Introduction

Saad Sulieman and Lam-Son Phan Tran

There is a strong awareness that the world population will grow more rapidly during the few coming years. The world population of 6.91 billion in 2010 will increase to 8.43 billion in 2030 and 9.55 billion in 2050, which will be probably stabilized at around 10–11 billion by the end of the century (http://en.wikipedia.org/wiki/World_population). This awareness must be translated into a parallel increase in the agricultural production to secure adequate food for the additional 3–4 billion inhabitants. If such an increase in production should be realized with current agricultural management that would similarly require the double use of fossil fuel energy for fertilizer production. This would cause economic hardship and surpassing damage to the environment. The intensive application of chemical nitrogen (N) fertilizers has led to an unprecedented perturbation of the N cycle, illustrated by the growing accumulation of nitrates in soils and waters and of nitrogen oxides in the atmosphere. Sustainable agriculture has mandated that alternatives to chemical N fertilizers must be urgently sought. Biological dinitrogen (N_2) fixation, a microbiological process that converts atmospheric N_2 into a plant-usable form, offers this alternative. Among these renewable sources, N_2-fixing legumes offer an economically attractive and ecologically sound means of reducing external inputs and improving internal resources.

Legumes (*Leguminosae* or *Fabaceae*) represent the second major crop of agricultural importance worldwide and cover about 14 % of total land under cultivation. In many regions of the world, legumes contribute a number of function and ecosystem services with great impact to the sustainability of various agricultural systems.

S. Sulieman (✉)
Department of Agronomy, Faculty of Agriculture, University of Khartoum,
13314 Shambat, Khartoum North, Sudan
e-mail: saadsulieman@hotmail.com

L.-S.P. Tran (✉)
Signaling Pathway Research Unit, RIKEN Center for Sustainable Resource Science (CSRS),
1-7-22, Suehiro-cho, Tsurumi, Yokohama 230-0045, Japan
e-mail: son.tran@riken.jp

S. Sulieman, L.-S.P. Tran (eds.), *Legume Nitrogen Fixation in a Changing Environment*, DOI 10.1007/978-3-319-06212-9_1

These plants provide important sources of oils, fiber, micronutrients, minerals, and vegetable proteins suitable for livestock feed and human consumption while supplying N to agro-ecosystems via their unique ability to fix atmospheric N_2 in symbiosis with the soil rhizobia. Legumes therefore possess great potential for use in soil stabilization, reforestation, and agricultural practices. The symbiotic relationship between legumes and their rhizobial partners takes place in the root nodules and provides access to atmospheric N_2. Nevertheless, the contribution of the symbiotic process to legume production is recognized to be highly sensitive to adverse environmental conditions, such as edaphic and environmental constraints. Therefore, understanding how symbiotic N_2 fixation responds to the surrounding environmental conditions is particularly important for both agriculture and preservation of the ecosystems.

As leguminous plants are inextricably linked to the surrounding environment, their mere inclusion in various cropping systems does not always ensure the attainment of the estimated optimal levels of symbiotic N_2 fixation in the field. Day by day, the cycle of climate on earth is changing and according to the predictions of the Intergovernmental Panel on Climate Change (IPCC), most climatic scenarios are expected to be affected by climate change. Expectations of impending climates specify immense alterations in temperature, rainfall pattern, humidity, and soil moisture regimes. Changes in climate not only influence the entire cropping system but also affect the performance of cultivars of different field crops, including legumes. Thus, climate change has become a major concern in agricultural development. Several environmental factors, such as drought, elevated temperature, salinity, soil acidity, and rising CO_2, are known to dramatically affect the symbiotic process and thus play a part in determining the actual amount of N fixed by a given legume in the field. Accordingly, environmental stress factors adversely affect N_2-fixing legume growth and pose a growing threat to sustainable agriculture. This has become a hot issue due to concerns about the effects of climate change on plant resources, biodiversity, and global food security. Understanding the responses of N_2 fixation and legume performance to global environmental change is crucial for improving legume production and maintaining agricultural sustainability in the context of global change. In this thoughtful and provocative new volume, we provide critical information on how current and projected future changes in the environment will affect legume growth and their symbiotic N_2-fixing capabilities.

To cope with various abiotic constraints, legumes have evolved a number of strategies at both morphological and physiological levels. With the advances in physiological methodology and molecular biotechnology, diverse arrays of biochemical, physiological, and molecular mechanisms underlying those adaptive strategies have been well studied in a broad range of plants, both model and crop species. Some particular strategies have been observed for the adaptation of nodulated leguminous plants to drought, elevated temperature, salinity, soil acidity, and rising CO_2. The application of omic technologies, i.e., transcriptomics, proteomics, metabolomics, and comparative genomics, reveals complex internal reactions and acclimations of plant organs to unfavorable conditions. Significant research efforts in the genomics of various stresses have shown that many genes regulated in a coordinated fashion are involved in plant acclimation to abiotic stresses. Being the most important model legumes, the sequenced genomes of *Medicago truncatula* Gaertn., *Lotus japonicus* (Regel) K. Larsen, and more recently soybean (*Glycine max* (L.) Merr.) have provided valuable resources for dissecting the molecular events regulating physiological and biochemical responses of legumes to abiotic stresses. Thus, a better understanding of the mechanisms of crop adaptations under variable climatic conditions will remarkably assist in breeding or engineering of future stress-tolerant crop plants. The development of such improved leguminous plants with more efficient symbiotic capabilities is a necessity for sustainable farming practices as well as mitigation of the negative impact of climatic changes. The challenge now is the translation of knowledge gained in model systems to cash crops grown in open-field conditions which are facing with the simultaneous occurrence of extreme events, such as drought, heat stress, salinity, soil acidity, and elevated levels of CO_2.

Evidence about the changing climate and its negative impact on plants and development is increasing. As biologists, we cannot ignore this reality; and if we want our work to be relevant, we then need to consider carefully whom and how we are targeting with our knowledge. In this book volume, we are honored to have five distinguished research groups to review the main effects of environmental changes on the legume performance, of which we are most concerned about those of drought, elevated temperature, salinity, rising CO_2, and soil acidity. These adverse environmental factors currently represent the greatest challenge affecting the symbiotic N_2-fixing process, and thus are expected to have tremendous effects particularly at long-term scale. Each chapter will review the current state of knowledge of nodule performance to one of these major stress factors, including the perspectives on the molecular approaches used for the analyses of stress responses in legumes and the possible biotechnological strategies to overcome their detrimental effects. Achievements as well as challenges are discussed across the chapters. Several perspectives regarding new approaches for screening, breeding, or engineering legumes with desirable abiotic stress-tolerant traits are anticipated. Graduate students and researchers of various disciplines relating to crop productivity and global change will find the perspectives and analyses offered by this volume an exciting contribution to the development of our understanding of these ongoing environmental changes for present and future legume production as a means to enhance food security for a rapidly expanding population.