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Achieving sustainable cultivation of soybeans

Volume 1: Breeding and cultivation techniques

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Contents

Series list	ix
Acknowledgements	xiii
Introduction	xiv

Part 1 Plant physiology and breeding

1	Advances in understanding soybean physiology and growth	3
	<i>M. B. Zhang and X. T. Chu, Centre for Integrative Legume Research, University of Queensland, Australia; H. N. Su, University of Queensland, Australia, and National Navel Orange Engineering Research Center, Gannan Normal University, China; and A. H. Hastwell, P. M. Gresshoff and B. J. Ferguson, Centre for Integrative Legume Research, University of Queensland, Australia</i>	
1	Introduction	3
2	Biological nitrogen fixation in soybean	4
3	Classical techniques for understanding soybean physiology	5
4	Mutagenesis methods and soybean mutant lines	8
5	Modern experimental techniques applicable to soybean physiology research	11
6	The soybean genome and associated bioinformatics resources	13
7	Conclusion	15
8	Where to look for further information	15
9	References	15
2	Maintaining and utilizing the genetic diversity of soybeans	23
	<i>Randall Nelson, USDA-ARS and University of Illinois, USA</i>	
1	Introduction	23
2	Germplasm collections	23
3	The U.S. gene pool	25
4	Categories of exotic germplasm	30
5	Utilizing new genetic diversity	32
6	Conclusion	34
7	References	35
3	Advances in conventional soybean breeding techniques	39
	<i>E. E. Large, E. Beche, D. Mutoni and A. Scaboo, University of Missouri, USA</i>	
1	Introduction: evolution of the modern soybean	39
2	The rise of genetically engineered soybeans	42
3	Genetic architecture	43
4	Germplasm diversity	54
5	Seed certification and mechanization for plant breeding	57
6	Minimizing phenotypic variation due to non-genetic factors	60
7	Field and laboratory phenotyping	63
8	Breeding to reduce losses from biotic and abiotic stresses	67

9	Management and analysis of phenotyping data	71
10	Soybean cultivation in developing countries	72
11	Case study: the USAID SIL	74
12	Summary and future trends	76
13	Where to look for further information	78
14	References	79
4	Mapping the soybean genome	89
	<i>Xiaobo Wang, Anhui Agricultural University, China; and Lijuan Qiu, Chinese Academy of Agricultural Sciences, China</i>	
1	Introduction	89
2	Mapping the soybean genome: development of genome maps	90
3	New mapping techniques: specific-locus amplified fragment sequencing (SLAF-seq) mapping, whole-genome re-sequencing mapping and comparative genome mapping	93
4	Case study: comparing wild and cultivated soybean varieties	97
5	Case study: identifying salinity tolerance in soybean	98
6	Summary	98
7	Future trends	99
8	Where to look for further information	101
9	References	102
5	Advances in marker-assisted breeding of soybean	109
	<i>T. Vuong, University of Missouri, USA; and D. Walker, USDA-ARS and University of Illinois, USA</i>	
1	Introduction	109
2	Molecular marker types	110
3	Marker assays and genotyping platforms for marker-assisted selection	113
4	Marker-assisted selection in soybean breeding	121
5	Genomic selection	128
6	Conclusion and future trends	130
7	Acknowledgements	132
8	Where to look for further information	132
9	References	132
6	Advances in the genetic modification of soybeans	147
	<i>Wensheng Hou, Chinese Academy of Agricultural Sciences, China</i>	
1	Introduction	147
2	Genetic modification of agronomic traits: herbicide tolerance and insect resistance	148
3	Genetic modification of other agronomic traits	152
4	Genome editing technology	156
5	Case studies	159
6	Summary	160
7	Future trends in research	161
8	Where to look for further information	162
9	References	162

7	Advances in the drought and heat resistance of soybean <i>Heng Ye, Babu Valliyodan, Li Song, J. Grover Shannon, Pengyin Chen and Henry T. Nguyen, University of Missouri, USA</i>	171
1	Introduction	171
2	Drought resistance traits: introduction, root system architectures and anatomy	173
3	Other traits for drought resistance and heat tolerance	177
4	Genomic resources and strategies	179
5	Advances in breeding for drought and heat resistance	181
6	Conclusions and future perspectives	181
7	Acknowledgements	182
8	References	182
8	Towards improving the salt tolerance of soybean <i>Ailin Liu, Wai-Lun Cheung, Wai-Shing Yung, Carol Lee, Fuk-Ling Wong, Kit-Wah Siu and Hon-Ming Lam, The Chinese University of Hong Kong, China</i>	191
1	Introduction	191
2	Soybean germplasm resources for salt tolerance	194
3	Integrating -omic approaches for investigating salt tolerance in soybean	196
4	Molecular breeding of salt-tolerant soybean	199
5	Future trends and conclusion	200
6	Where to look for further information	206
7	Acknowledgements	206
8	References	206
9	Advances in flood-tolerant varieties of soybean <i>C. Wu, L. Mozzoni and W. Hummer, University of Arkansas, USA; P. Chen, G. Shannon, H. Ye and H. T. Nguyen, University of Missouri, USA; G. Kaur and J. Orłowski, Mississippi State University, USA; T. Carter, USDA-ARS, USA; and B. Buckley, Louisiana State University, USA</i>	217
1	Introduction	217
2	Flooding stress and damage	218
3	Responses of soybean to flooding	220
4	Agronomic management strategies	223
5	Breeding soybean for flooding tolerance	224
6	Summary	229
7	References	230

Part 2 Cultivation techniques

10	Modelling the effects of temperature and photoperiod on soybean reproductive development <i>H. Yang, University of Nebraska, USA</i>	239
1	Introduction	239
2	Observed responses of soybean reproductive stages to temperature and photoperiod	242
3	Modelling approaches for soybean reproductive stages	245

4	Discussion of models	256
5	Conclusion	258
6	References	258
11	Defining and implementing best management practices in soybean production	265
	<i>D. Reynolds, Mississippi State University, USA</i>	
1	Introduction	265
2	Tillage	266
3	Soil fertility	268
4	Variety selection	269
5	Agronomic practices	270
6	Pest management	271
7	Development of best management practices	271
8	References	272
12	Sustainable soybean production research and practice: contrasting case studies from three soybean production areas	277
	<i>Roger W. Elmore, Rodrigo Werle and Charles Wortmann, University of Nebraska, USA; Phinehas Tukamuhabwa, Makerere University, Uganda; and Nathan Mueller, University of Nebraska, USA</i>	
1	Introduction	277
2	Soybean production in Nebraska, USA	279
3	Soybean production in Uganda	289
4	Soybean production in Brazil	293
5	Summary and conclusions	300
6	Where to look for further information	300
7	References	301
13	Supporting smallholders in soybean cultivation: the example of Zimbabwe	305
	<i>Byron Zamasiya and Kefasi Nyikahadzo, University of Zimbabwe, Zimbabwe</i>	
1	Introduction	305
2	Background to soybean production in Zimbabwe	306
3	Review of selected soybean promotion projects in Zimbabwe	307
4	Constraints to soybean cultivation in Zimbabwe	311
5	Opportunities for soybean cultivation in Zimbabwe	314
6	Conclusion and recommendations	316
7	Where to look for further information	316
8	References	316
	Index	321

Introduction

Soybeans are one of the most widely grown crops in the world. As the world's main source of vegetable protein, they have a wide range of food and non-food uses. Current yields need to increase significantly to meet growing demand but in a way that reduces input use, does not damage the environment and is resilient to climate change. These challenges are addressed in the two volumes of *Achieving sustainable cultivation of soybeans*:

- Volume 1: Breeding and cultivation techniques
- Volume 2: Diseases, pests, food and other uses

Volume 1 reviews the wealth of research addressing this challenge, focussing particularly on breeding and cultivation techniques. The volume reviews the latest research on crop physiology and genetic diversity, providing detailed coverage of key advances in breeding and their application to produce more resilient drought, salt and flood-tolerant varieties of soybean. The volume also summarises research on good agricultural practices to optimise soybean cultivation and make it more sustainable.

Part 1 Plant physiology and breeding

The chapters in the first part of the volume review our understanding of soybean physiology and genetic diversity. They then discuss advances in conventional and marker-assisted breeding, as well as transgenic techniques, and their use to produce more stress-resistant varieties. The subject of Chapter 1 is advances in understanding soybean physiology and growth. The chapter covers biological nitrogen fixation in soybean and classical techniques for understanding soybean physiology. It then moves on to look at soybean mutagenesis methods and soybean mutant lines, as well as modern experimental techniques applicable to soybean physiology research. Finally, the chapter examines the soybean genome and associated bioinformatics resources.

Chapter 2 moves on to look at the challenge of maintaining and utilizing the genetic diversity of soybeans. The aim of plant breeding is to create genetically diverse gene pools and then devise strategies to consolidate favorable alleles whilst eliminating those that impede improvement. The chapter describes the major soybean germplasm collections of the world as sources of available genetic diversity, then reviews the formation of the current commercially-used gene pool for soybean breeding in North America. It then considers how adding new genetic diversity can improve the rate of gain for seed yield and how various sources of exotic germplasm can be utilized within different segments of a national soybean program.

Complementing the preceding chapter's focus on soybean genetic diversity, Chapter 3 examines advances in conventional soybean breeding techniques. The chapter provides an overview of the evolution of modern soybean varieties. The chapter examines the genetic architecture of soybean and its germplasm diversity, as well as describing the process of seed certification for plant breeding. The chapter looks at the challenge of minimizing phenotypic variation due to non-genetic factors, examining field and laboratory phenotyping, breeding to reduce losses from biotic and abiotic stress, and the management and analysis of phenotyping data. Finally, the chapter looks at soybean cultivation in developing countries and includes a detailed case study of the work of the USAID Soybean Innovation Lab.

Continuing the preceding chapters' focus on genetics, the subject of Chapter 4 is mapping the soybean genome. Soybean is one of the most important grain legumes, but genetic mapping has been less advanced for soybean than for other crops, which limits modern soybean molecular breeding. The chapter discusses the significant progress in mapping the soybean genome that has now been made. The chapter examines the use of restriction fragment length polymorphism molecular markers, high-throughput genotyping markers, SLAF-Seq (specific-locus amplified fragment sequencing) mapping, whole-genome re-sequencing mapping and comparative genome mapping. This has allowed the identification of quantitative trait loci (QTLs) or genes to improve yield, nutritional quality, as well as biotic and abiotic stress tolerance. Finally, the chapter includes two detailed genomics case studies on comparing wild and cultivated soybean varieties and identifying salinity tolerance in soybean.

Chapter 5 continues the focus on soybean genetics, discussing advances in marker-assisted breeding of soybeans. It begins by discussing types of molecular markers such as simple sequence repeats (SSRs) and single nucleotide polymorphism (SNPs). It then discusses marker assays and genotyping platforms for marker-assisted selection, including SSR marker genotyping and developments in high-throughput genotyping. The chapter then reviews applications of marker-assisted selection in soybean breeding to deal with biotic threats such as nematodes, rusts and aphids, abiotic threats such as salinity, as well as aspects of quality such as fatty acid composition. The chapter concludes by looking at developments in genomic selection.

The following chapter, Chapter 6 considers advances in genetic modification of soybeans. Transgenic soybean holds a significant share of the market. However, the traits improved by genetic modification of soybean so far remain limited, with herbicide tolerance the primary trait exhibited by genetically modified (GM) soybean. Several other agronomic traits could be usefully improved, such as insect resistance, oil composition and amino acid composition. Valuable genes and efficient transformation systems are the key requirements for the improvement of GM soybean. The chapter describes recent advances in the genetic modification of important agronomic traits of soybean, and reviews the genome editing technology available.

Moving on to focus on the effects of genetics on specific characteristics of soybean, Chapter 7 examines advances in improving drought and heat resistance in soybean. Drought combined with heat is the major abiotic stress that threatens soybean crop production, particularly in the context of climate change. The success of soybean improvement under drought and heat stress depends on the discovery and utilization of genetic variations present in germplasm. The chapter discusses the identification of quantitative trait loci (QTL) associated with the traits contributing to drought and heat tolerance. In addition, the chapter discusses genomic resources that can facilitate a better understanding of phenotype-genotype association and formulate genomic-assisted breeding strategies.

As Chapter 8 indicates, the production of soybean is severely restricted by salt stress. The chapter describes different approaches to developing salt tolerance in soybean, including a study of germplasm resources for salt tolerance, 'omic' approaches and molecular breeding of salt-tolerant soybean varieties. The final chapter in Part 1, Chapter 9, deals with advances in flood-tolerant varieties of soybean. Flooding is a serious abiotic stress that can cause drastic soybean yield loss around the world. As a result, a large number of studies have been conducted to understand soybean responses to flooding on agronomic, morphological, physiological, and molecular levels. The chapter summarises current understanding of the impact of flooding and the natural adaptation of

soybean to flooding. The chapter evaluates current and future flooding survival strategies, including the use of genetic engineering to improve flooding tolerance, and various agronomic techniques for the management of flooding stress. The chapter concludes that an integrated approach is likely to prove most effective in preventing and mitigating the effects of flooding on soybean growth and yield.

Part 2 Cultivation techniques

The second part of the volume reviews key advances in cultivation techniques to make the most of these new varieties. The subject of Chapter 10 is modelling the effects of temperature and photoperiod on soybean reproductive development. It has long been recognized that the development rate and yield of soybean is sensitive to temperature and photoperiod. The chapter considers a range of experimental evidence concerning the precise effects of these factors on soybean reproductive development, and reviews methods of modelling these effects. The chapter concludes that integrated modelling and experimentation at gene level may hold the key to improving the modelling of temperature and photoperiod effects on soybean development.

Chapter 11 moves on to the subject of defining and implementing best management practices in soybean production. In order to optimise the profitability of soybean production while minimizing adverse effects on the environment, it is important to define and implement the most effective management, agronomic and technological practices. The chapter considers the following components of soybean production: tillage systems, soil fertility, variety selection, agronomic practices and pest management. Such practices will, of course, vary between geographic regions; for instance, best tillage practice may be determined by soil type and environmental conditions. However, in each case, the chapter describes general practices that transcend geographic areas, giving consideration to how these practices might be adjusted to accommodate region-specific factors. The chapter concludes with recommendations for how these practices could be implemented within an overall management plan.

As Chapter 11 points out, good agricultural practices (GAPs) vary within and among production systems. Complementing the themes of the preceding two chapters on modelling and best management practices, Chapter 12 examines contrasting case studies from three soybean production areas to illuminate sustainable soybean production research and practice. The chapter focuses on examples from the USA (Nebraska), Brazil, and Uganda to compare and contrast current production practices and ways they can be optimized. As the chapter shows, in all three cases abundant opportunities exist to overcome production constraints while improving sustainability.

The final chapter of the volume, Chapter 13, looks at supporting smallholders in soybean cultivation, with a particular focus on the example of Zimbabwe. Low crop productivity due to soil fertility decline is a major challenge, constraining smallholder farming systems in sub-Saharan Africa. The decline in soil fertility is largely due to continuous cropping without soil replenishment and reduced nitrogen fixation. In Zimbabwe, soybean has emerged as a key crop that has the potential to help to improve soil fertility and food and income security among smallholder farmers. The chapter reviews collaborative projects that have promoted soybean cultivation by smallholder farmers, and makes recommendations regarding the training, financial and marketing systems required to support smallholder farmers further in improving soybean cultivation.

Index

- Agronomic
 - management 223
 - practices 270–271
 - traits 148–156
- Amino acid composition 153–154
- Aphid 124–125
- APSIM model 251

- Best management practices (BMPs)
 - agronomic 270–271
 - development of 271–272
 - overview 265–266
 - pesticides 271
 - soil fertility 268–269
 - tillage 226–227
 - variety selection 269–270
- Biological nitrogen fixation 4–5
- Biotic and abiotic stresses 67–71, 154–155
- Brazil, production in
 - management 297–299
 - cover crops 299
 - crop rotation 298–299
 - disease, insect, nematode and weed 299
 - nutrient supply 298
 - site-specific 299
 - soil fertility 298
 - tillage and soil 297–298
 - water-use efficiency 298
 - before planting 293–297
 - cultivar selection 295–296
 - date of planting 296
 - row width 297
 - seeding rate 296–297
- Breeding advancement 181
- Breeding for flood tolerance
 - active efforts 228
 - genetic diversity 224
 - genetic variation 224–226
 - QTL mapping 224–226
 - screening methods 226–228
- Breeding techniques
 - for biotic and abiotic stresses 67–71, 154–155
 - cultivation in developing countries 72–74
 - field and laboratory phenotyping 63–67
 - genetic architecture 43–54
 - genetically engineered soybeans 42–43
 - germplasm diversity 54–57
 - overview 39–41
 - phenotypic variation 60–63
 - phenotyping data 71–72
 - planting and harvesting mechanization 59–60
 - seed certification 57–59
 - USAID SIL 74–76
- Classical techniques 5–8
- Comparative genome mapping 95–97, 100–101
- Construction of fine pan-genome 101
- Conventional techniques 39–78
- CRISPR/Cas9-mediated genome editing 160–161
- CROPGRO model 250–251
- CropSyst model 252–253

- Drainage system 223
- Drought and heat resistance
 - breeding advancement 181
 - genomic resources and strategies 179–180
 - overview 171–173
 - pollination and seed development 179
 - RSAs and anatomy 174–177
 - sustained N-fixation 178–179
 - traits 173–174
 - water use and canopy wilting 177–178

- Epigenetic modification 198–199
- Ethyl methanesulfonate 9–10
- Exotic germplasm categories 30–32

- Fast neutron 10
- Field and laboratory phenotyping 63–67
- Flood-tolerant varieties
 - agronomic management 223
 - drainage system use 223
 - breeding 224–228
 - molecular responses 222
 - morphological responses 220–221
 - nutrient management 223
 - overview 217–218
 - physiological responses 221–222
 - QTL mapping 224–226
 - raised bed cultivation 223
 - stress and damage 218–219
- Functional genes 195–196

- Genetic architecture 43–54
- Genetic diversity 23–35, 224
 - exotic germplasm categories 30–32
 - germplasm 23–25
 - overview 23
 - U.S. gene pool 25–30
- Genetic modification
 - amino acid 153–154
 - biotic and abiotic stresses 154–155

- CRISPR/Cas9 system 160–161
- genome editing technology 156–157
- herbicide tolerance 148–150
- insect resistance 150–152
- methionine levels 160
- oil composition 152–153
- overview 147–148
- Genetic variation 224–226
- Genetically engineered soybeans 42–43
- Genome and bioinformatics 13–15
- Genome editing technology
 - Clustered regularly interspaced short palindromic repeat (CRISPR)/CPISPR-associated system (Cas) 157–159
 - ZFNs and TALENs systems 156–157
- Genome mapping
 - construction of 101
 - development of 90–93
 - high-throughput genotyping markers 92–93
 - by RFLP markers 91
 - by SSR markers 91–92
 - overview 89–90
 - salinity tolerance 98
 - SMS sequencing 99–100
 - techniques 93–97
 - comparative genome 95–97, 100–101
 - specific-locus amplified fragment sequencing (SLAF-seq) 93–94
 - whole-genome re-sequencing 94–95
 - wild and cultivated varieties 97–98
- Genomic resources and strategies 179–180
- Genotyping platforms 113–121
- Germplasm
 - categories 30–32
 - collections 23–25
 - diversity 54–57
 - resources 194–196
 - screening 194–195
- Grafting 5–6
- Hadley model 245–246
- Herbicide tolerance 148–150
- High-throughput developments 120–121
- Hydroponics 7–8
- Insect resistance 150–152
- Jones and Liang model 246
- Major model 245
- Marker-assisted breeding
 - genomic selection 128–130
 - high-throughput developments 120–121
 - marker-assisted selection (MAS) 121–130
 - molecular marker 110–113
 - overview 109–110
 - SNP marker 114–120
- SSR marker 113–114
- Marker-assisted selection
 - aphid 124–125
 - fatty acids 125–127
 - nematodes 121–122
 - salinity 127–128
 - soybean rust 122–124
- Metabolomic analyses 199
- Modern techniques 11–12
- Molecular
 - breeding 199–200
 - marker 110–113
- Mutagenesis 8–10
 - ethyl methanesulfonate 9–10
 - fast neutron 10
 - Targeting Induced Local Lesions in Genomes (TILLING) 10
 - transferred DNA (T-DNA) 10
- Mutant lines 8–10
- N-fixation sustainability 178–179
- Nebraska, USA, production in
 - management
 - cover crops 287–288
 - crop rotation 287
 - disease, insect and weed 288
 - nutrient supply 286
 - site-specific 288–289
 - soil fertility 286
 - tillage and soil 285
 - water-use efficiency 286–287
 - before planting
 - cultivar selection 280–282
 - date of planting 282–283
 - row width 284
 - seeding rate 283–284
- Nematode species causes 121–122
- Non-genetic factors 60–63
- Nutrient management 223
- Oil composition and genetic modification 152–153
- Pest management 271
- Petiole feeding 8
- Phenotyping 63–67
- Physiology and growth
 - biological nitrogen fixation 4–5
 - classical techniques 5–8
 - genome and bioinformatics 13–15
 - grafting 5–6
 - hydroponics 7–8
 - modern techniques 11–12
 - mutagenesis methods 8–10
 - mutant lines 8–10
 - overview 3–4
 - petiole feeding 8
 - pouch growth 6–7

- research techniques 11–12
 - split root 6
 - xylem sap 8
- Pollination and seed development 179
- Pouch growth 6–7
- Production research and practice
 - in Brazil 293–299
 - in Nebraska, USA 279–289
 - overview 277–279
 - in Uganda 289–293
- Proteomic analyses 197–198
- Quantitative trait loci (QTLs) 49
- Raised bed cultivation 223
- Resistance traits
 - canopy wilting 177–178
 - N-fixation sustainability 178–179
 - pollination and seed development 179
 - water use 177–178
- Responses to flooding 220–222
 - molecular 222
 - morphological 220–221
 - physiological 221–222
- Restriction fragment length polymorphisms (RFLPs) 49, 91
- Root system architectures (RSA) 174
- RSAs and anatomy 174–177
- Salinity tolerance
 - epigenomic studies 198–199
 - functional genes 195–196
 - and germplasm screening 194–195
 - metabolomic analyses 199
 - and molecular breeding 199–200
 - overview 191–194
 - proteomic analyses 197–198
 - soybean genome 196
 - transcriptomic analyses 196–197
- Simple sequence repeats (SSRs) 49, 91–92
- Sinclair–Horie model 246–247
- Single nucleotide polymorphisms (SNP) 112–113
- Single-molecule sequencing (SMS) 99
- SLAF-seq mapping 93–94
- Soil fertility 268–269
- Soybean Innovation Lab (SIL) 74
- Soybean rust 122–124
- SOYDEV model 253–256
- SOYGRO model 247–250
- Specific-locus amplified fragment sequencing (SLAF-seq) 93–94
- Split root 6
- Stewart–Cober model 251–252
- STICS model 252–253
- TALENs systems 156–157
- Targeting Induced Local Lesions in Genomes (TILLING) 10
- Temperature and photoperiod effects
 - APSIM model 251
 - CROPGRO model 250–251
 - CropSyst model 252–253
 - Hadley model 245–246
 - Jones and Liang model 246
 - Major model 245
 - model approaches 256–258
 - observed responses 242–244
 - overview 239–242
 - and reproductive stages 242–243
 - reproductive stages modelling 245–256
- Tillage 226–227
- Transcriptomic analyses 196–197
- Transcription Activator-Like Effectors Nucleases (TALENs) 11
- Transferred DNA (T-DNA) 10
- U.S. gene pool 25–30
- Uganda, production in
 - management 291–293
 - cover crops 293
 - crop rotation 292
 - disease, insect and weed 293
 - nutrient supply 292
 - site-specific 293
 - soil fertility 292
 - tillage and soil 291
 - water-use efficiency 292
 - before planting 289–291
 - cultivar selection 290–291
 - date of planting 291
 - seeding rate and row width 291
- United States Agency for International Development (USAID) 74
- Whole-genome re-sequencing mapping 94–95
- WOFOST model 252–253
- Xylem sap 8
- Zimbabwe, cultivation in
 - constraints 311–314
 - large-scale production 306–307
 - opportunities 314–315
 - overview 305–306
 - promotion projects review
 - emerging lessons from 311
 - and Hurungwe district 307–308
 - N2Africa 310–311
 - promotion taskforce 308–309
- Zinc-finger nucleases (ZFNs) 11
- ZFNs systems 156–157