences <i>A. Muir</i>	739
44. Examples of high quality land (a) Class 1 land <i>B. R. Hall and Soil Survey of England and Wales</i> (b) Class 2 land <i>J. M. Ragg and Soil Survey of Scotland</i>	745
45. Examples of medium quality land (a) Stony and liable to drought <i>A. J. Thomasson and Soil Survey of England and Wales</i> (b) Wet, improved and unimproved <i>A. D. S. Macpherson, Stirling</i>	746
46. Example of low quality land <i>J. K. St. Joseph and Cambridge University</i>	747
47. (a) Wheat stubble after being cultivated with the Noble cultivator (b) Alternate strips of wheat and fallow near Monarch, Alberta <i>Dominion Experimental Station, Lethbridge, Alberta</i>	776
48. Splash created by a water drop falling on a wet surface <i>W. D. Ellison</i>	781
49. Example of a well-planned soil conservation scheme in an area of small farms on hill slopes in the Central Province of Kenya <i>Kenya Information Service</i>	785
50. Maize growing on ridges with the furrows tied to conserve water <i>R. J. Ofield and National Institute for Agricultural Engineering</i>	788
51. The system of cracks produced by a subsoiler working in compacted soil at a suitable moisture content <i>Ransome, Sims and Jefferies, Ipswich</i>	800
52. The effect of inter-row cultivation and of herbicides on the root system of blackcurrant bushes <i>D. W. Robinson</i>	806

Historical and introductory

In all ages the growth of plants has interested thoughtful men. The mystery of the change of an apparently lifeless seed to a vigorous growing plant never loses its freshness, and constitutes, indeed, no small part of the charm of gardening. The economic problems are of vital importance, and become more and more urgent as time goes on and populations increase and their needs become more complex.

There was an extensive literature on agriculture in Roman times which maintained a pre-eminent position until comparatively recently. In this we find collected many of the facts which it has subsequently been the business of agricultural experts to classify and explain. The Roman literature was collected and condensed into one volume about the year 1240 by a senator of Bologna, Petrus Crescentius, whose book¹ was one of the most popular treatises on agriculture of any time, being frequently copied, and in the early days of printing, passing through many editions—some of them very handsome, and ultimately giving rise to the large standard European treatises of the sixteenth and seventeenth centuries. Many other agricultural books appeared in the fifteenth and early sixteenth centuries, notably in Italy, and later in France. In some of these are found certain ingenious speculations that have been justified by later work. Such, for instance, is Palissy's remarkable statement in 1563: 'You will admit that when you bring dung into the field it is to return to the soil something that has been taken away. . . . When a plant is burned it is reduced to a salty ash called *alcaly* by apothecaries and philosophers. . . . Every sort of plant without exception contains some kind of salt. Have you not seen certain labourers when sowing a field with wheat for the second year in succession, burn the unused wheat straw which had been taken from the field? In the ashes will be found the salt that the straw took out of the soil; if this is put back the soil is improved. Being burnt on the ground it serves as manure because it returns to the soil those substances that had been taken away.' But for every speculation that has been confirmed will be found many that have not, and the beginnings of agricultural chemistry

¹ *Ruralium commodorum libri duodecim*, Augsburg, 1471, and many subsequent editions.