
Contents

Preface.....	xv
Author Bio	xvii
Chapter 1 Criteria for sustainable agricultural chemistry	1
1.1 Environmental science	1
1.1.1 Four spheres	2
1.1.2 Dynamic interaction among spheres	4
1.1.3 Foundation of sustainability	4
1.2 Agricultural chemistry	4
1.3 Components of sustainable agricultural chemistry	7
1.3.1 Four drivers	7
1.4 Contributing to the success of sustainability through a green chemistry nexus	8
1.4.1 Guidance from green chemistry	8
1.4.2 Response of agricultural chemistry to the world.....	9
1.4.3 Lithosphere.....	9
References	9
Chapter 2 Agricultural chemistry in global sustainability	11
2.1 Sustainability and sustainable development	11
2.2 Agricultural chemistry (AC) through the lens of the four spheres.....	12
2.2.1 Lithosphere.....	12
2.2.2 Role of water (hydrosphere).....	15
2.2.3 Role of air (atmosphere).....	16
2.2.4 Role of humans (biosphere)	16
2.3 Factors challenging sustainable agriculture	17
2.3.1 Soil integrity	17
2.3.2 Water	18
2.3.3 Carbon footprint	18
2.3.4 Ecology/economy	19
2.3.5 Nutrients and food safety	20
2.3.6 Climate change	21
2.4 Emerging areas.....	22
2.4.1 Green chemistry	22
2.4.2 World health	22
2.4.3 Modeling sustainability	23
2.4.4 Bioeconomy/biorefinery	24
2.4.5 Biochar	25

2.5	Conclusion and a path forward	26
	References	26
Chapter 3	Forces in agricultural chemistry and the need for circularity	31
3.1	Agriculture and the case for circularity	32
3.1.1	Four fields of strategic importance	32
3.1.2	Earth as a system	33
3.1.3	Identification of issues	33
3.1.4	Closed loop toward circular agricultural chemistry	34
3.2	Moving agricultural chemistry to sustainability through chemistry	34
3.2.1	Food systems	34
3.2.2	Problems facing agriculture	35
3.2.3	Economy, society, and culture	36
3.3	Circular thinking in agricultural chemistry	36
3.3.1	Circular economy	37
3.3.2	Agriculture and chemistry	37
3.3.3	The biorefinery and biochar as ways to promote AC sustainability	39
3.3.4	Life cycle analyses	39
3.4	Developing a new paradigm	40
	References	41
Chapter 4	Life cycle assessment with circularity	45
4.1	Introduction	45
4.2	Life cycle assessment	47
4.2.1	Components	47
4.2.2	Purpose of LCA	48
4.2.3	Limitations of LCA	49
4.2.4	Cost of LCA	50
4.2.5	LCA and sustainable circularity	50
4.3	Circularity: circular economy and circular chemistry	51
4.3.1	Circular thinking as a complement to LCA	51
4.3.2	LCA adapting to agricultural chemistry in the twenty-first century	52
4.3.2.1	Land use	52
4.3.2.2	Crop rotation	53
4.3.2.3	Biodiversity loss	53
4.4	Agricultural chemistry responding to needs of the twenty-first century	54
4.4.1	Agricultural sustainability through LCA	55
4.4.2	Agricultural chemistry expressed in the biorefinery	55

	4.4.3	LCA, AC, and water	56
	4.4.4	LCA, AC, and energy	57
	4.5	LCA, CIR, and the bioeconomy	57
		References	57
Chapter 5		Use of natural resources affecting sustainability	61
	5.1	Agriculture in the twenty-first century	62
	5.1.1	Three roles of agriculture	63
	5.1.2	Global partnerships.....	63
	5.2	Systems of cycles and spheres	64
	5.2.1	Importance of soil for agriculture and global issues	65
	5.2.2	Advancing food security	65
	5.3	The earth as a system	66
	5.3.1	Importance of soil.....	67
	5.3.2	Transport processes	68
	5.3.2.1	Energy and material flows.....	68
	5.3.2.2	Biogeochemical cycles.....	69
	5.4	Sustainability model.....	69
	5.4.1	Material circulation	70
	5.4.2	Resources recovery.....	70
	5.5	Agriculture, human activity, and global sustainability	71
	5.5.1	Anthropocene	71
	5.5.2	Human sustainability.....	72
	5.6	Preservation of necessary resources through circular chemistry	73
	5.6.1	Introduction to SIA.....	74
	5.6.2	Components of SIA	75
	5.7	Agricultural chemistry contributions to promoting sustainability	75
	5.7.1	Sustainable biomass	76
	5.7.2	Biochar	76
	5.7.3	Plant health protection.....	77
		References	77
Chapter 6		Programs and processes that define agricultural chemistry in the twenty-first century.....	81
	6.1	Characteristics of twenty-first century agricultural chemistry	81
	6.1.1	Smart	81
	6.1.2	Intense	82
	6.1.3	Green	82
	6.1.4	Circular.....	83

6.1.5	Renewable	83
6.1.6	Sustainable	83
6.2	Centrality of chemistry	83
6.2.1	Explaining activities, processes, and transport in spheres.....	84
6.2.2	Human health and agricultural chemistry	87
6.2.3	Climate instability	87
6.2.4	Energy usage	88
6.2.5	Analytical techniques that open new areas of science.....	88
6.2.6	Microbe chemistry.....	89
6.3	Existing agricultural structures	89
6.3.1	Small scale farming methods	90
6.3.1.1	Characteristics of small-scale farming.....	90
6.3.1.2	Main differences between small-scale and conventional farming.....	90
6.3.1.3	Challenges and problems	91
6.3.1.4	Greenhouse farming.....	91
6.3.2	Industrial intense farming.....	91
6.3.2.1	Description.....	91
6.3.2.2	Problems	92
6.3.2.3	Solutions	92
6.3.3	Environment	92
6.3.4	Pesticides.....	93
6.4	New face of agricultural chemistry	94
6.4.1	Genetically Modified Crops	95
6.4.2	Artificial Intelligence.....	96
6.4.3	Chemical products from agriculture.....	97
6.4.4	Green chemistry	98
6.4.5	Sustainable intense agriculture.....	99
6.4.6	Circularity.....	100
6.5	Agricultural chemistry in the twenty-first century.....	100
	References	101
Chapter 7	Unsustainable agricultural waste streams.....	105
7.1	Magnitude of agricultural waste	105
7.1.1	Types of FLW	106
7.1.2	Causes of food losses and waste.....	106
7.1.3	Economic consequences of waste	108
7.1.4	Social impacts/nutrition.....	109
7.1.5	Climate change.....	109
7.2	Treatments.....	110
7.3	Valorization of waste.....	111
7.3.1	Food waste management gaps.....	111

7.4	Food waste management in the twenty-first century	112
7.4.1	Reusing and recycling	113
7.4.2	Valorizing waste	113
7.4.2.1	Biofuel.....	113
7.4.2.2	Valuable biomaterials.....	114
7.4.2.3	Bioactive compounds.....	115
7.4.2.4	Food waste as additives in food products	115
7.5	Food and nutrition security through waste circularity	116
7.5.1	Biorefinery for agricultural food waste	117
7.5.2	Circular approaches.....	118
7.5.2.1	Digestate	118
7.5.2.2	Composting	118
7.5.2.3	Anaerobic digestion	119
7.5.2.4	Land applications.....	119
7.6	Concluding remarks.....	120
	References	120
Chapter 8	Agricultural chemistry in the food, energy, and water nexus.....	125
8.1	The nexus of food, energy, and water (FEW).....	125
8.1.1	What is the FEW nexus	127
8.1.2	Interaction among nexus	127
8.1.3	Dimensions of the FEW nexus.....	129
8.1.4	Food.....	130
8.1.5	Circularity in the FEW nexus.....	131
8.2	Chemistry	131
8.2.1	Past	132
8.2.2	Present	132
8.2.3	Future	133
8.3	Agricultural chemistry role.....	133
8.3.1	Water availability and scarcity	134
8.3.2	Water reclamation.....	134
8.3.3	Water quality	135
8.3.4	Impact of contaminated water on food.....	135
8.3.5	Food and biofuels	136
8.3.6	Renewable sources of energy	136
8.4	Food security with FEW nexus.....	137
8.4.1	Employing sustainable production methods.....	138
8.4.2	Changing diets.....	139
8.4.3	Reducing food loss and waste	140
8.5	Sustainable solutions.....	141
	References	142

Chapter 9	Sustainable intensive agriculture	147
9.1	Background	147
9.1.1	Paradigm	148
9.1.2	Necessity for a paradigm shift	149
9.1.3	Criteria	150
9.1.4	Definition of sustainable intensive agriculture (SIA)	151
9.2	Intensive sustainable practices for human needs	152
9.2.1	Sources of practices	153
9.2.2	Biophysical safe space	153
9.2.3	Transforming the Anthropocene	154
9.2.4	Sustainable examples with Intensive Agriculture (IA)	155
9.3	Sustainable practices for the four spheres	156
9.3.1	Working with nature	156
9.3.2	Managing sustainable increases	158
9.3.3	Twenty-first century production	158
9.4	The way forward	159
9.4.1	Transformation, co-design, and learning	160
	References	161
Chapter 10	Circularity: Environmental, chemical, agricultural	165
10.1	The nature of circularity	165
10.1.1	Circular economy	166
10.1.2	Transitioning to a circular economy	167
10.1.3	Circularity goals	168
10.2	Environmental circularity – a necessary first step	169
10.2.1	Introduction	169
10.2.2	Linking environmental and agricultural circularity	170
10.2.3	Areas of environmental circularity applications	170
10.3	Chemical circularity	171
10.3.1	Circular chemistry to enable a circular economy	173
10.3.2	Integrating chemistry into a circular economy	175
10.3.3	Examples	177
10.3.4	Afterthoughts on circular chemistry	179
10.4	Agricultural chemistry circularity	179
10.4.1	Introduction	180
10.4.2	Dimensions and models for agricultural circularity	181
10.4.3	Examples of agricultural circularity	182
10.5	Conclusion	184
	References	185

Chapter 11	Smart agriculture through agricultural chemistry	189
11.1	Introduction.....	190
11.1.1	Food security	192
11.1.2	Smart farming technologies.....	192
11.1.3	Metrics for the three pillars of CSA	193
11.1.4	Environmental impacts and climate change	195
11.2	Agricultural sustainability and climate change.....	195
11.2.1	Current situation	196
11.2.2	Consumers	196
11.2.3	Politics	197
11.3	Climate smart agriculture.....	198
11.3.1	Overview	199
11.3.2	Science in CSA.....	199
11.3.3	Impacts	200
11.3.4	Intensification within the constraints of CSA	202
11.4	Tools for climate smart agriculture	202
11.4.1	Cloud computing	203
11.4.2	Artificial intelligence.....	204
11.4.3	Data mining	204
11.4.4	Internet of Things (IoT).....	205
11.5	Resources and engineering that comprise CSA.....	206
11.5.1	Monitoring.....	206
11.5.2	Nanomaterials for fertilizers and pesticides	207
11.5.3	Hydroponics	207
11.5.4	Biosensors	208
11.5.5	Genetic engineering.....	209
11.5.6	Land recovery	209
11.5.7	Diffusion.....	210
11.5.8	Scaling	210
11.6	Afterthoughts	211
	References	212
Chapter 12	Crop protection and agricultural green chemistry	217
12.1	Introduction.....	217
12.2	Classes of CPCs used in twenty-first-century agriculture...	219
12.2.1	Need for innovation.....	219
12.2.2	Fungicides for disease control.....	219
12.2.3	Herbicides for weed control	220
12.2.4	Safeners for weed control.....	221
12.2.5	Insecticides for pest control.....	222
12.2.6	Nematicides	224
12.2.7	Managing microbes	225
12.3	Principles of green chemistry applied in crop protection ...	225
12.3.1	Prevent waste.....	226

12.3.2	Maximize atom economy	227
12.3.3	Design less hazardous synthesis of CPCs	228
12.3.4	Design safer chemicals and products	229
12.3.5	Use safer solvents and reaction conditions.....	229
12.3.6	Design for energy efficiency and production of biofuel.....	230
12.3.7	Use renewable feedstocks.....	232
12.3.7.1	Biorefinery	232
12.3.7.2	CPC.....	232
12.3.7.3	Bioplastics	233
12.3.7.4	Biopolycarbonates	234
12.3.7.5	Oils	234
12.3.8	Avoid derivatives in synthesis steps	234
12.3.9	Use catalysis, not stoichiometric reagents.....	235
12.3.9.1	Chemical reactions	235
12.3.9.2	Catalysts from waste.....	236
12.3.9.3	Asymmetric synthesis.....	236
12.3.9.4	Enzymes	236
12.3.10	Design products to degrade after use	237
12.3.11	Analyze in real time	237
12.3.11.1	Manufacturing	237
12.3.11.2	Pesticide analyses	238
12.3.11.3	Field analyses/Smart Agriculture	239
12.3.12	Minimize potential for accidents.....	239
12.3.12.1	Personal Protection Equipment	240
12.3.12.2	Phytomanagement	240
12.4	Conclusion	241
	References	242
Chapter 13	Sustainable agricultural chemistry: The biorefinery	247
13.1	Biorefinery overview.....	247
13.1.1	Principles of a sustainable biorefinery.....	248
13.1.2	Global drivers	250
13.1.3	Types of biorefineries	250
13.1.4	Pretreatment processes	251
13.1.5	Separation and recovery technologies.....	251
13.1.6	Role of enzymes	252
13.1.7	Microorganisms.....	253
13.1.8	Biorefinery and circular economy	254
13.1.9	Green biorefineries	255
13.2	Connection to agriculture.....	255
13.2.1	Lignocellulosic biorefinery (LBR).....	256
13.2.2	Food waste.....	257
13.2.3	Biomass	257

13.2.4	Fruit	258
13.2.5	Rice.....	259
13.2.6	Corn.....	259
13.3	Role of agricultural chemistry in the biorefinery	260
13.3.1	Food waste biorefineries (FWB)	260
13.3.2	Modeling biowaste biorefineries	261
13.3.3	Integrated biorefineries of agricultural waste	261
13.3.4	Challenges in integrated biorefinery of agricultural waste	262
13.4	Sustainability contributions by biorefineries.....	263
13.4.1	Wastewater.....	264
13.4.2	Energy	265
13.4.3	Biowaste	267
13.4.4	Chemical production	267
13.4.5	Circular economy	270
	References	272
Chapter 14	Epilogue: Building a sustainable agricultural chemistry.....	277
14.1	Challenge of building sustainable agricultural chemistry...277	
14.1.1	Agricultural chemistry as a tangled ball of yarn ...277	
14.1.2	Necessary methodology	278
14.1.3	Importance of agricultural chemistry	279
14.2	Problems affecting sustainability	279
14.2.1	Intensification	280
14.2.2	Dietary challenges	280
14.2.3	Land use	280
14.2.4	Climate change	281
14.2.5	Smart agriculture	281
14.2.6	Disappearing water.....	281
14.2.7	Societal education.....	282
14.3	Integration of solutions	282
14.3.1	Improving policy environment/education	282
14.3.2	New practices and technologies	283
14.3.3	Fertilizers/crop protection	283
14.3.4	Improve seed growth	284
14.3.5	Valorizing waste	285
14.3.6	Smart agriculture through IoT.....	285
14.3.7	Biorefinery.....	286
14.4	From this day forward.....	287
	References	288
Index.....		291