BIODIVERSITY & ECOSYSTEM SERVICES IN AGRICULTURAL PRODUCTION SYSTEMS

PERENNIAL CROPS FOR FOOD SECURITY

PROCEEDINGS OF THE FAO EXPERT WORKSHOP

28-30 August, 2013, Rome, Italy

PERENNIAL CROPS FOR FOOD SECURITY

PROCEEDINGS OF THE FAO EXPERT WORKSHOP

28-30 August, 2013, Rome, Italy

Special acknowledgements to the
Ministero delle Politiche Agricole, Alimentari e Forestali
who supported the proceedings

EDITORS

Caterina Batello
Senior Officer and Team Leader, Ecosystem Approach to Crop Production Intensification,
Plant Production and Protection Division, (AGP) Food and Agriculture Organization (FAO)

Len Wade
Strategic Research Professor - Systems Agronomy and Crop Physiology,
Charles Sturt University

Stan Cox
Senior Researcher, The Land Institute

Norberto Pogna
Consiglio per la Ricerca e la sperimentazione in Agricoltura (CRA)

Alessandro Bozzini
Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile (ENEA)

John Choptiany
Ecosystem Approach to Crop Production Intensification, Plant Production and Protection Division,
(AGP) Food and Agriculture Organization (FAO)

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, ROME 2014

ISBN 978-92-5-107998-0 (print)
E-ISBN 978-92-5-107999-7 (PDF)

FAO information products are available on the FAO website (www.fao.org/publications)
and can be purchased through publications-sales@fao.org

FOREWORD TO THE PROCEEDINGS

Sustainable production systems have always relied on the flexibility, efficiency, and multiple functions of perennial trees and forages grown in combination with annual cereals, legumes, and oil species. But over the last 50 years, research, technologies and markets have focused mainly on a limited number of annual species to meet the increased demand for food. Furthermore, the primary focus was on increasing grain yields with reduced attention given to the social, environmental and market consequences of these food systems.

However, food security and agriculture are now entering an era characterized by scarce and depleted resources, climate change, price volatility and job losses. To adapt to this new era, agricultural technologies, science and markets have to be transformed to ensure sufficient food is produced for a growing population, while meeting simultaneously the economic, social and environmental challenges of twenty first century.

Perennial cereals, legumes and oil species represent a paradigm shift in agriculture and hold great potential to move towards sustainable production systems. Today, most agronomic practices used to grow annual crops require excessive water consumption, significant amounts of synthetic mineral fertilizers, labour, emissions of CO_2 and disrupt natural biological processes. Perennial crops instead are more rustic, improve soil structure and water retention capacity and contribute to increase climate change adaptation and mitigation practices and promote biodiversity and ecosystem functions.

Although in some ways perennial crops are at the forefront of scientific research with new varieties being developed, they also represent a thinking that goes back thousands of years when many cropping systems were based on perennial species including fruit trees, alfalfa, perennial rice, rye, and olive trees. In addition to modern breeding techniques, many wild and poorly domesticated species and varieties are available for research and interbreeding and hold potential to contribute to modern sustainable production systems. Through the development and breeding of these wild and semi-domesticated perennial varieties with commercially important and high yielding crops we will be able to achieve the best of both worlds.

Perennial crop research began in earnest about 30 years ago and has been growing ever since. There are now perennial crop varieties of oilseeds, legumes, wheat, sorghum, rice, sunflowers among many other crops. Significant uncertainties and challenges remain, related to increasing perennial crop yields and how to mainstream perennial crops into common farming practices and market systems.

FAO's Strategic Objectives are central to perennial crop research, specifically Strategic Objective 2 to: *Increase and improve provision of goods and services from agriculture, forestry and fisheries in a sustainable manner*. Perennial crops and the workshop were also developed under the framework of *Save and Grow* principles of ecological intensification of agricultural production.

CRA's strategic objectives are central to perennial crop research as well. In facts, CRA's mission is to perform agricultural research and develop innovation systems to alleviate poverty, increase food security and promote the sustainable use of natural resources, the same multiple objectives of perennial crops.

The proceedings of the Workshop held in FAO, 28-30 August 2013 organized by the Food and Agriculture Organization of the United Nations and the Consiglio per la Ricerca e la sperimentazione in Agricoltura (CRA) are intended to allow for the dissemination of the most recent research in the field. During the workshop gaps were identified, new partnerships discussed and priorities were identified for follow up actions.

The papers in these proceedings are arranged by the three main themes outlined during the workshop and include: *Genetics and breeding: state of the art, gaps and opportunities*; *Agro-systems, ecology and nutrition*; and *Policy, economics and way forward*. This was preceded by a welcoming address by Dr. Ren Wang, Assistant Director-General, Agriculture and Consumer Protection Department (AG), and followed by closing remarks by Dr. Clayton Campanhola, Director AGP.

The videos outline the main messages of the workshop by the participants and can be found at:

www.youtube.com/playlist?list=PLzp5NgJ2-dK4_itTMZqwUEg4BTBymkWgw, while material for the workshop can be found at:

www.fao.org/agriculture/crops/thematic-sitemap/theme/spi/fao-expert-workshop-on-perennial-crops-for-food-security/en/

We would like to thank the support for this workshop provided by FAO (especially Dr. Clayton Campanhola, Dr. Shakeel Bhatti, Dr. Constance Neely and Dr. Barbara Herren), the Consiglio per la Ricerca e la sperimentazione in Agricoltura (CRA) (especially Dr. Norberto Pogna, Dr. Stefano Bisoffi and Dr. Ida Marandola), the Land Institute (especially Dr. Stan Cox), Charles Sturt University (especially Dr. Len Wade) and CSIRO. We would like to thank all the presenters and participants at the workshop.

Joint signatures by:

Dr. Ren Wang
Assistant Director General
Department of Agriculture,
Food and Agriculture Organization
of the United Nations

Prof. Giuseppe Alonzo
President CRA
Consiglio per la Ricerca e
la sperimentazione in Agricoltura

CONTENTS

LIST OF FIGURES AND TABLES

02 Perennial rice: challenges and opportunities

03 The progression of perennial rice breeding and genetics research in China

04 Perennial wheat breeding current germplasm and a way forward for breeding and global cooperation

05 Evaluation of nine perennial wheat derivatives grown in Italy

06 Current efforts to develop perennial wheat and domesticate *Thinopyrum intermedium* as a perennial grain

07 Viewpoint: multiple-harvest sorghums toward improved food security

08 Breeding and genetics of perennial maize: progress, opportunities and challenges

09 Evaluating perennial candidates for domestication: lessons from wild sunflower relatives

11 Agriculture redesign through perennial grains: case studies and next steps

12 From genetics and breeding to agronomy to ecology

13 Economics and system applications for perennial grain crops in dryland farming systems in Australia

LIST OF ABBREVIATIONS

ACIAR	Australian Centre for International Agricultural Research
AFLP	Amplified Fragment Length Polymorphism
AG	Agriculture and Consumer Protection Department
AGP	Plant Production and Protection Division
AGPM	Ecosystem Approach to Crop Production Intensification, Plant Production and Protection Division
AgriSA	Centre for Agriculture and Food Systems Analysis and Synthesis
AH	Agricultural Handbook
A-PAGE	Acidic Polyacrylamide Gel Electrophoresis
AR	5-n-alkylresorcinols
ArcGIS	Esri Geographic Information System software
ASEAN	Association of Southeast Asian Nations
ASL	Above Sea Level
CA	Conservation Agriculture
Ca	Calcium
CAPS	Cleaved Amplified Polymorphic Sequence
CAWT	Conservation Agriculture With Trees
CBOs	Community Based Organizations
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CP	Crude Protein Content
CPS	Maize/Pennycross/Soybean
CRA	Consiglio per la Ricerca e la sperimentazione in Agricoltura
CRC-PbMDS	Cooperative Research Centre for Plant-based Management of Dryland Salinity
CRC-FFI	Cooperative Research Centre for Future Farm Industries
CRS	Corn (maize)/Rye/Soybean
CS	Corn (maize)/Soybean
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTAB	Cetyltrimethyl Ammonium Bromide
cv.	cultivar
cvs	cultivars
DF	Dietary Fibre
DM	Dry Matter
DNA	Deoxyribonucleic Acid
ERS	Economic Research Service
EST	Expressed Sequence Tags
FAO	Food and Agriculture Organization of the United Nations
GBS	Genotyping-By-Sequencing
GBSSI	Granule-Bound Starch-Synthase
GIS	Geographic Information System

GISH	Genomic *In Situ* Hybridization
GRDC	Grains Research and Development Corporation
GRIN	Germplasm Resources Information Network
GS	Genomic Selection
gSSURGO	Gridded Soil Survey Geographic
GWAS	Genome-Wide Association Studies
HMW-GS	High Molecular Weight-Glutenin Subunits
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
ICRAF	World Agroforestry Centre
ICRISAT	The International Crops Research Institute for the Semi-Arid-Tropics
IRRI	The International Rice Research Institute
LD	Linkage Disequilibrium
LiDAR	Light Detection and Ranging
LMW-GS	Low Molecular Weight-Glutenin Subunits
MAS	Marker Assisted Selection
Mistra	Swedish Foundation for Strategic Environmental Research
MSTATC	Microcomputer Program for the Design, Management, and Analysis of Agronomic Research Experiments
NAD	Nicotinamide Adenine Dinucleotide
NERICA	New Rice for Africa
NGOs	Non-Governmental Organizations
NGS	Next Generation Sequencing
NLCD	National Land Cover Dataset
NRCS	Natural Resources Conservation Services
NSW DPI	New South Wales Department of Primary Industries
NUE	N-Uptake Efficiency
PCF	Protein Conversion Factor
PHR	Post-Harvest Regrowth
PIN-A	Puroindoline A
PIN-B	Puroindoline B
QTLs	Quantitative Trait Loci
RFLP	Restriction Fragment Length Polymorphism
R/qtl	an extensible, interactive environment for mapping quantitative trait loci
RNA	Ribonucleic Acid
RNA-seq	sequencing of Ribonucleic Acid
rRNA	Ribosomal Ribonucleic Acid
RS	Resistant Starch
RUSLE	Revised Universal Soil Loss Equation
UNEP	United Nations Environment Program
SDS	Sodium Dodecyl Sulphate
SDS-PAGE	Sodium Dodecyl Sulphate-Polyacrylamide Gel Electrophoresis

SLU	Swedish University of Agricultural Sciences
SKCS	Single Kernel Characterization System
SNPs	Single-Nucleotide Polymorphisms
SP	Soluble Polyphenols
sp.	species (singular)
spp.	species (plural)
SSR	Simple-Sequence Repeats
TL	Tillers per plant
TNC	Total Non-structural Carbohydrate
UNEAK	Universal Network Enabled Analysis Kit
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator
WSU	Washington State University
YP	Yellow Pigments

INTRODUCTION

PERENNIAL CROPS FOR FOOD SECURITY

Stan Cox

The Land Institute, 2440 E. Water Well Rd., Salina, Kansas, 67401, United States of America

Email: cox@landinstitute.org, Phone: (+1) 785 823 5376

Interest in breeding new perennial grain crops first arose in the early twentieth century, but it has been only in the past few years that the potential benefits of developing perennial grain-based cropping systems and the need to do so have become widely acknowledged. The subject is now drawing the attention of major scientific societies, leading journals, and governmental agencies. Much of that recent attention has been focused on the ecological benefits that communities of perennial plants can confer on a landscape: erosion prevention, efficient capture and use of water and nutrients, protection of water resources, carbon sequestration, and maintenance of thriving soil ecosystems. But with food security and rural livelihoods becoming an increasingly serious concern throughout the world, there is growing recognition of the potential benefits that intercropping of perennial grains offers smallholder farmers: reduced expenditure for seed, fertilizer, and other inputs; more reliable stand establishment and early vigour; less effort expended on weed control; extended growing seasons; less transplanting or other stoop labour, especially for women; and protection of biodiversity.

Perhaps the most important benefit of perennial agriculture will be the protection and development of healthy soil ecosystems that can ensure food security over the long term. That would achieve an important reversal of what is now an alarming trend. In 2011, the Food and Agriculture Organization (FAO) released its report The State of the World's Land and Water Resources for Food and Agriculture, concluding that 25 percent of the world's food-producing soils are highly degraded or are rapidly being degraded and that if moderately degraded soils are included, one-third of Earth's entire endowment of cropland is under threat. Loss of productive soil is most severe in the Himalayan and Andean regions; semi-arid tropical regions of Africa and India; rice-growing lands of Southeast Asia; and areas of intensive and industrialised farming throughout the world. Eighteen countries - nine of them in sub-Saharan Africa and four in Southeast Asia - now see more than half of their entire land area degrading rapidly. And while past production increases have received much of their impetus from irrigation, future freshwater resources are in at least as much trouble as the world's soils.

It is in this context that FAO, along with Italy's Council on Agricultural Research (CRA), Australia's Charles Sturt University, and The Land Institute in the United States, joined to host a meeting on Perennial Crops for Food Security in Rome in August, 2013. Seeing on the one hand the possibility that perennial crops can help address soil and water degradation, economic stresses, and malnutrition in food-insecure countries and on the other hand the emerging body of research on various aspects of perennial grain crops being produced by plant breeders, geneticists, agronomists, agro-ecologists, social scientists, and policy experts around the world, FAO determined that the time had come to bring together the key people involved in these disparate efforts. Forty-one people from ten nations participated in the meeting. The goals were to aggregate and put in context all research done on perennial grains up to now, begin forming a researchers' network, and plan for more extensive, well-coordinated and better-supported research in coming years. Essential to that effort will be drawing many more researchers and organizations into the perennial world.

The chapters that follow expand on the intense discussions that occurred in Rome. They provide a broad picture of the current state of perennial grain development and the diverse directions in which it is heading. Research on perennial cereals, grain legumes, and oilseeds, along with the cropping systems into which they will be assembled, can benefit from methods and technologies that have been well developed for staple grains grown currently. But to succeed, those methods must be supplemented by knowledge and experience, new and old, that applies uniquely to perennial crops. Domesticators and breeders of perennial grains have much to learn not only from farmers' experience but also from methods used in breeding woody perennials and perennial forage crops. Genomics research is already well-accustomed to moving across species boundaries, multiplying its possibilities. Meanwhile, working first with prototypes of perennial grains and later with improved lines and cultivars, agronomists, agro-ecologists, plant pathologists, and other researchers will face not only new challenges but also vast new opportunities to take advantage of natural processes that can improve and ensure food production. Grain quality and nutrition researchers, like all of the others mentioned above, will require significant input from farmers in the regions where the new perennial crops will be grown, as well as from social, economic, and policy analyses.

Emerging molecular-scale techniques have the potential to greatly improve the efficiency of perennial-grain breeding, but genotypic analyses cannot substitute for extensive phenotypic evaluations in diverse field locations. The three chief sets of traits that researchers are attempting to bring together—perenniality, productivity, and grain quality—are highly complex genetically, and they are strongly influenced by their environment. Relative expression of perenniality and other traits among genotypes is almost certain to vary widely over the diverse range of landscape positions, soils, climates, stresses, farming methods, and human preferences that perennial grains will encounter. Breeding populations must experience an adequate sample of all those factors, and must do so in the region where they are expected to be grown. The authors of this book take us on a tour of the ecological and human landscape where perennial grains currently grow and are being developed. Along the way, they relate how in their experience diverse scientific disciplines can converge to make perennial agriculture a mainstreamed reality. While this book furthers the exchange of knowledge and experience (and, one hopes, of plants and seed as well), its ultimate goal is to begin charting a course that will take perennial-grain research—which now consists of geographically and scientifically diverse, conceptually bold, but largely autonomous and independent projects—and weave them into a global network that can make this new agricultural concept a reality. In the interest of doing that, the final chapter attempts to lay out that course toward the new landscapes of the future.