

Table of contents

Foreword	5	1.3.7 Social and community impacts	46
Preface	7	1.3.8 Summary of Good Management Practices	47
About the Authors	9	1.4 The soil-plant-climate continuum	51
Acknowledgements	13	1.4.1 Climate	51
Abbreviations	22	1.4.2 Soils	53
Units	23	1.5 Physiology of the sugarcane plant	54
Technical Glossary	24	1.5.1 Brief overview	54
		1.5.2 Main growth stages in sugarcane	56
		1.5.3 Plant characteristics that impact on cultivar performance	56
		1.6 Sugarcane cultivars	59
		1.6.1 Cultivars the key to economic sustainability	59
		1.6.2 New emerging developments	59
		1.6.3 Sugarcane taxonomy	60
		1.6.4 Centers of origin	60
		1.6.5 Hybridization	61
		1.6.6 Diseases	61
		1.6.7 Pests	61
		1.7 Cultivar management	62
		1.7.1 Identification	62
		1.7.2 Agronomic characteristics	62
		1.7.3 Main components of yield	63
		1.7.4 Harvesting and transport	63
		1.7.5 Milling quality characteristics (see also Section 2)	63
		1.7.6 Plant breeding and selection	64
		1.7.7 Field and planting hygiene	64
		1.7.8 Seedcane management	64
		1.8 Conclusions	66
		1.9 References	68
Part 1: SUGARCANE AGRICULTURE	33		
1 SUGARCANE AND ITS ENVIRONMENT	35	2 THE SOIL AND ITS ENVIRONMENT	73
1.1 Introduction	35	2.1 Why is knowledge of soil important?	73
1.2 The changing global sugarcane landscape	35	2.2 Origin of soils and their distribution	73
1.2.1 Sugar supply and demand dynamics	35		
1.2.2 Trade liberalization	36		
1.2.3 Economic development	36		
1.2.4 Biofuel and renewable energy	37		
1.2.5 Technological change	37		
1.2.6 Global warming and climate change	37		
1.2.7 Environmental issues	38		
1.3 The impacts of sugarcane production on the environment	39		
1.3.1 Biodiversity loss	39		
1.3.2 Water resource use	40		
1.3.3 Pollution of water sources	41		
1.3.4 Soil loss impacts	43		
1.3.5 Soil degradation	44		
1.3.6 Air quality impacts	45		

2.2.1	Soil composition and functions	73	3.2.4	Planting	134
2.2.2	Weathering agents contributing to soil formation	74	3.2.5	Ratoon management	138
2.2.3	Soil development	75	3.3	References	143
2.3	Recognizing important soil properties	78	4	WEED CONTROL	145
2.4	Impact of clay content on agronomic management	83	4.1	Background	145
2.5	Classifying soils	86	4.2	The need for weed control in sugarcane	145
2.6	Use of soil specific management guidelines	91	4.3	Weeds of sugarcane	146
2.7	The role of soil mapping	93	4.3.1	Weed groups	146
2.7.1	Choosing an appropriate classification system	94	4.3.2	Weeds associated with poor growth areas	148
2.7.2	Potential benefits of soil survey maps	94	4.3.3	Some problem species	149
2.7.3	Range of soil mapping options	95	4.4	Non-chemical weed control methods	150
2.8	Soil health issues	95	4.4.1	Physical	150
2.8.1	The new emerging view of soil health	95	4.4.2	Hand weeding and hand hoeing	151
2.8.2	Yield plateau assessments	96	4.4.3	Mechanical cultivation	152
2.8.3	Paired site outcomes	96	4.5	Chemical weed control	152
2.8.4	Loss of organic matter	97	4.5.1	Broad categories of herbicides and their use	152
2.8.5	Acidification	98	4.5.2	Chemical groups of herbicides	153
2.8.6	Soil salinity and sodicity	99	4.5.3	Timing of herbicide application	155
2.8.7	Soil compaction	99	4.5.4	Fate of herbicides in the environment	157
2.9	Management strategies for improving soil health	100	4.5.5	Choice of herbicide treatment	159
2.9.1	What constitutes a healthy soil?	101	4.5.6	Formulations	160
2.9.2	Good management practices to improve soil health	101	4.6	Application of herbicides	160
2.9.3	Green manuring	102	4.6.1	Application equipment	160
2.9.4	Bioremedial amelioration with organic amendments	105	4.6.2	Weather conditions and drift control	162
2.9.5	Minimum or reduced tillage	107	4.6.3	Chemigation	162
2.9.6	Managing soil acidification	107	4.6.4	Herbicide regulation	163
2.9.7	Trash management	107	4.6.5	Responsible use of herbicides	163
2.9.8	Managing soil compaction	111	4.7	Integrated weed control	164
2.9.9	Financial, social and environmental costs of improving soil health	111	4.8	Weed control planning	164
2.10	Conclusions	113	4.9	Optimizing performance and minimizing negative impacts	164
2.11	References	113	4.10	References	168
3	SUGARCANE CROPPING SYSTEM	117	5	SUGARCANE NUTRITION AND FERTILIZATION	169
3.1	Land use planning and conservation	117	5.1	Introduction	169
3.1.1	Introduction	117	5.1.1	Nutrients required by sugarcane	169
3.1.2	Land evaluation	117	5.1.2	Principles of nutrient management	170
3.1.3	The land use plan	123	5.1.3	Amounts of nutrients taken up by sugarcane	171
3.1.4	Monitoring and evaluation plan	127	5.1.4	Impact of climate on nutrient uptake	171
3.2	Crop establishment	128	5.1.5	Soil factors affecting nutrient supply	173
3.2.1	Introduction	128	5.1.6	Clay minerals	173
3.2.2	Crop eradication	129	5.1.7	Cation exchange capacity	173
3.2.3	Seedbed preparation	132	5.1.8	Soil organic matter	174
			5.1.9	Soil pH, acidity and alkalinity	174

5.1.10	Movement of nutrients in the soil	175	6.2.2	Soil physical properties affecting irrigation	222
5.2	Nitrogen (N)	176	6.2.3	Soil texture as a factor in choice of irrigation method	223
5.2.1	Importance of nitrogen	176	6.2.4	Management allowable deficit	224
5.2.2	The nitrogen cycle	176	6.2.5	Moisture extraction patterns	225
5.2.3	Nitrogen losses	178	6.2.6	Soils and water quality	225
5.2.4	Factors affecting the nitrogen requirement of sugarcane	179	6.3	Irrigation application systems	225
5.2.5	How to adopt soil specific nitrogen recommendations	183	6.3.1	Low pressure systems: surface irrigation	225
5.2.6	Nitrogen fertilizers	186	6.3.2	Medium pressure systems: drip irrigation	227
5.2.7	Managing N fertilizer	187	6.3.3	Medium pressure mechanized systems: center pivot irrigation	230
5.3	Phosphorus (P)	191	6.3.4	Medium pressure mechanized systems: linear systems (moving laterals)	231
5.3.1	The importance of phosphorus	191	6.3.5	High pressure manually moved systems: impact sprinklers	232
5.3.2	Phosphorus cycle in the soil	192	6.3.6	Very high pressure self-traveler systems: travelling guns/rain guns	234
5.3.3	Factors affecting phosphorus availability	193	6.4	Choice of irrigation method	235
5.3.4	Phosphate carriers	194	6.4.1	Economic aspects	235
5.3.5	Managing the P requirement of sugarcane	194	6.4.2	Summary of factors influencing the selection of a particular irrigation system	236
5.4	Potassium (K)	196	6.4.3	Energy aspects	236
5.4.1	Importance of potassium	196	6.5	Irrigation performance	237
5.4.2	Potassium cycle in the soil	197	6.5.1	Efficiency	237
5.4.3	Factors affecting potassium availability	197	6.5.2	Uniformity	239
5.4.4	Potassium sources	199	6.5.3	Improvement of irrigation efficiency	240
5.4.5	Managing the K requirement of sugarcane	200	6.6	Scheduling	243
5.5	Calcium (Ca)	203	6.7	Potential impact of irrigation practices on the environment, communities and health	244
5.6	Magnesium (Mg)	203	6.7.1	Environmental impact assessment (EIA) for irrigation developments	245
5.7	Sulfur (S)	205	6.7.2	Environmental Management System (EMS) for sugarcane developments	245
5.8	Silicon (Si)	206	6.7.3	Effects on communities	245
5.8.1	Benefits from silicon treatment	207	6.7.4	Effects on health	246
5.8.2	Soil Si source/sink pools	207	6.8	Water supply and hydrology	246
5.8.3	Managing silicon nutrition	208	6.9	References	248
5.8.4	Silicon fertilizer sources for sugarcane	208			
5.8.5	Silicon leaf deficiency symptoms	209			
5.9	Micronutrients	209			
5.10	Good management practices for minimizing environmental impact	211			
5.11	General conclusions	212			
5.12	References	213			
6	IRRIGATION	219	7	DRAINAGE, IRRIGATION WATER QUALITY AND SALT AFFECTED SOILS	251
6.1	Sugarcane water demand	219	7.1	Introduction	251
6.1.1	Crop water requirements (CWR)	219	7.2	Drainage of agricultural lands	252
6.1.2	Irrigation requirements in relation to the soil water balance	220	7.3	Types of drainage	252
6.2	Influence of type of soil on irrigation	221	7.3.1	Internal drainage of soils	252
6.2.1	Soil morphology	221			

7.3.2	Inundation	253	8.8	Other cultural methods of disease control	291
7.3.3	Aeration	254	8.9	Sugarcane industry disease control schemes	291
7.4	Water table management	254	8.10	Monitoring disease incidence	291
7.5	Drainage methods	256	8.10.1	Monitoring diseases in seedcane nurseries	291
7.5.1	Surface drainage	256	8.10.2	Monitoring diseases in commercial fields	292
7.5.2	Subsurface drainage	258	8.11	Chemical control	292
7.5.3	Mole drains	259	8.12	Some common diseases of importance	292
7.6	Drainage design	261	8.12.1	Ratoon stunting disease (RSD)	293
7.6.1	Surface drainage design	261	8.12.2	Smut	293
7.6.2	Subsurface drainage design	263	8.12.3	Mosaic	294
7.6.3	Pumped outfalls	266	8.12.4	Rust	295
7.7	Flood control	266	8.12.5	Red rot	295
7.8	Water quality	266	8.13	Diseases in selected regions	296
7.9	Water blending	268	8.13.1	Australia	297
7.10	Water table depth	269	8.13.2	Papua-New Guinea	297
7.11	Salt affected soils	270	8.13.3	The Far East and India	297
7.12	Salinity dominated soils	270	8.13.4	Africa	297
7.12.1	Origin of saline soils	270	8.13.5	The Americas	297
7.12.2	Measurement of salinity	271	8.14	The way forward towards sustainable control of diseases	297
7.12.3	Influence of salinity on crop yield	271	8.15	Summary	298
7.13	Reclamation of saline soils	272	8.16	References	300
7.14	Irrigation method and salinity control	273	9	PEST CONTROL	301
7.15	Sodicity dominated soils	273	9.1	Introduction	301
7.16	Reclamation of sodic soils	276	9.1.1	Integrated pest management	302
7.17	Salinity, sodicity and cane yield	277	9.1.2	Pesticides	302
7.18	Impact of drainage and salinity on the environment	278	9.1.3	Steps in managing a pest problem	305
7.19	Impact of drainage on health	279	9.2	Stalk borers	308
7.20	Good management practices	280	9.2.1	Top borer, <i>Scirpophaga excerptalis</i>	308
7.20.1	Pre-implementation: survey and planning requirements for drainage	280	9.2.2	Sugarcane stem borers, <i>Diatraea</i> species	309
7.20.2	Post-implementation: identification of drainage, salinity and sodicity problems	280	9.2.3	African sugarcane borer, <i>Eldana saccharina</i>	311
7.20.3	Monitoring of drainage, salinity and sodicity problems	281	9.2.4	Other stalk borers	312
7.20.4	Mitigation measures	281	9.3	White grubs	315
7.21	References	282	9.3.1	Canegrubs in Australia	315
8	DISEASE CONTROL	285	9.3.2	Other white grubs and soil insect pests	317
8.1	Introduction	285	9.4	Sap feeders	318
8.2	Sugarcane quarantine	286	9.4.1	Above ground sap feeders	318
8.3	Integrated disease control in sugarcane	287	9.4.2	Below ground sap feeders	319
8.4	Varietal resistance	287	9.5	Leaf feeders	321
8.5	Seedcane health	288	9.6	Nematodes	322
8.6	Effective crop eradication	290	9.6.1	Control strategies	323
8.7	Roguing	290	9.7	Vertebrates	324

9.8	Social, financial and environmental costs of pest control	325	11	HARVESTING AND HAULAGE	355
9.8.1	Social cost of practices used to control pests	325	11.1	Harvesting	355
9.8.2	Financial cost of pests	325	11.1.1	Pre-harvest	355
9.8.3	Environmental cost of practices used to control pests	326	11.1.2	Manual system	355
9.9	Summary	326	11.1.3	Mechanical whole stick	358
9.10	References	327	11.1.4	Chopper harvesters	359
10	CHEMICAL RIPENING, FLOWER SUPPRESSION AND GROWTH	331	11.1.5	Factors affecting harvesting and loading	360
10.1	Introduction	331	11.1.6	Summary of social, financial and environmental risks and benefits of each practice	362
10.2	Background	331	11.2	Haulage	363
10.3	Natural ripening	332	11.2.1	Haulage systems	363
10.3.1	Temperature	332	11.2.2	Transloading	366
10.3.2	Age	334	11.2.3	Factors affecting haulage systems	367
10.3.3	Water stress	335	11.2.4	Summary of social, financial and environmental risks and benefits of each practice	370
10.4	Chemical ripening	336	11.3	References	372
10.4.1	Milling periods and crop characteristics	336	12	AGROCHEMICALS AND FARM SAFETY	375
10.4.2	Identifying crops that are suitable for chemical ripening	337	12.1	Agrochemicals	375
10.4.3	Chemicals used for ripening	337	12.1.1	Background	375
10.4.4	Cultivar responses to chemical ripening	339	12.1.2	Pesticide regulation	376
10.4.5	Methods of applying chemical ripeners	340	12.1.3	Agrochemicals used in sugarcane production	380
10.4.6	Factors influencing crop response to chemical ripeners	341	12.1.4	Environmental and safety concerns with sugarcane pesticides	380
10.5	Flowering	344	12.1.5	Minimizing negative impacts	381
10.5.1	The occurrence of flowering	344	12.1.6	Standards and certification	386
10.5.2	Suppression of the flowering process	345	12.2	Farm safety	386
10.6	Possible environmental impacts of chemicals used for ripening and flower control	346	12.2.1	Background	386
10.6.1	Effects of some ripening chemicals on soil organisms	346	12.2.2	Safety management systems (also see Part 3, Chapter 3.)	387
10.6.2	Chemical release into the environment	347	12.3	References	392
10.7	Potential impacts of growth regulators on economics and possible collateral damage	348	13	BIOMASS MANAGEMENT: ETHANOL AND ELECTRICITY GENERATION	395
10.7.1	Economic impacts	348	13.1	Co-products: ethanol and biomass for electricity production	395
10.7.2	Potential social health impacts	348	13.1.1	Introduction	395
10.8	Mitigating factors impacting on the effective use of ripeners and ethephon to control flowering	349	13.1.2	Ethanol	396
10.9	Conclusion	350	13.1.3	Power generation	400
10.10	References	352	13.1.4	Cellulose technology	400
			13.2	Variety breeding for ethanol and biomass	401
			13.2.1	Recent directions in plant breeding	401
			13.2.2	Future strategies in plant breeding	402
			13.3	Towards good pre-harvest field management practices	403

1.4.10	Energy efficiency	453	2	MANAGEMENT OF WASTES AND EFFLUENTS	477
1.5	Energy and chemical use in refining	454	2.1	Identification/characterization and disposal of solid wastes	477
1.5.1	Refined sugar – autonomous refineries	454	2.1.1	Roadside cane spillage	477
1.5.2	Refined sugar – back-end refineries	455	2.1.2	Cane washing mud	477
1.5.3	Plantation white sugar	455	2.1.3	Filter cake from juice clarification	477
1.6	Process loss control and monitoring	456	2.1.4	Press muds from refinery processes	479
1.6.1	Measurement of recovery efficiency	456	2.1.5	Boiler ash (and fly ash)	480
1.6.2	Physical losses	456	2.1.6	Sludge from effluent treatment plants	481
1.6.3	Chemical losses	457	2.1.7	Laboratory filter papers with lead acetate precipitates	481
1.6.4	Microbiological losses	457	2.2	Management of waste water and other liquid effluents	482
1.7	Environmental management systems	457	2.2.1	Sources of liquid effluents	482
1.7.1	Procedures and monitoring systems	457	2.2.2	Legal requirements and reporting	484
1.7.2	Factory policies	458	2.2.3	Treatment technologies	486
1.7.3	Internal audits	458	2.3	Management of dust/particulate emissions	493
1.7.4	External audits and reporting	458	2.3.1	Boiler emissions regulations	493
1.7.5	Bundling of storage areas	458	2.3.2	Removal of particulates from boiler flue gas	494
1.8	Management of energy	459	2.3.3	Gaseous emissions	496
1.8.1	Energy generation from bagasse	459	2.3.4	Management of dust from bagasse systems	497
1.8.2	Bagasse balance and management of surplus/deficit	460	2.3.5	Dust in the workplace	498
1.8.3	Bagasse drying	461	2.4	References	498
1.8.4	Efficient management of boilers	462	3	CO-PRODUCT PRODUCTION	500
1.8.5	Supplementary fuels	462	3.1	Management of molasses storage and handling	500
1.8.6	Factory steam and energy balance	463	3.1.1	Losses in storage	500
1.8.7	Batch vs. continuous processing	464	3.1.2	Maillard reactions in molasses	500
1.8.8	Generation of power for export	465	3.2	Large scale storage of bagasse	501
1.8.9	Utilization of waste heat	467	3.2.1	Dry bulk storage of bagasse	501
1.8.10	Potential for biogas generation and use	467	3.2.2	Storage for paper manufacture	503
1.8.11	Energy-saving lighting, ventilation and other opportunities	468	3.2.3	Export of bagasse	503
1.9	Sustainability and management of carbon emissions	468	3.3	Management of vinasse from a distillery	504
1.9.1	Sustainability	468	3.3.1	Direct use of vinasse for irrigation	504
1.9.2	Estimation/measurement of carbon footprint	469	3.3.2	Evaporation to Condensed Molasses Solubles (CMS)	505
1.9.3	Finance opportunities for emission reductions	470	3.3.3	Spray drying	505
1.9.4	Use of sustainability metrics	471	3.3.4	Incineration in boilers	505
1.10	Safety training and safety management	472	3.3.5	Use in composting	505
1.10.1	Policy and management	472	3.3.6	Anaerobic digestion to produce biogas	505
1.10.2	Hazards in the workplace	472	3.3.7	Life cycle assessment of various options for vinasse usage	508
1.10.3	Risk assessment and mitigation	472	3.4	Marketability of treated residues	508
1.10.4	Training	473	3.4.1	Compost	508
1.10.5	Safety equipment	473			
1.10.6	Measurement of lost time due to safety incidents	474			
1.11	References	475			

3.4.2	Filter cake	509	5.2.5	Capacity	554
3.4.3	Boiler fly ash	509	5.2.6	Ownership	554
3.4.4	CMS and spray dried vinasse	509	5.2.7	Culture and tradition	554
3.4.5	Bagasse pellets	510	5.3	Outgrower models	554
3.4.6	Yeast	510	5.3.1	The individual outgrower model	555
3.5	References	510	5.3.2	The block farm model	556
			5.3.3	The trust and management company model	558
			5.3.4	The association led model	559
			5.3.5	The community trust farm model	559
			5.3.6	The joint venture model	561
			5.3.7	The partnership model	562
			5.4	Building capacity	563
			5.4.1	Training	563
			5.4.2	Methods and models for training outgrowers	565
			5.5	Extension services	567
			5.5.1	Extension service providers	567
			5.5.2	Payment mechanisms for extension	575
			5.5.3	Monitoring and evaluation of extension	577
			5.6	Supporting services	577
			5.6.1	Management Information Systems (MIS)	577
			5.6.2	Aerial imagery and mapping	578
			5.6.3	Contracted services	579
			5.6.4	Seedcane supply	579
			5.6.5	Input supply	580
			5.7	Contractual arrangements	580
			5.7.1	Cane supply agreement	580
			5.8	Summary of good management practice recommendations	581
			5.9	Conclusion	582
			5.10	References	582
			APPENDIX 1	Soil form identification key used in the South African sugar industry	587
			APPENDIX 2	Guide to taking soil and leaf samples	588
			APPENDIX 3	Examples of selected soil specific crop management recommendations	592
			APPENDIX 4	Land forming for sugarcane	594
			APPENDIX 5	Relevant chapter cross reference Index to IFC and Bonsucro Standards	597
			INDEX		599
Part 3: SOCIAL, LABOR AND OUTGROWERS		513			
1	INTRODUCTION	515			
2	REGULATORY FRAMEWORKS	517			
2.1	Legal and industry regulation	517			
2.2	Market driven regulation	519			
2.2.1	Bonsucro	520			
2.2.2	Fair Trade International	522			
2.2.3	Organically certified sugar	523			
2.2.4	Partner organizations	526			
3	HUMAN RESOURCE MANAGEMENT	527			
3.1	Compliance	527			
3.1.1	International labor conventions	528			
3.1.2	Healthy working environment	531			
3.1.3	Human resource development	534			
3.1.4	Gender equality	534			
4	SOCIAL WELFARE AND COMMUNITY INITIATIVES	537			
4.1	Welfare service provision	538			
4.1.1	Housing	538			
4.1.2	Community industry engagement and environmental management	539			
4.1.3	Education	539			
4.1.4	Health care	541			
4.2	Land and resource management	545			
4.2.1	Land ownership	545			
4.2.2	Displacement and compensation	546			
4.2.3	Cultural practice and cultural asset management	546			
5	OUTGROWERS	549			
5.1	Outgrowers and the changing dynamics of the industry	549			
5.2	Important factors in outgrower development	550			
5.2.1	Social and technical preparation	550			
5.2.2	Demand driven approach	551			
5.2.3	Land	552			
5.2.4	Climatic conditions – irrigation	552			