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Achieving sustainable cultivation of soybeans

Volume 1: Breeding and cultivation techniques

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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.

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