

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

# Achieving sustainable cultivation of maize

Volume 2: Cultivation techniques, pest and disease control

Edited by Dr Dave Watson, CGIAR Maize Research Program Manager, CIMMYT, Mexico



# Contents

Series list	xii
Introduction	xvi
<b>Part 1 Maize cultivation techniques</b>	
1 Modelling crop growth and grain yield in maize cultivation <i>Alan Sher, Xiaoli Liu and Jincal Li, Anhui Agricultural University, China; and Youhong Song, Anhui Agricultural University, China and The University of Queensland, Australia</i>	3
1 Introduction	3
2 Crop modelling principles	4
3 Predicting crop development under drought and heat stress	4
4 Predicting biomass production under drought and heat stress	7
5 Predicting grain yield formation under drought and heat stress	7
6 Conclusions	8
7 Where to look for further information	8
8 References	8
2 Optimizing maize-based cropping systems: sustainability, good agricultural practices (GAP) and yield goals <i>Charles Wortmann, Patricio Grassini and Roger W. Elmore, University of Nebraska-Lincoln, USA</i>	13
1 Introduction	13
2 Defining sustainable crop production	13
3 Good agricultural practices	14
4 Setting targets and measuring performance	16
5 Case study: improving maize cultivation in the United States, Ethiopia and Argentina	19
6 Conclusions	28
7 References	28
3 Maize seed variety selection and seed system development: the case of southern Africa <i>Peter S. Setimela, Global Maize Program, International Maize and Wheat Improvement Center (CIMMYT), Zimbabwe</i>	33
1 Introduction	33
2 Maize variety development in southern Africa (SA)	36
3 Maize seed industries	37
4 The development of maize seed systems in SA	43
5 The adoption of modern maize varieties	44
6 Conclusions and future trends	45
7 Where to look for further information	46
8 References	46

4	Good agricultural practices for maize cultivation: the case of West Africa <i>Alpha Kamara, International Institute of Tropical Agriculture, Nigeria</i>	49
1	Introduction	49
2	Poor soil fertility and effects of drought on maize in West Africa	50
3	Weed competition with maize	51
4	Maize nutrient management	52
5	Weed management for maize cultivation	54
6	Management of soil moisture stress in maize	55
7	Future trends and conclusion	56
8	Where to look for further information	56
9	References	56
5	Zero-tillage cultivation of maize <i>Wade E. Thomason, Bee Khim Chim and Mark S. Reiter, Virginia Tech University, USA</i>	61
1	Introduction	61
2	History of zero-tillage maize cultivation	61
3	Advantages of zero-tillage maize production: reduced soil erosion	65
4	Advantages of zero-tillage maize production: reduced nutrient losses	67
5	Advantages of zero-tillage maize production: water infiltration and use, economics and soil organic matter	69
6	Potential disadvantages of zero-tillage maize production	72
7	Success with zero-tillage maize production	75
8	The future of zero-tillage maize production	76
9	Where to look for further information	76
10	References	76
6	Conservation agriculture (CA) for sustainable intensification of maize and other cereal systems: the case of Latin America <i>Bram Govaerts, International Maize and Wheat Improvement Center (CIMMYT), Mexico; Isabelle François, Consultant, Belgium; and Nele Verhulst, CIMMYT, Mexico</i>	81
1	Introduction: the need for sustainable soil management	81
2	Introduction to CIMMYT's long-term experimental sites	83
3	The influence of CA on physical soil quality	85
4	The influence of CA on chemical soil quality	87
5	The influence of CA on biological soil quality	89
6	Weed management under CA	92
7	The influence of CA on productivity	93
8	CA and climate change	94
9	Implementation of CA	96
10	Conclusions	100
11	Where to look for further information	100
12	Acknowledgements	101
13	References	101
7	Precision maize cultivation techniques <i>Louis Longchamps, Agriculture and Agri-Food Canada, Canada; and Raj Khosla, Colorado State University, USA</i>	107
1	Introduction	107

2	Pre-planting	109
3	Planting	117
4	Nutrition	119
5	Precision maize irrigation	127
6	Pesticides	128
7	Harvest	130
8	Data analysis	132
9	Future trends	135
10	Conclusion	138
11	References	138
8	Improving nutrient management for sustainable intensification of maize <i>Kaushik Majumdar, International Plant Nutrition Institute – South Asia, India; Shamie Zingore, International Plant Nutrition Institute – Sub-Saharan Africa, Kenya; Fernando García and Adrian Correndo, International Plant Nutrition Institute – Latin America – Southern Cone, Argentina; Jagadish Timsina, University of Melbourne, Australia; and Adrian M. Johnston, International Plant Nutrition Institute, Canada</i>	149
1	Introduction	149
2	Nutrient management challenges in maize	151
3	Improved nutrient management	156
4	Case studies in improving nutrient management: South Asia	158
5	Case studies in improving nutrient management: Sub-Saharan Africa (SSA)	160
6	Case studies in improving nutrient management: Latin America – Southern Cone	166
7	Case studies in improving nutrient management: use of the Nutrient Expert® tool in China	170
8	Research priorities	170
9	Conclusions	173
10	Where to look for further information	174
11	References	174
9	Crop rotation: a sustainable system for maize production <i>Bao-Luo Ma, Ottawa Research and Development Centre, Agriculture and Agri-Food Canada; and Zhigang Wang, Inner Mongolia Agricultural University, China</i>	181
1	Introduction: escalating global food demand and environmental challenges	181
2	The simplification of cropping systems and associated problems for sustainability	182
3	Yield enhancement in maize–legume rotation systems	184
4	The impact of crop rotation on soil quality	188
5	The impact of crop rotation on soil fertility and nutrient use efficiency	189
6	Additional benefits of maize–legume rotation	192
7	Summary and future trends	195
8	Where to look for further information	195
9	Acknowledgements	196
10	References	196

10	Intercropping in sustainable maize cultivation <i>Abeya Temesgen, Shu Fukai and Daniel Rodriguez, The University of Queensland, Australia</i>	203
1	Introduction	203
2	Intercropping under different conditions: moisture and nitrogen levels	204
3	Resource capture and use efficiency in maize-based intercropping: water, nitrogen and light	207
4	Competition and complementary interactions in maize–legume intercropping	213
5	Maize–legume intercropping evaluation	217
6	Conclusions	220
7	Where to look for further information	220
8	References	220
11	Climate risk management in maize cropping systems <i>Daniel Rodriguez, Caspar Roxburgh, Claire Farnsworth, Ariel Ferrante, Joseph Eyre, Stuart Irvine-Brown, James McLean, Martin Bielich, Queensland Alliance for Agriculture and Food Innovation (QAAFI), The University of Queensland, Australia</i>	227
1	Introduction	227
2	Sensitivity of rainfed maize cultivation	230
3	Assessing the risk of rainfall variability	233
4	Risk management in smallholder maize cropping	235
5	Climate risk at the whole farm level	238
6	A case study: the sustainable intensification of rainfed maize cropping in Mozambique	239
7	Future trends	241
8	Acknowledgements	242
9	Where to look for further information	242
10	References	242
12	Advances in maize post-harvest management <i>Tadele Tefera, International Center of Insect Physiology &amp; Ecology (icipe), Ethiopia</i>	247
1	Introduction	247
2	Post-harvest losses in maize: an overview	248
3	Major storage insects and fungi	249
4	Traditional storage structures and food security	250
5	Institutional factors impacting post-harvest losses	251
6	Reducing post-harvest losses through technological interventions	251
7	Conclusions	256
8	Where to look for further information	257
9	References	257

## Part 2 Maize pests, diseases and weeds

13	Economically important insect pests of maize <i>William D. Hutchison and Theresa M. Cira, University of Minnesota, USA</i>	263
1	Introduction	263

2	Below-ground insect pests	264
3	Above-ground insect pests	269
4	Stored products pests	283
5	Case study: management of European corn borer in the United States	283
6	Future trends and conclusion	285
7	Where to look for further information	286
8	References	287
14	Nematodes associated with maize	293
	<i>T. L. Niblack, The Ohio State University, USA</i>	
1	Introduction	293
2	Soil and plant nematodes: characteristics, identification and effects on maize	294
3	Lesion nematodes, <i>Pratylenchus</i> spp.	297
4	Root-knot nematodes, <i>Meloidogyne</i> spp.	300
5	Vermiform nematodes restricted to sandy soils: <i>Belonolaimus</i> , <i>Longidorus</i> , <i>Paratrichodorus</i> and <i>Trichodorus</i> spp.	302
6	Other nematodes	304
7	Conclusions	310
8	Where to look for further information	311
9	References	311
15	Control of rodent pests in maize cultivation: the case of Africa	317
	<i>Loth S. Mulungu, Sokoine University of Agriculture, Tanzania</i>	
1	Introduction	317
2	The impact of rodents on maize crops in Africa	319
3	Rodent pests affecting maize	323
4	Managing rodent pests in maize crops	327
5	Summary	330
6	Future trends in rodent research	331
7	Where to look for further information	332
8	References	333
16	Rapid response to disease outbreaks in maize cultivation: the case of maize lethal necrosis	339
	<i>George Mahuku, International Institute of Tropical Agriculture (IITA), Tanzania; and P. Lava Kumar, International Institute of Tropical Agriculture (IITA), Nigeria</i>	
1	Introduction	339
2	Emerging plant diseases	340
3	Factors influencing the emergence of maize diseases	342
4	Overview of strategies for mitigating risks from emerging maize diseases	347
5	Components of an effective rapid response system	347
6	Strategies for managing maize disease outbreaks	352
7	The emergence of MLN in Eastern Africa	356
8	Responding to the MLN outbreak and minimizing its impact	359
9	Conclusions	363
10	Where to look for further information	364

11	Acknowledgements	364
12	References	364
17	Controlling aflatoxins in maize in Africa: strategies, challenges and opportunities for improvement	371
	<i>Amare Ayalew and Martin Kimanya, Partnership for Aflatoxin Control in Africa, Ethiopia; Limbikani Matumba, Lilongwe University of Agriculture and Natural Resources, Malawi; Ranajit Bandyopadhyay and Abebe Menkir, International Institute of Tropical Agriculture (IITA), Nigeria; and Peter Cotty, USDA-ARS, USA</i>	
1	Introduction	371
2	Aflatoxin contamination in maize	372
3	Pre-harvest aflatoxin control	373
4	Preventing post-harvest aflatoxin contamination	380
5	Removing aflatoxin contamination	381
6	Detoxification	383
7	Role of policy and public awareness in aflatoxin control	384
8	Conclusion and future trends	385
9	Where to look for further information	386
10	References	387
18	Integrated weed management in maize cultivation: an overview	395
	<i>Khawar Jabran, Duzce University, Turkey; Mubshar Hussain, Bahauddin Zakariya University, Pakistan; and Bhagirath Singh Chauhan, The University of Queensland, Australia</i>	
1	Introduction	395
2	Weeds and their impact on maize cultivation	396
3	The use of herbicides	404
4	Integrated weed management	406
5	IWM techniques: land preparation, cultivars, planting, cultivation and allelopathy	406
6	IWM techniques: herbicide tolerant cultivars, rotations, allelopathy, intercropping and cover crops	407
7	IWM techniques: mechanical control and flame weeding	408
8	Conclusions and future trends	409
9	Where to look for further information	409
10	References	409
19	Weed management of maize grown under temperate conditions: the case of Europe and the United States	415
	<i>Vasileios P. Vasileiadis and Maurizio Sattin, National Research Council (CNR), Institute of Agro-Environmental and Forest Biology, Italy; and Per Kudsk, Aarhus University, Department of Agroecology, Denmark</i>	
1	Introduction	415
2	Maize cropping systems and weed flora in the United States and Europe	417
3	Weed management in maize cropping systems in the United States and Europe	418
4	Decision-support tools and bottlenecks hindering IWM implementation	425

Contents	xi
5 Case study: IWM tools as evaluated in three European maize production regions	427
6 Summary and future trends	430
7 Where to look for further information	431
8 References	431
Index	439



# Introduction

Maize is one of the most widely-grown crops in the world, both for food and livestock feed, biofuels and other uses. Cultivated on 184 million hectares globally, maize is cultivated in 160 countries throughout the continents of America, Europe, Oceania, Africa, and Asia. Maize is fundamental to global food and economic security, providing up to 30% of total calorie intake in some developing countries. It has been estimated that maize yields need to increase by 60% by 2050 in the context of increasing competition for land, water, energy and labour. Maize production is currently held back by factors such as: lack of available improved cultivars or failure to take up new improved varieties, inadequate crop management and storage, poor soil quality, the impact of pests and diseases, and more extreme weather related to climate change. Research needs to focus on supporting more productive, sustainable and nutritionally-valuable maize cultivation, particularly for smallholders in the developing world.

The two volumes of *Achieving sustainable cultivation of maize* summarise key research addressing these challenges. This volume looks at ways of improving maize cultivation as well as the management of pests and diseases. Volume 1 focuses on breeding, improving nutritional quality and ways of supporting smallholders.

## Part 1 Maize cultivation techniques

Crop models both help to identify opportunities for yield improvement and to predict the effects of factors such as changing weather patterns. Chapter 1 reviews the principles and development of existing crop models for maize. It then focuses on the problem of drought stress which is likely to increase in range and severity with climate change. Robust crop models are needed to predict likely drought impacts on maize production. The chapter reviews current research on predicting plant responses under drought and heat stress, particularly biomass production and grain yield formation. These models provide the foundation for assessing what interventions, whether in terms of breeding or cultivation practices, may be needed to maintain yields and grain quality.

To be sustainable maize production must meet a number of objectives. These range from producing a good quality product, optimising yields and ensuring a livelihood for the farmer to protecting the natural resource base in such areas as soil health and the broader environment. Good agricultural practices (GAP) allow farmers to achieve these objectives. However, the gap between potential and actual yields can make it complex to set realistic and achievable yield goals. In addition implementation of GAP will vary according to the demands of different production conditions. Chapter 2 addresses ways setting targets, establishing the right mix of cultivation practices and measuring performance. It includes case studies of practical GAP implementation in three different situations: irrigated production in Nebraska, smallholder rainfed production in the semi-arid Central Rift Valley of Ethiopia (CRVE), and rainfed maize in the Pampas of Argentina.

New maize varieties will not be effective if they are not properly disseminated and adopted by local farmers. Chapter 3 reviews the development and effectiveness of the collaborative drought and low nitrogen maize breeding program initiated by the International Maize and Wheat Improvement Centre (CIMMYT) to increase yields

in low input and drought prone environments in southern Africa. Reflecting themes discussed in Volume 1, it describes initiatives such as CIMMYT's use of mother-baby trial (MBTs), an innovative farmer participatory evaluation scheme that evaluates farmer responses to new maize varieties in their own environmental conditions. This approach has accelerated the development and dissemination of new stress tolerant and high yielding open pollinated varieties (OPVs) and hybrids in southern Africa. The chapter also highlights the development and selection of maize germplasm resistant to a range of biotic and abiotic stresses, and the role of the seed industry in disseminating improved maize germplasm.

Maize is the most important staple food crop for over 300 million people in Sub-Saharan Africa but poor management practices and problems related to climate and soil quality mean that yields regularly fall below what is needed to feed the population. Chapter 3 begins by describing the effect on maize yields of poor soil fertility, drought and weeds (especially *Striga hermonthica*). Building in particular on Chapter 2, it then identifies good agricultural practices (GAP) to address these problems. These techniques include targeted nutrient management to improve soil health and techniques for weed management. The chapter also examines ways of dealing with the challenge of drought, including improved irrigation methods and development of drought-resistant maize varieties.

Chapter 5 builds on Chapter 4 by focussing on the role of zero-till cultivation of maize. This technique aims to reduce erosion, improve soil structure and nutrient composition, decrease costs, and improve long-term sustainability of maize cultivation. However, it is important to understand what factors determine whether the technique is effective or not. The chapter reviews current research on the effects of zero till cultivation in such areas as reduced soil erosion and nutrient losses, water infiltration and soil organic matter. This chapter discusses suggestions for best management of zero-till maize systems.

Zero-till cultivation is one element in a broader set of practices known as 'conservation agriculture' (CA). CA emphasises practices designed to improve soil health such as: zero or reduced tillage; retention of adequate levels of crop residues and soil surface cover to improve water productivity and to enhance soil physical, chemical and biological properties; and use of crop rotations to help control weeds and pests, improve soil health and provide more diverse sources of income for farmers. Based on long-term experimental sites managed by CIMMYT, Chapter 6 provides an authoritative review of the effectiveness of CA in such areas as physical soil quality (including reducing erosion), soil chemical and biological quality, and weed management. As it shows, forty years of research show that conservation agriculture has proved the better choice in providing continuously higher and more stable yields for both wheat and maize when compared to traditional practices in rainfed conditions. The chapter discusses the future potential of CA in maize cultivation and, specifically, its further development in Latin America.

As Chapter 7 points out, information and communication technologies are transforming the way maize is cultivated around the world by providing farmers with a suite of novel tools and techniques for improving crop production, enhancing input use efficiency, and increasing profitability while achieving environmental sustainability. Chapter 7 provides an overview of the current state of precision maize cultivation techniques at different stages of maize cultivation. A section on pre-planting assesses current knowledge on the spatial variability of soil properties and how it influences precision maize cultivation techniques. Subsequent sections address planting and the current state of variable-rate seeding, nutrition and various approaches for site-specific fertilizer management. The chapter also reviews developments in precision irrigation, different aspects of precision pest control

and weed management, as well as the opportunities enabled by digital yield maps and big data management.

Sustainable cultivation requires more efficient resource use, including in the use of fertilisers. Chapter 8 looks at the various ways of improving nutrient management in maize cultivation. It includes a range of case studies from South Asia, Sub-Saharan Africa, Latin America as well as the use of the Nutrient Expert® tool in China. As an example, in the case of Sub-Saharan Africa, the chapter reviews ways of targeting fertilisers according to different soil conditions, establishing optimum nitrogen application rates and more effective timing of nitrogen application (depending on prevailing rainfall) as well as more targeted, site-specific fertilizer application. It shows for example that, when combined with mineral nitrogen fertilizers, manure resulted in better crop yields than fertilizer treatments alone. The chapter also demonstrates the success of more flexible systems of fertilization, in which optimum rates of P, K and S fertilizers are applied based on yield potential in an average rainfall season, while N is applied as a series of split applications, which are adjusted according to the evolving rainfall pattern in any one season.

Modern agriculture has led to a simplification of maize-based cropping systems and the extensive practice of monoculture maize. This has led to problems such as yield reduction and soil quality degradation. Meanwhile, as pointed out in Chapter 8, the overuse of inorganic fertilizer to increase yields comes with a high environmental cost. As suggested in Chapter 6, maize grown in rotation with grain or forage legume crops often yields more and requires less application of synthetic chemicals (fertilizers, pesticides, herbicides, etc.) than continuous monoculture maize. Rotations in tandem with the application of farmyard or dairy manure or other organic wastes has proved an environmentally-friendly strategy for sustainable agriculture development. Chapter 9 summarizes recent research on yield enhancement in maize-based rotation systems, as well as the impact of crop rotation on soil quality, fertility and nutrient use efficiency.

Chapter 10 reviews the existing evidence on the productivity and resource use efficiency of maize–legume intercropping systems compared to the use of single crops. Findings indicate that system productivity in intercropping systems is more resource-use efficient and productive, particularly in low-yielding environments and production systems where soil quality is poor and rainfall low. As the level of resource availability increases, the differences between intercropping and sole cropping are reduced, though intercropping still presents advantages over sole cropping in some cases.

Climate change, and the likelihood of hotter, drier conditions in many parts of the world, presents a particular threat to rainfed maize cultivation. Chapter 11 assesses the vulnerability of rainfed maize cultivation to changing conditions and the risk of rainfall variability. Supporting farmers to identify and manage risks and opportunities in these challenging conditions is essential. The chapter summarises recent research on risk management strategies for smallholder maize cropping. It concludes with a case study exploring practical options for the sustainable intensification of rainfed maize cropping in Mozambique.

## Part 2 Maize pests, diseases and weeds

Maize yields in many countries are negatively affected by damage from insect pests. Chapter 13 describes the main pests of maize. These include below-ground pests such as

various types of corn rootworm, above-ground pests such as the corn leaf aphid, as well as pests of stored maize products such as the larger grain borer. The chapter also includes a detailed case study of the European corn borer in the USA, assessing its life cycle and what this means for control using integrated pest management (IPM) techniques. Finally, the chapter assesses potential future directions for research in this area.

Plant-feeding, or plant-parasitic, nematodes are ubiquitous in soils that support plant growth. The effects of phytophagous nematodes are, however, notoriously difficult to test and measure, and depend upon many factors associated with the plant, its environment, and the nematodes themselves. This chapter begins with an introduction to soil and plant nematodes, covering their general characteristics, identification and an overview of our current knowledge of their effects on maize. Subsequent sections review various types of nematodes, with particular focus on those which are highly likely to cause yield losses and other damage to maize crops such as lesion, root-knot and vermiform nematodes.

Rodents cause significant damage at the sowing, seedling and maturity stage of maize. Rodent management programs in regions such as Sub-Saharan Africa have traditionally been reactive and most suited to managing low-density local rodent populations. More effective rodent management requires a more proactive and integrated approach. Chapter 15 describes the range of cultural, chemical and biological methods of control that make up an integrated rodent management programme. It also looks at improvements in surveillance and early warning systems.

Emerging plant diseases (EPDs) can cause significant losses to maize and other crops. Chapter 16 reviews research on factors influencing the origins and spread of EPDs affecting maize. Effective control of EPDs relies on rapid detection, accurate diagnosis, as well as speedy deployment of preventive and containment measures to prevent the spread of disease. The efficiency of a response also depends on networking and collaboration among all the stakeholders, including intergovernmental and nongovernmental organizations and specialized agencies in developed and developing countries. The chapter reviews strategies for mitigating risks from emerging maize diseases, components of an effective rapid response system and strategies for managing maize disease outbreaks. These include effective models to predict the likely spread of disease, quarantine procedures, effective seed systems, integrated disease management and pre-emptive breeding measures. The chapter includes a case study of how procedures worked in practice with the emergence of maize lethal necrosis (MLN) in eastern Africa, reviewing how effective various agencies were in responding to the MLN outbreak and minimizing its impact.

Maize is subject to pre- and post-harvest contamination with aflatoxins, which are acutely toxic and carcinogenic compounds. This chapter describes in detail mechanisms of aflatoxin contamination in maize. It also reviews the current strategies employed for aflatoxin control and the challenges associated with them, including pre- and post-harvest methods of control and prevention. The chapter also addresses the detoxification of aflatoxin-affected maize as well as suggesting lines of future research in this area.

Weeds are one of the major constraints on maize productivity. Chapter 18 discusses the impact of weeds on maize cultivation and methods of control. It focuses on integrated weed management (IWM) techniques which reduce the need for herbicides. IWM techniques include methods of cultural control such as: land preparation, choice of cultivars, planting schemes and methods of cultivation. They also include cropping systems such as rotations, intercropping and cover crops, as well as physical methods of control. The development of herbicide-tolerant maize cultivars and image-based site specific herbicide applications are expected to contribute significantly in improving weed management in maize.

Chapter 18 is complemented by Chapter 19 which reviews the types of maize cropping systems used to grow maize under temperate conditions, with a particular focus on the situation in the US and Europe. After reviewing weed flora in these regions, it discusses current weed management systems and the herbicide resistance issues that have developed through the continuous use of herbicides. Echoing Chapter 18, it emphasises the importance of integrated weed management (IWM) techniques in achieving more sustainable maize production. The chapter concludes with IWM case studies in three European maize production regions.

# Index

- Abutilon theophrasti* 421  
Acidity 89  
Actellic Super 253, 256  
Adoption process  
    conservation agriculture 99  
    good agricultural practices 25–26  
    of modern maize varieties 44–45  
*Aeolus* spp., 268–269  
Aflatoxin contamination 371–373  
    detoxification  
        ammoniation 384  
        heating 383  
        nixtamalization 384  
    policy and public awareness 384–385  
    post-harvest aflatoxin control  
        fungal growth control in storage 381  
        proper storage 380–381  
        timing of harvest and drying 380  
    pre-harvest aflatoxin control  
        biological control 377–380  
        crop rotation 373–374  
        host plant resistance 374–375  
        seed vigour 376–377  
        soil nutrient supply 376  
        tillage 374  
        timely planting 375  
        water stress management 375–376  
    removing  
        dry milling 382–383  
        solvent extraction 383  
        sorting 381–382  
        wet milling 383  
Africa, MLN outbreak in 362–363  
African giant rat 330  
African pink stem borer. *see* *Sesamia calamistis*  
African Union Commission (AUC) 385  
*Aglaia odorata* Lour. 407  
Agricultura Sostenible Basada en la Siembra Directa (ASOSID) 82  
Agriculture, and climate change 94  
*Agriotes* spp., 268–269  
Agro-ecological zones 34  
Air temperature 194  
Allelopathy, and integrated weed management 406–408  
Alliance for Green Revolution (AGRA) 45  
*Alternaria alternata* 424  
*Amaranthus*  
    *A. retroflexus* 403  
    *A. rudis* 420  
*Ambrosia artimisiifolia* L. 403  
Ammoniation 384  
Anthesis-silking interval (ASI) 7  
Apparent electrical conductivity (EC<sub>a</sub>) 113–116  
APSIM-Maize 3–7  
Aquifer protection 15  
Argentina  
    nutrient management 154–155  
    yield gaps 19–22  
*Arthrobacter* spp., 405  
Arthropods, precision maize cultivation 129  
*Arvicanthis* spp. 318  
Asian corn borer. *see* *Ostrinia furnacalis*  
ASOSID. *see* Agricultura Sostenible Basada en la Siembra Directa (ASOSID)  
*Aspergillus* 377  
    *A. flavus* 249, 371, 374  
    *A. parasiticus* 371  
AUC. *see* African Union Commission (AUC)  
Awl nematodes. *see* *Dolichodoros* spp.  
  
*Bacillus subtilis* 377  
Banded leaf 350  
*Belonolaimus* spp. 302–304  
*Bidens pilosa* 190  
Biodiversity, and ecological services 193–194  
Biological control  
    European corn borer 286  
    of weeds 423–424  
Biological soil quality 89–92  
Biomass production 7  
Bio-physical determinants 159–160  
Biophysical factors, emerging plant diseases  
    agricultural policies 346  
    agronomic practices 343–344  
    change in cropping systems 344–345  
    climate change 345–346  
    institutional factors 346  
    prevention and control 346  
    travel, migration and trade 344  
*Bipolaris maydis* L. 74  
Breeding programme 39  
British Agricultural Revolution 182  
Brown stripe downy mildew 350  
Burrowing nematodes. *see* *Radopholus* spp.  
*Busseola fusca* 281–282  
  
CA. *see* Conservation agriculture (CA)  
Cane rat 330  
Canola (*Brassica napus* L.) 187  
*Capsicum chinense* 328  
Carbon sequestration 72  
Catholic Relief Services (CRS) 253  
Central Mexico, rainfed systems in 83–85  
Central Rift Valley of Ethiopia (CRVE)  
    labour productivity 23  
    livelihood security 25–26  
    rain-fed maize in 21

- semi-arid 15, 27
- worker safety 16
- Cercospora zeae-maydis* L. 74, 343
- Cereal leaf beetle. *see Oulema melanopa*
- CERES-Maize 3–8, 54
- Chaetocnema pulicaria* 361
- Chemical control of weeds 424–425
- Chemical soil quality 87–89
- Chenopodium*
  - C. album* 405, 418, 428
  - C. polyspermum* 428
- Chilo partellus* 279–280
- China
  - Nutrient Expert® 170
  - nutrient management 155–156
- Cicadulina*
  - C. mbila* 269–270
  - C. parazeae* 269–270
  - C. storeyi* 269–270
- CIMMYT. *see* International Maize and Wheat Improvement Centre (CIMMYT)
- Cirsium arvense* 424
- Climate change
  - adapting to 27–28
  - agriculture and 94
  - conservation agriculture 94–96
  - and emerging plant diseases 345–346
  - and insect pests 285–286
- Climate risk management
  - development 241–242
  - Mozambique 239–240
    - endowed farmers 241
    - subsistence farming 240–241
  - rainfall variability 233–234
  - rainfed maize cultivation,
    - sensitivity of 230–233
  - smallholder maize cropping 235–238
  - whole farm level 238
- Cochliobolus heterostrophus* 340, 343
- Cold soils, and zero-tillage cultivation 73
- Conoderus* spp. 268–269
- Conservation agriculture (CA) 82–83
  - adoption rates 99
  - on biological soil quality 89–92
  - on chemical soil quality 87–89
  - CIMMYT's long-term experimental sites 83–85
  - and climate change 94–96
  - implementation
    - innovation hub concept 97–99
    - limiting factors 96
    - residue trade-off 96–97
  - on physical soil quality 85–87
  - on productivity 93–94
  - systems 61–62
  - weed management under 92–93
- Conventionally tilled beds (CTBs) 87
- Convolvulus arvensis* L. 408
- Corn earworm. *see Helicoverpa zea*
- Corn flea beetle. *see Chaetocnema pulicaria*
- Corn leaf aphid. *see Rhopalosiphum maidis*
- Corn stunt complex 350
- Cotton bollworm. *see Helicoverpa armigera*
- Cover crops 75, 407–408
- CPWC. *see* Critical period for weed control (CPWC)
- Crested porcupine 330
- Criconemella ornata* 308
  - C. sphaerocephala* 308
- CRISPR/Cas9, 285
- Critical period for weed control (CPWC) 406, 416
- Crop canopy sensing 121–123
- Crop development, under drought
  - and heat stress 4–7
- Crop health care system 351
- Crop modelling 3, 4
- Crop-nutrient response function 24
- Crop physiological models 3
- Cropping systems
  - simplification of 182–184
  - in United States and Europe 417–418
- Crop residues
  - management 75
  - retention 83, 91
- Crop rotation 75
  - biodiversity and ecological services 193–194
  - on control of diseases, insects
    - and weeds 192–193
  - economic benefit of 194–195
  - and integrated weed
    - management 407–408
  - on nutrient use efficiency 189–192
  - pre-harvest aflatoxin control 373–374
  - on soil fertility 189–192
  - on soil quality 188–189
  - use of 83
  - yield benefit 182
- CRS. *see* Catholic Relief Services (CRS)
- Cry1Ab 273, 276, 282, 284
- Cry1F 277, 284
- CSIRO-Mk3.0, 8
- CTBs. *see* Conventionally tilled beds (CTBs)
- Cultivars 293, 406–407
- Cultivation
  - history of 107
  - and integrated weed management 406–407
  - inter-row cultivation 423
  - stages of 108
  - in United States, Ethiopia and
    - Argentina 19–28
  - and water availability 3
- Cyperus*
  - C. esculentus* L., 408
  - C. rotundus* L., 408
- Cyst nematodes 305–306

- Dagger nematodes. *see* *Xiphinema* spp.
- Dalbulus maydis* 345, 346
- Decision-aid methods (DSS) 425–426
- Decision support system (DSS) 121, 125
- Delia platura* 267–268
- Deoxynivalenol (DON) 250
- Desmodium uncinatum* 408
- Detoxification 383–384
- Diabrotica*
- D. barberi* 264–267
  - D. virgifera virgifera* 264–267, 361
- Diatraea* spp. 274
- D. grandiosella* 274
  - D. saccharalis* 274
- Diseases, crop rotation on control of 192–193
- Ditylenchus dipsaci* 309
- Diversification 344
- Dolichodorus* spp., 305
- DON. *see* Deoxynivalenol (DON)
- Drip irrigation 127
- Drought stress
- biomass production 7
  - climate change and 8
  - crop development 4–7
  - grain yield formation 7–8
  - RUE reduction by 7
  - soil fertility and effects 50–51
- Drought Tolerant Maize for Africa (DTMA) Project 39, 55
- Dry milling 382–383
- DSS. *see* Decision-aid methods (DSS); Decision support system (DSS)
- DTMA. *see* Drought Tolerant Maize for Africa (DTMA) Project
- Eastern Africa
- MLN in 356–359
  - seed supply and need 38
- Echinochloa*
- E. crus-galli* 403, 404, 425, 428
  - E. muricata* 404
- Ecological services, biodiversity and 193–194
- Ecological zones for maize production 51
- Economic
- benefit of crop rotation 194–195
  - loss 249
  - zero-tillage cultivation 70–71
- Eco-physiology 235
- Electrical conductivity (EC<sub>s</sub>) 113–116
- Emerging plant diseases (EPDs) 339–342
- biophysical factors
    - agricultural policies 346
    - agronomic practices 343–344
    - change in cropping systems 344–345
    - climate change 345–346
    - institutional factors 346
    - prevention and control 346
    - travel, migration and trade 344
  - disease monitoring 352–353
  - drivers of 342
  - early detection
    - diagnostic networks 347–348
    - research 348–349
    - training 349
  - economic losses from 341
  - factors influencing 342–343
  - forecasting 352–353
  - host–pathogen interaction 353
  - host plant resistance 354–355
  - integrated management 355
  - mitigating risks from 347
  - MLN (*see* Maize lethal necrosis (MLN))
  - networking 356
  - pre-emptive breeding 355
  - preliminary risk assessments 349–351
  - quarantine system and regulatory framework 352
  - rapid response 351–352
  - seed-based solutions 355–356
  - surveillance 352–353
- Environmental challenges 181–182
- Eoreuma loftini* 274
- EPDs. *see* Emerging plant diseases (EPDs)
- Ethiopia
- cultivation in 19–28
  - maize yield trend 22
- EU Project PURE 427
- EU projects ENDURE 427
- Europe
- maize cropping systems and weed flora 417–418
  - weed management in 418–420
- European corn borer. *see* *Ostrinia nubilalis*
- Exserohilum turcicum* L., 74
- Fall armyworm. *see* *Spodoptera frugiperda*
- Farmer-participatory research 43
- Farmers
- livelihood security 25–26
  - profitability 24–25
- Farmers' fertilization practices (FFP) 158
- Farming 194
- Farmyard manure (FYM) 156
- Farm yields 150
- Fertilizer 25
- levels of 43
  - micro-dosing technology 165
  - spot application of 165–166
- Fertilizer management 95, 422
- Fertilizer replacement value (FRV) 192
- FFP. *see* Farmers' fertilization practices (FFP)
- Flame weeding 408–409
- Food security 250–251
- 4R Nutrient Stewardship Principles 156–157, 171
- Frankliniella williamsi* 361



- FRV. see Fertilizer replacement value (FRV)  
 Functional diversity 90  
 Fungi, post-harvest losses 249–250  
 Furrow irrigation 85  
*Fusarium* spp., 249, 272  
   *F. graminearum* 300  
   *F. moniliforme* 300  
   *F. root rot* 91  
   *F. scribneri* 300  
   *F. verticillioides* 300  
 Fusion of information 123–124  
 FYM. see Farmyard manure (FYM)
- GAP. see Good agricultural practices (GAP)  
 Genetically modified herbicide-tolerant (GMHT) crops 416–419, 421, 423–425  
 Genomics 285  
 Geographical positioning system (GPS) 405  
 Geographic information systems (GIS) 108  
 Geometric mean diameter (GMD) values 188  
 Geo-statistics 108  
*Gerbilliscus* spp. 318  
   *G. vicinus* 319  
 Gerbils 330  
 Germplasm, biotic and abiotic stresses  
   resistance 39  
 GHG emission. see Greenhouse gas (GHG)  
   emission
- GIS. see Geographic information systems (GIS)  
*Gliricidia sepium* 328  
 Global food demand 181–182  
 Globalization of agriculture 344  
 Global positioning systems (GPS) 108  
 Global warming 193, 345  
 Global warming potential (GWP) 94  
 GLS. see Grey leaf spot (GLS)  
 Glyphosate-resistant (GR) weeds 416  
 GMD values. see Geometric mean diameter (GMD) values  
 GMHT crops. see Genetically modified herbicide-tolerant (GMHT) crops  
 GMP. see Good manufacturing practices (GMP)  
 Good agricultural practices (GAP) 373  
   adoption of 25–26  
   aquifer protection 15  
   climate change, adapting to 27–28  
   farmer profitability 24–25  
   farmers and local communities, livelihood security for 25–26  
   natural resources and environment 26–27  
   nutrient losses 15–16  
   resource productivity 22–23  
   soil management 14–15  
   targets and measuring performance 16–19  
   in West Africa  
   nutrient management 52–54  
   soil fertility 50–51  
   soil moisture stress 55  
   weed competition with maize 51–52  
   weed management 54–55  
   worker safety 16  
 Good manufacturing practices (GMP) 373  
 GPS. see Geographical positioning system (GPS); Global positioning systems (GPS)  
*Gracilacus* 307  
 Grain-filling period 51  
 GrainPro 254  
 Grain yield formation 7–8  
 Greenhouse gas (GHG) emission 16, 82  
 Green Revolution 20  
 GreenSeeker 123, 124  
 Grey leaf spot (GLS) 74, 343, 350  
 Grid soil sampling 109  
 Ground squirrels 330  
 GR weeds. see Glyphosate-resistant (GR) weeds  
 GWP. see Global warming potential (GWP)
- HACCP. see Hazard Analysis Critical Control Point (HACCP)  
*Hadroplontus litura* 424  
 Haemoparasites 331  
 Harvest yield maps 130–132  
 Hazard Analysis Critical Control Point (HACCP) 373  
 Heat stress  
   biomass production 7  
   climate change and 8  
   crop development 4–7  
   grain yield formation 7–8  
   RUE reduction by 7  
*Helicotylenchus* 304, 308–309  
   *H. digonicus* 309  
   *H. pseudorobustus* 308–309  
*Helicoverpa*  
   *H. armigera* 276–277, 284  
   *H. zea* 274–276, 284  
 Herbicide-resistant (HR) weed populations 416  
 Herbicides  
   application 128  
   tolerant cultivars 407–408  
   use of 404–405  
   weed management 416, 424–425  
 Herbivores 293  
 Hermetic bagging 254  
*Heterodera*  
   *H. avenae* 305  
   *H. cajani* 306  
   *H. delvii* 306  
   *H. gambiensis* 306  
   *H. oryzae* 306  
   *H. sorghi* 306  
   *H. zea* 305  
 High-dose refuge (HDR) strategy 284  
 High plains diseases 350  
*Hoplolaimus* spp., 306–307  
   *H. magnistylus* 307

- Host–pathogen interaction 353  
 Host plant resistance 374–375  
 HR weed populations. *see* Herbicide-resistant (HR) weed populations  
 Hybrid breeding 41  
 Hybrid/cultivar selection 75  
 Hybrid-Maize 5–7  
 Hydraulic conductivity 85–86
- ICRISAT. *see* International Crop Research Institute for Semi-Arid Tropics (ICRISAT)  
 IITA. *see* International Institute of Tropical Agriculture (IITA)
- India  
*Helicoverpa armigera* 277  
 maize validation trials in 158
- Infiltration  
 and run-off 86  
 and zero-tillage cultivation 69–70
- Insect pests  
*Aeolus* spp. 268–269  
*Agriotes* spp. 268–269  
*Busseola fusca* 281–282  
 challenges 285–286  
*Chilo partellus* 279–280  
*Conoderus* spp. 268–269  
*Delia platura* 267–268  
*Diabrotica barberi* 264–267  
*Diabrotica virgifera virgifera* 264–267  
*Helicoverpa armigera* 276–277  
*Helicoverpa zea* 274–276  
*Limonius* spp. 268–269  
 maize leafhoppers 269–270  
*Melanotus* spp. 268–269  
*Ostrinia furnacalis* 273  
*Ostrinia nubilalis* 270–273, 283–285  
*Rhopalosiphum maidis* 269, 270  
*Sesamia calamistis* 282–283  
 south-western corn borer 274  
*Spodoptera frugiperda* 278–279  
 stored products pests 283  
*Striacosta albicosta* 277–278
- Insects  
 crop rotation on control of 192–193  
 post-harvest losses 249–250
- Integrated pest management (IPM) 15, 271, 419  
 Integrated rodent management (IPM) 329–330  
 Integrated soil fertility management (ISFM) 53, 170  
 Integrated *Striga* control (ISC) 54–55  
 Integrated systems 137  
 Integrated weed management (IWM) 406–409  
 biological control 423–424  
 chemical control 424–425  
 implementation 419–420  
 decision-aid methods 425–426  
 in European maize production regions 427–430  
 lack of 426–427  
 preventive and cultural methods 420–422  
 tillage and mechanical weed control 422–423
- Intensification 344
- Intercropping  
 component crops of 204  
 and integrated weed management 407–408  
 maize–legumes intercropping competition and complementary interactions in 213–217  
 evaluation 217–220  
 and moisture conditions 204–206  
 and nitrogen supply 206–207  
 productivity 203  
 resource capture 207–213  
 use efficiency 207–213
- International Crop Research Institute for Semi-Arid Tropics (ICRISAT) 108  
 International Institute of Tropical Agriculture (IITA) 53  
 International Maize and Wheat Improvement Centre (CIMMYT)  
 with Kenyan Agricultural Research Institute 46  
 long-term experimental sites 83–85  
 long-term trials 89  
 Sustainable intensification strategy 98
- Internet of things (IoT) 136  
 Inter-row cultivation 423  
 Invasive species 285  
 IoT. *see* Internet of things (IoT)
- IPM. *see* Integrated pest management (IPM); Integrated rodent management (IPM)
- Irrigation  
 in arid north-western Mexico 95–96  
 for maize cultivation 55  
 in north-western Mexico 85  
 precision maize cultivation 127–128
- ISC. *see* Integrated *Striga* control (ISC)  
 ISFM. *see* Integrated soil fertility management (ISFM)
- IWM. *see* Integrated weed management (IWM)
- Jatropha curcas* 328  
 Java downy mildew 350
- Kenyan Agricultural Research Institute 46
- Labour productivity 23  
 Lance nematodes. *see* *Hoplolaimus* spp.  
 Land equivalent ratio (LER) 204–207, 214–219  
 Land preparation, and integrated weed management 406–407  
 Landscape ecology 285  
 Larger grain borer (LGB) 249

- Latin America  
 agriculture challenges 81–82  
 conservation agriculture (CA) in 82–83  
   adoption rates 99  
   on biological soil quality 89–92  
   on chemical soil quality 87–89  
 CIMMYT's long-term experimental sites 83–85  
 and climate change 94–96  
 implementation 96–99  
 on physical soil quality 85–87  
 on productivity 93–94  
 weed management under 92–93
- Latin America–Southern Cone  
 micronutrient deficiencies 168  
 nitrogen for early and late-season maize 166–167  
 N, P and S nutrient efficiency and effectiveness 169  
 nutrient management 154–155  
 research priorities 172–173  
 soil phosphorus tests 167  
 sulphur diagnosis 167–168  
 variable nutrient management 169
- LER. *see* Land equivalent ratio (LER)
- Lesion nematodes. *see* *Pratylenchus* spp.
- LGB. *see* Larger grain borer (LGB)
- Light-limited biomass accumulation 7
- Limonius* spp. 268–269
- Livelihood security, for farmers and local communities 25–26
- Local communities, livelihood security for 25–26
- Longidorus* spp., 302–304  
*L. breviannulatus* 303
- Maize–alfalfa rotation 189
- Maize-based cropping systems (MBCS) 417–418
- Maize chlorotic dwarf virus (MCDV) 350
- Maize chlorotic mottle virus (MCMV) 344–345, 350  
 diagnostic methods 348  
 global occurrence and reports 357  
 initial observation for 358–359  
 occurrence in Africa 358  
 transmission 360–361
- Maize leafhoppers 269–270
- Maize–legume rotation 54, 189  
 benefits of 192–195  
 biodiversity and ecological services 193–194  
 control of diseases, insects and weeds 192–193  
 economic benefit of 194–195  
 environmental costs, reducing 193  
 yield enhancement in 184–188
- Maize–legumes intercropping  
 competition and complementary interactions in 213–217  
 evaluation 217–220
- Maize lethal necrosis (MLN)  
 in Africa 362–363  
 distribution 358  
 in Eastern Africa 356–359  
 global occurrence and reports 357  
 host resistance, developing 361–362  
 information dissemination 360  
 initial observation for 358  
 phytosanitary measures and regulations 360  
 prevention and control 359  
 research efforts in region 362  
 Tanzania maize field affected by 340  
 transmission 360–361
- Maize Rayado fino virus (MRFV) 350
- Maize stalk borer. *see* *Busseola fusca*
- Maize streak virus (MSV) 39, 345, 350
- MAIZSIM 5–7
- Malawi  
 adoption rate 44–45  
 maize revolution 36  
 MH17 and MH18, 36–37
- Mal del Río Cuarto 350
- Management zones 112–115
- Management Zones Analyst (MZA) 120
- MasAgro project 96, 98
- Mastomys natalensis*  
 breeding 318, 326  
 feeding behaviour 321  
 in irrigated rice fields 320  
 population density 325  
 seed damage reduction 328  
 survival 329  
 in Tanzania 330
- MBCS. *see* Maize-based cropping systems (MBCS)
- MCDV. *see* Maize chlorotic dwarf virus (MCDV)
- MCMV. *see* Maize chlorotic mottle virus (MCMV)
- Mean weight diameter (MWD) 188–189
- Mechanical control, and integrated weed management 408–409
- Melanotus* spp. 268–269
- Meloidogyne* spp. 300–302  
*M. arenaria* 301  
*M. chitwoodi* 302  
*M. incognita* 301  
*M. javanica* 301
- Merlinius* 309
- Mexico  
 agricultural development 98  
 semi-arid highlands of 94–95
- MH17 and MH18 36–37
- Microbial community structure 90–91
- Micro-elements 126
- Micronutrient deficiencies 168
- Micro-topography 117

- MIROC 3.2 8
- MLN. *see* Maize lethal necrosis (MLN)
- MM. *see* Mono-cropping maize (MM)
- Modern maize varieties 44–45
- Moisture  
intercropping and 204–206  
requirement of maize 51
- Mole rat 330
- Mono-cropping maize (MM) 182–184
- Mother-baby trial (MBT) design 39, 41–43
- Mozambique  
climate risk management  
endowed farmers 241  
household description 239–240  
subsistence farming 240–241  
rainfed maize cropping  
endowed farmers 241  
households 239–240  
subsistence farming 240–241  
sustainable intensification 239
- MRFV. *see* Maize Rayado fino virus (MRFV)
- MSV. *see* Maize streak virus (MSV)
- MWD. *see* Mean weight diameter (MWD)
- Mycotoxins 249–250
- MZA. *see* Management Zones Analyst (MZA)
- Nanotechnology 136
- National Agricultural Research Systems (NARS) 39
- National Maize Breeding Program of Malawi 36
- National Seed Authorities 44
- Natural resources, and environment 26–27
- Nebraska  
aquifer protection in 15  
livelihood security 25  
nitrogen response curves 23  
rain-fed and irrigated fields in 27  
yield gaps 19  
yield trends 22
- Nematodes  
awl nematodes 305  
burrowing nematodes 305  
cyst nematodes 305–306  
dagger nematodes 306  
lance nematodes 306–307  
lesion nematodes 297–300  
pin nematodes 307  
reniform nematodes 307–308  
ring nematodes 308  
root-knot nematodes 300–302  
soil and plant nematodes 294–297  
spiral nematodes 308–309  
stem and bulb nematode 309  
stunt nematodes 309–310  
vermiform nematodes 302–304
- Niger seed oil 256
- Nile rat 330
- Nitrogen 88  
crop productivity and economic returns 162–164  
for early and late-season maize 166–167  
fertilizer  
efficiency 16  
lack of 50  
losses reduction 67–68  
management  
crop canopy sensing 121–123  
decision support systems 125  
fusion of information 123–124  
management zones 119–120  
proximal soil sensing 120–121  
recommendations, extrapolating 53–54  
supply, intercropping and 206–207  
Nitrogen nutrition index (NNI) 211–212  
Nitrogen physiological efficiency (NPE) 209–210  
Nitrogen recovery efficiency (NRE) 209–210  
Nitrogen-use efficiency (NUE) 190, 209–212  
Nixtamalization 384  
NNI. *see* Nitrogen nutrition index (NNI)  
Norfolk four-crop rotation 182  
Northern corn rootworm. *see* *Diabrotica barberi*  
Northern leaf blight 74  
North-western Mexico, irrigated conditions in 85  
No-tillage production systems 374  
NPE. *see* Nitrogen physiological efficiency (NPE)  
NRE. *see* Nitrogen recovery efficiency (NRE)  
NUE. *see* Nitrogen-use efficiency (NUE)  
Nutrient availability 88–89  
Nutrient Expert® (NE) 158–159  
Nutrient losses  
from agricultural land 15–16  
reduction in zero-tillage cultivation 67–69  
Nutrient management 52–54  
bio-physical and socio-economic determinants 159–160  
China 155–156  
improvement 156–157  
inter- and intra-seasonal rainfall 164–165  
Latin America 154–155  
micronutrient deficiencies 168  
nitrogen  
for early and late-season maize 166–167  
efficiency and effectiveness 169  
rates 162–164  
research priorities 170–173  
soil fertility variability 160–162  
soil P tests 167  
South Asia 151–152  
spot application of fertilizer 165–166  
Sub-Saharan Africa 152–154  
sulphur diagnosis 167–168  
using fertilizer decision support tool 158–159  
variable nutrient management 169

- Nutrient use efficiency, crop  
rotation on 189–192
- Nutrition, precision maize cultivation  
nitrogen management 119–126  
temporal synchrony 126–127
- Old World Bollworm. *see Helicoverpa armigera*
- On-farm biodiversity 194
- On-farm field trials 137
- On-the-go soil sensors 120–121
- Open-pollinated varieties (OPVs) 36–37, 39,  
41, 44, 263
- Ostrinia*  
*O. furnacalis* 273  
*O. nubilalis* 270–273, 283–285
- Oulema melanopa* 361
- PACA. *see* Partnership for Aflatoxin Control in  
Africa (PACA)
- Paratrichodorus* spp., 302–304  
*P. minor* 303
- Parthenium hysterophorus* L., 402
- Partial factor productivity (PFP) 153, 155
- Partial nutrient balance (PNB) 155
- Partnership for Aflatoxin Control in Africa  
(PACA) 384–385
- PARUE. *see* Photosynthetically active radiation  
use efficiency (PARUE)
- PBs. *see* Permanent beds (PBs)
- Permanent beds (PBs) 85–89, 95
- Pest biology 285
- Pesticides  
in Nebraska 15  
precision maize cultivation  
arthropods 129  
soil applied pesticide  
degradation 129–130  
weeds 128–129
- PFP. *see* Partial factor productivity (PFP)
- Phalaris minor* 92
- Philippine downy mildew 350
- PHLs. *see* Post-harvest losses (PHLs)
- Phosphorus  
efficiency and effectiveness 169  
losses reduction 68–69  
nitrogen management 126  
soil phosphorus tests 167
- Phosphorus use efficiency (PUE) 166
- Phostoxin 253
- Photosynthetically active radiation use efficiency  
(PARUE) 212–213
- Phyllochron 4–5
- Physical soil quality 85–87
- PICS bags. *see* Purdue Improved Crop Storage  
(PICS) bags
- Pin nematodes 307
- Plant available water 86–87
- Plant disease 74
- Planting  
and integrated weed  
management 406–407  
precision maize cultivation 117–119  
pre-harvest aflatoxin control 375  
time 232–233
- Plant-parasitic nematodes 296–297
- PMC techniques. *see* Precision maize cultivation  
(PMC) techniques
- PNB. *see* Partial nutrient balance (PNB)
- Poaceae 293
- Post-emergence herbicides 404, 424
- Post-harvest aflatoxin control  
fungal growth control in storage 381  
proper storage 380–381  
timing of harvest and drying 380
- Post-harvest insect control 286
- Post-harvest losses (PHLs)  
food security 250–251  
incidence and significance 248  
insects and fungi 249–250  
institutional factors impacting 251  
reducing through technological  
interventions 251–256  
storage structures 250–251  
types and causes 248–249
- Post-harvest management 247.  
*see also* Post-harvest losses (PHLs)
- Potassium 88–89, 126
- Potential yields 150
- Pratylenchus* spp., 297–300, 307  
*P. brachyurus* 299, 300  
*P. coffeae* 299  
*P. crenatus* 299  
*P. hexincisus* 299, 300, 307  
*P. microdorus* 307  
*P. neglectus* 299  
*P. penetrans* 299  
*P. scribneri* 299  
*P. thornei* 299  
*P. vulnus* 299  
*P. zeae* 299, 300
- Precision maize cultivation (PMC)  
techniques 108  
data analysis  
big data 132–133  
economics 133–135  
harvest yield maps 130–132  
integrated systems 137  
internet of things 136  
irrigation 127–128  
nanotechnology 136  
nutrition  
nitrogen management 119–126  
temporal synchrony 126–127  
on-farm field trials 137  
pesticides  
arthropods 129

- soil applied pesticide
  - degradation 129–130
  - weeds 128–129
- planting
  - case study 118–119
  - precision planting 117–118
- pre-planting
  - apparent electrical conductivity 113–116
  - management zones 112–113
  - remote sensing 117
  - soil sampling 109–112
  - spatial soil variability at 117
  - stratified soil sampling 112
  - topography 116–117
  - yield maps 116
- robotics 137
- sensor fusion 135
- soil microbiome 136–137
- unmanned aerial vehicles 135
- wireless sensor networks 136
- Pre-emergence herbicides 404, 424, 425
- Pre-emptive breeding 355
- Pre-harvest aflatoxin control
  - biological control 377–380
  - crop rotation 373–374
  - host plant resistance 374–375
  - seed vigour 376–377
  - soil nutrient supply 376
  - tillage 374
  - timely planting 375
  - water stress management 375–376
- Pre-planting, precision maize cultivation
  - apparent electrical conductivity 113–116
  - management zones 112–113
  - remote sensing 117
  - soil sampling 109–112
  - spatial soil variability at 117
  - stratified soil sampling 112
  - topography 116–117
  - yield maps 116
- Pre-sowing herbicides 424
- Private sector, in post-harvest technology 251
- Production 149–150
  - area characteristics 20
  - yield variability 227–229
- Production-protection agriculture 82
- Program for Monitoring Emerging Diseases (ProMED) 348
- Prolificity in maize 231
- ProMED. *see* Program for Monitoring Emerging Diseases (ProMED)
- Prostephanus truncatus* 283
- Proximal soil sensing 120–121
- Pseudomonas*
  - P. solanacearum* 377
  - P. syringae* 424
- PUE. *see* Phosphorus use efficiency (PUE)
- Punctodera chaltoensis* 305–306
- Purdue Improved Crop Storage (PICS)
  - bags 253–255
- Quarantine system 352
- Quinisulcius* 309
- Radiation use efficiency (RUE) 7
- Radopholus* spp. 305
- Rainfall 50–51
  - inter- and intra-seasonal rainfall 164–165
  - intercropping 205
  - variability, risk of 233–234
- Rainfed conditions 94–95
- Rainfed maize cultivation 230–233
- Rainfed systems, in central Mexico 83–85
- RCI. *see* Relative competition intensity (RCI)
- Regulatory framework 352
- Relative competition intensity (RCI) 216–217
- Remote sensing (RS) 108, 117
- Reniform nematodes. *see* *Rotylenchulus* spp.
- Residue management 91
- Resource capture 207–213
- Resource productivity 22–23
- Rhodesia's Salisbury Agricultural Experimental Station (SAES) 36, 37
- Rhopalosiphum maidis* 269, 270
- Rhizopertha dominica* 283
- Ricinus communis* 328
- Ring nematodes 308
- RNAi 285
- Robotics 137
- Rodent
  - behaviour of 331
  - biological control 329
  - chemical control 328–329
  - conservation 332
  - cultural approaches 328
  - damage 317–318
    - crop compensation/recovery after 321
    - at crop's maturity stage 320–321
    - disease transmission to humans 322–323
    - early warning signs 330
    - in fields 319
    - nature of damage 319–321
    - in stores 321–322
  - disease 331–332
  - distribution 323
  - ecology and breeding patterns 323–327
  - integrated rodent management 329–330
  - management methods 327
  - management technologies 332
  - population ecology 331–332
  - populations, monitoring and modelling 332
  - species 323
  - taxonomy and systematics 331
- Root-knot nematodes. *see* *Meloidogyne* spp.
- Rotylenchulus* spp. 307–309
  - R. parvus* 308

- Rotylenchus* 304, 308  
 RS. see Remote sensing (RS)
- Salinity 89
- SCAN system. see Soil, Crops and Atmosphere for Nitrogen (SCAN) system
- SCLB. see Southern corn leaf blight (SCLB)
- SCMV. see *Sugarcane mosaic virus* (SCMV)
- Scutellonema* 308
- SDC. see Swiss Development Cooperation (SDC)
- Seed-based solutions 355–356
- Seed corn maggot. see *Delia platura*
- Seeding equipment 75
- Seedling emergence 73
- Seed systems in Southern Africa  
 agro-ecological zones of 34  
 air temperature 35  
 average maize yields in 34  
 challenges 46  
 climate predictions 34  
 development 43–44  
 maize variety development in 36–37  
 on-farm experiments 40  
 production distribution by environment 35–36  
 rainfall 34–35  
 seed industries 37–43  
 seed supply and need 38  
 stress-tolerant varieties in 39  
 trends in average maize production 35
- Seed vigour, pre-harvest aflatoxin control 376–377
- Semi-arid CRVE 23
- Semi-variograms 109–110
- Sensor-based irrigation scheduling 127
- Sensor fusion 135
- Sesamia* spp., 282–283  
*S. calamistis* 282–283
- Sheath blight 350
- Silent Spring* (Carson) 15
- SilicoSec 256
- Site-specific herbicide applications 405
- Site-specific weed control 405
- Sitophilus zeamais* 283
- Slash-mulch system 82
- Smallholder farmers 24, 49  
 intercropping 218  
 maize genetic improvement for 39  
 risk management 235–238  
 in southern Africa 34, 35, 37
- Small-scale farmers, and conservation agriculture 96
- Smart delivery system 136
- Smart sampling. see Stratified soil sampling
- SMB. see Soil microbial biomass (SMB)
- SOC. see Soil organic carbon (SOC)
- Socio-economic determinants 159–160
- Sodicity 89
- Soil and plant nematodes  
 characteristics of 294–295  
 identification 295–296  
 stages 294
- Soil applied pesticide degradation 129–130
- Soil-borne diseases 91–92
- Soil compaction 73–74
- Soil, Crops and Atmosphere for Nitrogen (SCAN) system 125
- Soil erosion 87  
 control 15  
 reduction in zero-tillage cultivation 65–67
- Soil fertility 50–51  
 crop rotation on 189–192  
 variability 160–162
- Soil meso- and macrofauna 92
- Soil microbial biomass (SMB) 88, 90
- Soil microbiome 136–137
- Soil microfauna and flora 89–90
- Soil moisture stress 55
- Soil nitrogen 53
- Soil nutrient supply 376
- Soil organic carbon (SOC) 72, 87, 188
- Soil organic matter (SOM) 15, 26, 156
- Soil phosphorus tests 167
- Soil quality 188–189
- Soil sampling  
 precision maize cultivation 109–112  
 rule of thumb 112
- Soil spatial variability 117
- Soil structure and aggregation 85
- Soil surface cover 83
- Soil temperature 87, 95, 233
- Soil water content 86–87
- Soil water deficits 23
- Solvent extraction 383
- SOM. see Soil organic matter (SOM)
- Sorghum halepense* 425
- South America, zero-tillage cultivation 62, 64–65
- South Asia  
 bio-physical and socio-economic determinants 159–160  
 nutrient management 151–152  
 research priorities 170–172  
 using fertilizer decision support tool 158–159
- Southern Africa Drought and Low Fertility (SADLF) programme 39, 41
- Southern African Development Community (SADC) 44
- Southern Africa, seed systems in agro-ecological zones of 34  
 air temperature 35  
 average maize yields in 34  
 challenges 46  
 climate predictions 34

- development 43–44
- maize variety development in 36–37
- on-farm experiments 40
- production distribution by
  - environment 35–36
- rainfall 34–35
- seed industries 37–43
- seed supply and need 38
- stress-tolerant varieties in 39
- trends in average maize production 35
- Southern corn leaf blight (SCLB) 340
- Southern leaf blight 74
- South-western corn borer 274
- Spatial analysis approaches 172
- Spine mice 330
- Spiral nematodes 308–309
- Spiroplasma kunkelii* 346
- Split-hoe tool 408
- Spodoptera frugiperda* 278–279, 284
- Spoon feeding maize 127
- Spot-spraying weeds 128–129
- Spotted stalk borer. *see* *Chilo partellus*
- Sprayer boom-mounted sensors 121–122
- Spray irrigation 127
- SR52, 36
- SSA. *see* Sub-Saharan Africa (SSA)
- State recommendations (SR) 158
- Stem and bulb nematode. *see* *Ditylenchus dipsaci*
- Stewart's wilt 350
- Storage structures 250–251
- Stored products pests 283
- Stratified soil sampling 112
- Stress environments 231
- Striacosta albicosta* 277–278, 284
- Striga hermonthica* 50–52, 407–408
- Striga*-resistant maize 55
- Stripped grass mouse 330
- Stunt nematodes 309–310
- Sub-Saharan Africa (SSA)
  - inter-and intra-seasonal rainfall 164–165
  - nitrogen rates 162–164
  - nutrient management 152–154
  - poverty line in 49
  - rained maize cropping systems 230
  - research priorities 172
  - soil fertility variability 160–162
  - spot application of fertilizer 165–166
  - yield in 20
  - zero-tillage maize in 62
- Subsistence farming 240–241
- Sugarcane downy mildew 350
- Sugarcane mosaic virus* (SCMV) 346, 348
- Sulphur
  - efficiency and effectiveness 169
  - nutrient management 167–168
- SuperGrain II™, 254, 255
- Sustainability
  - metrics 19
  - problems for 182–184
- Sustainable crop production
  - defining 13–14
  - targets and measuring performance 16–19
- Sustainable intensification 203
- Sustainable soil management
  - long-term experiments 83
  - need for 81–83
- Swiss Development Cooperation (SDC) 253
- Tar spot complex 350
- Temporal synchrony 126–127
- Tephrosia vogelii* 328
- TFI. *see* Treatment frequency index (TFI)
- Topography, precision maize
  - cultivation 116–117
- Toxicogenic fungi 372
- Tractor roof-mounted sensors 122
- Transgenic 285
- Treatment frequency index (TFI) 429
- Trianthema portulacastrum* 408
- Trichoderma* 378
- Trichodorus* spp. 302–304
- Tylenchorhynchus* 309
  - T. claytoni* 310
  - T. maximus* 310
  - T. zambiensis* 310
- Tylenchulus* 309
- UAVs. *see* Unmanned aerial vehicles (UAVs)
- Uganda
  - crop-nutrient choices 25
  - rain-fed maize in 23
- Uniformity and stability (DUS) 44
- United States
  - cultivation in 19–28
  - European corn borer in 283–285
  - maize cropping systems and weed flora 417–418
  - weed management in 418–420
  - zero-tillage cultivation 63–64
- United States Agency for International Development (USAID) 100
- Unmanned aerial vehicles (UAVs) 135
- USAID. *see* United States Agency for International Development (USAID)
- USDA's Agricultural Resource Management Survey 134
- Value for cultivation and use (VCU) 44
- Variable-rate seeding 118
- VCGs. *see* Vegetative compatibility groups (VCGs)
- Vegetative compatibility groups (VCGs) 378
- Vegetative stages 6
- Vermiform nematodes 302–304
- Virtual reference strip 123



- Vittatidera zeaphila* 306
- Water  
 activity and aflatoxin 372  
 deficit biomass accumulation 7  
 erosion 15  
 extraction 214  
 holding capacity 85–86  
 productivity 23  
 stress management 375–376  
 stress, yield under 72  
 supply  
 yield gap and 20  
 yield potential 17
- Water-use efficiency (WUE) 71, 207–213
- WCA. *see* West and Central Africa (WCA)
- Weed 51  
 control 72–73  
 crop rotation on control of 192–193  
 impact on maize cultivation 396–403  
 precision maize cultivation 128–129  
 seedbank 417  
 yield losses by 403
- Weed flora, in United States and Europe 417–418
- Weed management  
 biological control 423–424  
 chemical control 424–425  
 under conservation agriculture 92–93  
 for maize cultivation 54–55  
 preventive and cultural methods 420–422  
 tillage and mechanical weed control 422–423  
 in United States and Europe 418–420
- Weight loss (WL) 249
- Well-fertilized maize 186–187
- West Africa, good agricultural practices in  
 nutrient management 52–54  
 soil fertility 50–51  
 soil moisture stress 55  
 weed competition with maize 51–52  
 weed management 54–55
- West and Central Africa (WCA) 50
- Western bean cutworm. *see* *Striacosta albicosta*
- Western corn rootworm. *see* *Diabrotica virgifera virgifera*
- Wet milling 383
- Wheat/maize rotation 91
- Whole farm level 238
- Wind erosion 15
- Wireless sensor network (WSN) 136
- Wireworms 268–269
- WL. *see* Weight loss (WL)
- Worker safety 16
- WSN. *see* Wireless sensor network (WSN)
- WUE. *see* Water-use efficiency (WUE)
- Xanthium strumarium* 403
- Xiphinema* spp., 306  
*X. americanum* 306  
*X. chambersi* 306  
*X. rivesi* 306
- Yaqui Valley 85
- YE. *see* Yield/agronomic efficiency (YE)
- Yield/agronomic efficiency (YE) 209–210
- Yield enhancement 184–188
- Yield gain rate 20, 22
- Yield gap (Yg) 17–22, 150
- Yield goals 18–19
- Yield losses  
 due to nematodes 91  
 by weeds 403
- Yield maps  
 harvest 130–132  
 precision maize cultivation 116
- Yield potential (Yp) 16–17
- Yield, under water stress 72
- Zambia  
 adoption rate 44–45  
 large-scale industrial agriculture crop 36  
 Zamseed Research Institute 37
- Zero tillage (ZT) 85, 86
- Zero-tillage cultivation  
 advantages  
 carbon sequestration 72  
 economics 70–71  
 infiltration 69–70  
 nutrient losses reduction 67–69  
 soil erosion reduction 65–67  
 soil organic matter 72  
 water use efficiency 71  
 yield under water stress 72  
 disadvantages  
 cold soils 73  
 compaction 73–74  
 decreased emergence 73  
 equipment 75  
 plant disease 74  
 weed control 72–73  
 history of 61–62  
 and integrated weed management 407  
 soils and climate 75  
 South America 62, 64–65  
 transition planning 75  
 USA 63–64  
 variable and machinery cost 71
- ZM309 42  
 ZM421 42  
 ZM521 42  
 ZM523 42  
 ZM623 42
- ZT. *see* Zero tillage (ZT)