Contents

Part	I	Introduction —— 1
1 1.1	T	he Sustainable Biofuels Paradigm — 3 Biofuels: Opportunities and Challenges — 3
1.1.1		From Fossil Fuels to 1st Generation Biofuels — 4
1.1.1		A Case for 2nd and 3rd Generation Biofuels —— 6
1.1.2		The Sustainability Paradigm and Biofuels ————————————————————————————————————
1.2		References —— 15
Part	П	Biofuel Crop Models —— 19
2	Sv	vitchgrass for Bioenergy: Agro-ecological Sustainability —— 21
2.1		Introduction —— 21
2.1.1		Switchgrass—A Short History of and the Case for
		Its Use as a Biofuel Feedstock ——— 21
2.2		Energetic and Economic Considerations in Sustainability —— 23
2.2.1		Energy In: Energy Out (Is Making Biofuel from
		Switchgrass Energetically Feasible?) ——— 23
2.2.2		Economic Tipping Points (Is Making Biofuel from
		Switchgrass Economically Feasible?) ————————————————————————————————————
2.2.3		Using Value-added Products to Shift the Tipping Point —— 27
2.2.4		Farmer and Factory Relationships: Getting the Ball Rolling —— 27
2.2.5		Ethical/Social/Fairness Dimensions of the Sustainability —— 28
2.3		Ecological/Environmental/Resource Considerations of
		the Sustainability ————————————————————————————————————
2.3.1		Sustaining the Soil Resource —— 29
2.3.2		Sustaining the Air Resource: GHGs and Climate ——— 30
2.3.3		Sustaining the Water Resource: Depletion and Pollution Concerns ——— 33
2.3.4		Sustaining Biological Resources: Biodiversity ——— 34
2.4		Managing Switchgrass for Bioenergy and Sustainability —— 38
2.4.1		Description, Adaptations, and Selection —— 38
2.4.2		Establishment —— 40
2.4.3		Fertility in an Agroecological and Sustainability Context —— 41
2.4.4		Mechanization, Storage, and Hauling —— 43



xvı —	- Contents
2.4.5	Demands of a Bioenergy Industry ——— 46
2.5	Conclusions —— 46
	References —— 47
3	Sugarcane as an Alternative Source of
	Sustainable Energy —— 59
3.1	Introduction —— 59
3.2	Energy Expenses in Sugarcane Production —— 61
3.3	Nutrient and Fertilizer Expenditures of Sugarcane —— 64
3.4	Sugarcane Bagasse: A Sustainable Energy Resource —— 64
3.4.1	Electricity Generation from Bagasse —— 65
3.4.2	Reduction in Greenhouse Gas (GHG) Emissions — 69
3.4.3	Bagasse-based Byproducts and Future Energy Assessment —— 69
3.5	Sugarcane Trash: A Potential Biomass for Sustainable Energy —— 71
3.6	Sugarcane Biomass for Biofuel Production — 72
3.6.1	Chemical Composition of Sugarcane Biomass —— 72
3.6.2	Conversion of Sugarcane Biomass into Ethanol —— 73
3.6.3	Pretreatment of Sugarcane Biomass —— 75
3.6.4	Enzymatic Hydrolysis/Saccharification of the Cellulosic Fraction —— 78
3.6.5	Detoxification of Cellulosic and Hemicellulosic Hydrolysates — 79
3.6.6	Fermentation of Sugars from Sugarcane Biomass into Ethanol —— 79
3.6.7	Pyrolysis of Sugarcane Biomass —— 80
3.7	Conclusions ———— 81
	References ——— 82
4	Jatropha (Jatropha curcas L.) as a New Biofuel Feedstock for
-1	Semi-arid and Arid Regions and Its Agro-ecological
	Sustainability Issues — 87
11	Introduction — 87
$4.1 \\ 4.2$	
4.2	Systematics and Global Distribution —— 88 Vegetative Growth and Sexual Reproduction —— 89
4.4	Optimal and Sub-optimal Climate and Growth Conditions —— 91
4.5	Propagation —— 92
4.6	Uses and Abuses of JCL —— 92
4.6.1	Traditional Non-fuel Uses —— 92
4.6.2	Feedstock for Biofuels —— 93
4.6.3	Utilization of JCL byproducts — 96
4.7	JCL as A Sustainable Alternative to Fossil Fuels —— 96
4.7.1	Environmental Impacts —— 97
4.7.2	Socioeconomic Impacts —— 99
4.8	Significance of Irrigation and Fertilization for JCL Cultivation —— 100
4.8.1	Effects of Irrigation on Pot-grown JCL Plants —— 102
4.8.2	Effects of Irrigation on Field-grown JCL Plants —— 102
4.8.3	Effects of Fertilization on JCL Plants —— 105

4.9	Conclusions —— 107
	References ——— 109
5	Environmental Aspects of Willow Cultivation for
	Bioenergy ——119
5.1	Introduction —— 119
5.2	Willow Plantations —— 120
5.3	Carbon Sequestration and Greenhouse Gas Fluxes ——— 121
5.3.1	Estimates of Growth and Carbon Sequestration —— 122
5.3.2	Eddy Flux Measurements —— 123
5.3.3	Closing the Carbon Budget —— 128
5.3.4	The Fertilization Effect —— 129
5.3.5	What Are the Limits? ——— 129
5.3.6	Substitution Efficiency and Climate Effect —— 130
5.4	Conclusions —— 132
	References ——— 133
Part	III Biofuels and Biogeochemical Impacts ——135
6	Short Rotation Forestry for Energy Production in Italy:
	Environmental Aspects and New Perspectives of
	Use in Biofuel Industry ——137
6.1	Introduction —— 137
6.2	Ecological Services Provided by SRF ——— 140
6.2.1	Buffer Strips and Ecological Corridors —— 140
6.2.2	Fertirrigation: Disposal of Livestock, Urban and
	Industrial Wastewaters —— 143
6.2.3	Soil Erosion Control —— 144
6.2.4	CO ₂ Uptake and Carbon Sequestration —— 145
6.3	Biofuel Production and SRF ——— 147
6.4	Conclusions —— 149
	References —— 150
7	Populus and Salix Grown in a Short-rotation Coppice for
	Bioenergy: Ecophysiology, Aboveground Productivity, and
	Stand-level Water Use Efficiency ——155
7.1	Introduction —— 155
7.2	Water Use of SRC —— 156
7.3	Water Use Efficiency of SRC —— 157
7.3 7.4	WUE and Related Ecophysiological Variables Literature Surveys ————————————————————————————————————
7.4	Case Study: Populus in the Bohemian-Moravian Highlands —— 171
7.5.1	Introduction —— 171
7.5.1	Site and Stand Description —— 172
7.5.2	Methods —— 173

xviii—	- Contents
7.5.4	Results and Discussion —— 176
7.6	Conclusions —— 180
	References ——— 181
Part	IV Biofuels and Natural Resource Management ——195
8	Afforestation of Salt-affected Marginal Lands with
	Indigenous Tree Species for Sustainable Biomass and
	Bioenergy Production ——197
8.1	Introduction —— 197
8.2	Origin and Distribution of Salt-affected Soils in India —— 199
8.3	Properties of Salt-affected Soils —— 201
8.4	Natural Vegetation on Salt-affected Soils —— 203
8.5	Management Practices for Afforestation on Salt-affected Soils —— 204
8.5.1	Selection of Tree Species —— 204
8.5.2	Pre-planting Management Strategies —— 207
8.5.3	Planting Techniques —— 208
8.5.4	Post-planting Management Strategies —— 211
8.6	Biomass Production —— 212
8.6.1	Saline Soils —— 212
8.6.2	Sodic Soils —— 213
8.7	Bioenergy Production —— 215
8.8	Soil Amelioration —— 217
8.9	Conclusions —— 222
	References —— 222
9	Bioenergy and Prospects for Phytoremediation ——227
9.1	Introduction ——— 227
9.2	Bioenergy Systems for Soil Phytoremediation —— 228
9.2.1	Phytoextraction of Heavy Metals —— 228
9.2.2	SRCs and Rhizodegradation of Organic Pollution —— 232
9.3	Bioenergy Systems for Water Phytoremediation —— 232
9.3.1	Phytoremediation Systems with Municipal Wastewater —— 232
9.3.2	Phytoremediation Systems with Landfill Leachate —— 234
	References —— 236
Part	V Life Cycle Assessment Principles ——241
10	Eight Principles of Uncertainty for Life Cycle Assessment of
	Biofuel Systems ——243
10.1	Introduction: Regulatory LCA —— 243
10.2	Eight Principles of Uncertainty for LCA of Biofuel Systems —— 244
10.3	Principle 1: Biofuel Production Is a Complex System of Systems ——245
10.4	Principle 2: Standardized LCA Methods for Biofuels Do Not Exist ——248
10.5	Principle 3: Empirical Data Are Scarce for Most Aspects of Biofuels ——24

10.6	Principle 4: Local Biofuel LCAs Reduce Uncertainty and Errors ——250
10.7	Principle 5: Sensitive Parameters Cause Order of
	Magnitude Changes —— 252
10.7.1	Biorefinery Natural Gas Efficiency —— 252
10.7.2	Agricultural N_2O Emissions —— 253
10.7.3	Soil Organic Carbon Dynamics and CO ₂ Emissions —— 254
10.7.4	Setting an Uncertainty Standard for Biofuel LCA —— 255
10.8	Principle 6: Indirect Emissions Are Numerous and
	Highly Uncertain —— 256
10.8.1	Indirect Land Use Change —— 256
10.8.2	Multiple Indirect Effects and Global Economic Forecasting —— 257
10.9	Principle 7: Transparency Is Essential for Regulatory LCA —— 260
10.10	Principle 8: Fossil Fuel Reference Systems Are Diverse and
	Uncertain —— 262
10.11	Conclusions —— 263
	References —— 263
11	Energy and GHG Emission Assessments of Biodiesel
	Production in Mato Grosso, Brazil ——269
11.1	Introduction —— 269
11.2	Study Area —— 272
11.3	Methods —— 274
11.3.1	Crop Selection —— 276
11.3.2	Identification of the Area Suitable for Cultivation —— 278
11.3.3	Settings and Constraints Specific for the Case Study —— 280
11.3.4	Problem Formulation —— 281
11.3.5	Other Impacts —— 287
11.4	Results —— 288
11.5	Discussion —— 291
11.6	Conclusions —— 293
	References —— 294
Part VI	Global Potential Assessments ——297
12	Biomass Potential of Switchgrass and Miscanthus on the
	USA's Marginal Lands ——299
12.1	Introduction —— 299
12.2	Methods302
12.2.1	Identification of the USA's Marginal Lands —— 302
12.2.2	Processing Land Cover Data —— 303
12.2.3	NCCPI —— 303
12.2.4	Determination of Marginal Lands —— 303
12.2.5	Development of Empirical Models —— 303
12.2.6	Sample Data —— 304
12.2.7	Regional Model Simulations —— 304

xx		Contents
12.5	2.8	Data Selection —— 305
12.2	2.9	Model Development and Validation —— 306
12.3	3	Results and Discussion —— 306
12.3	3.1	USA Marginal Lands —— 306
12.3	3.2	Model Developments and Validations —— 307
12.3	3.3	Biomass Estimates of Switchgrass and Miscanthus —— 310
12.3	3.4	Comparison of Switchgrass and Miscanthus —— 312
12.3	3.5	Limitations and Future Study —— 313
12.4	4	Conclusions —— 313
		References —— 314
13		Global Agro-ecological Challenges in Commercial Biodiesel
		Production from Jatropha curcas: Seed Productivity to
		Disease Incidence ——319
13.	1	Introduction —— 319
13.2	2	Standardization of Agro-technology —— 321
13.5	2.1	Propagation Techniques —— 321
13.2	2.2	Planting Material —— 323
13.2	2.3	Nursery Management ——— 324
13.2	2.4	Field Planting —— 324
13.3	3	Global Seed Productivity —— 326
13.4	4	Techno-commercial Economics —— 329
13.5	5	Scope for Improvements —— 331
13.6	3	Disease Incidence —— 333
13.	7	Soil Amelioration —— 335
13.8	3	Conclusions —— 335
		References —— 336

Subject Index ——343