FOURTH EDITION

AGROECOLOGY

LEADING THE TRANSFORMATION TO A JUST AND SUSTAINABLE FOOD SYSTEM

STEPHEN R. GLIESSMAN
V. ERNESTO MÉNDEZ
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Agroecology

Agroecology is at the forefront of transforming our food systems. This bestselling textbook provides the essential foundation for understanding this transformation in all its components: agricultural, ecological, economic, social, cultural, and political. It presents a case for food system change, explains the principles and practices underlying the ecological approach to food production, and lays out a vision for a food system based on equity and greater compatibility with the planet's life support systems. New to the fourth edition:

- A chapter on Alternatives to Industrial Agriculture, covering the similarities and distinctions among different approaches to sustainable agriculture
- A chapter on Ecological Pest, Weed, and Disease Management
- A chapter on Urban and Peri-urban Agriculture
- A chapter on Agriculture and the Climate Crisis
- A revised analysis and critique of the food system's embeddedness in the extractive capitalist world economy that reflects ideas in the emerging field of political agroecology
- Streamlined treatment of agroecology's foundations in ecological science, making the text more compatible with typical course curricula

Groundbreaking in its first edition and established as the definitive text in its second and third, the fourth edition of *Agroecology* captures recent developments in the field and forcefully applies the idea that agroecology is a science, a movement, and a practice. Written by a team of experts, this book will encourage students and practitioners to consider the critical importance of transitioning to a new paradigm for food and agriculture.

With each new version, this textbook is becoming an even more valuable tool for all those who wish to better understand and work toward a more sustainable and just food system.

Marcia DeLonge
Research Director & Senior Scientist, Food & Environment Program,
Union of Concerned Scientists, USA.

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Agroecology
Leading the Transformation to a Just and Sustainable Food System

Fourth Edition

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V. Ernesto Méndez
Victor M. Izzo
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Front Cover Description: Four of the many necessary paths to a just and sustainable food system: Growing food in and around cities (upper left), expanding participation in farmers' markets and other expressions of equitable local and regional food networks (upper right), re-asserting the importance of small holder traditional agroecosystems (lower right), and building a global movement for food justice and sovereignty (lower left).

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Foreword

On most of what is regarded as agricultural land, a system of agriculture, unique in history, dominates. Whether the maize fields of North America, the soybean plantations of South America, the oil palm plantations of South Asia, or the wheat fields of Ukraine, the pattern is evident. Industrial-scale production accounts for the majority of farmland area. Yet, across the world, most *people* we regard as farmers do not grow crops this way—the average small-scale producer uses a variety of more traditional methods, usually not in a monoculture and usually not heavily dependent on external and expensive inputs like pesticides and chemical fertilizers. This typical farmer, unsurprisingly, concentrates on producing food. In contrast, most industrial farmland produces animal feed, industrial feedstocks, and raw materials for "food-like substances," emitting an outsized share of humanity's greenhouse gases as it does so.

It is difficult to argue against the proposition that farmland should be mainly for food production. It is equally difficult to oppose the idea that, given the rapidly accelerating climate crisis, the contribution to global warming of agricultural production should be minimized. Why, then, is the notion of devoting agriculture to the production of food, while minimizing its contribution to climate change and maximizing its output of healthy food for people to eat, ridiculed by some as utopian? We find this to be a notable irony.

Utopian or not, agroecology stands as the alternative to industrial agriculture. A long time ago (1990), Peter Rosset, Ron Carroll, and one of us (Vandermeer) organized a series of essays about the global agricultural system and published them in a book, the title of which was *Agroecology*. There was little or no discussion about why we called it that; it just seemed right at the time. The chapters ranged over multiple disciplines, including rural sociology, ecology, economics, geography, and chemistry. All that interdisciplinary material seemed to be part of what we imagined as an "ecological" approach to agriculture, and the word *agroecology*, used earlier by a few others, jumped out as the unifying concept. Similar ideas were expressed by other terms like organic, ecological, sustainable, and renewable, but at the time the word agroecology seemed to encompass all those other handles.

That book clearly reflected what one of us (Vandermeer) had learned from his early dealings with Steve Gliessman in the highlands of Costa Rica and in the lowlands of Tabasco, Mexico. Indeed, it would be reasonable to credit Gliessman as the fourth—albeit indirect—editor of that early collection. For the other of us (Perfecto), interactions with Steve, connected with establishing an Agroecology section in the professional Ecological Society of America in the early 1990s, were similarly instructive. In so many ways he introduced us both to the criticism of industrial agriculture's anti-ecological (and anti-human) tendencies and kindled in us a spirit of examining agriculture from an ecological perspective and through a lens of social justice.

During subsequent years more meaning has been embedded in agroecology. It contains elements of its etymological parent, the science of ecology, but it is much more. Because it gathers information from those who have been farming in a traditional manner for generations, traditional knowledge has become one of its essential features. It rejects the ideology of complete domination over nature in favor of using nature's architecture as a blueprint for design. It has brought the political actions of peasant farmers—from the rebellions against historical land enclosures to the current rallying cry for food sovereignty—front and center. Most importantly, as the "magic bullet" approach to agriculture (a single problem calls for a single chemical solution) has fallen out of favor, agroecology has convinced ever-growing numbers of people that ecology is the proper scientific foundation of agriculture.

Agroecology today signifies a radical departure from the post-World War II industrial agricultural consensus, in both the Global North and the Global South. It is a powerful movement, with expansive expectations for "regime change." As with other movements with transformative potential (e.g., socialism, democracy), its precise meaning is inevitably vague, typically taking on the specific meaning any practitioner deems correct, or at least convenient. Yet agroecology clearly reflects a kind of New Deal idealism that has ushered its entrance into diverse forums ranging from the Food and Agriculture Organization of the United Nations to the Zapatista revolutionaries of southern Mexico.

So, what, indeed, is agroecology? It has developed over the past few decades into a complex field. In our interpretation, agroecology is now a platform for research, practice, and political action associated with small-scale (or peasant) agriculture and a strong rejection of the harmful practices of industrial capitalist agriculture. It is a platform that can be visualized as resting on four pillars: science, traditional knowledge, nature, and political action. Each of these pillars has its own history. The great Black educator George Washington Carver represents for us the science; the work of Albert Howard and Gabriella Matthaei in India, the appreciation of traditional knowledge; the vast vision of Rachael Carson, so evident in her early writings even before *Silent Spring*, the nature; and the famous proclamations of the Diggers, the spirit of rural radical politics. These histories live on today in agroecology.

The broad and diverse history of challenging industrial agriculture and its precursors forms the overall milieu into which Steve Gliessman brought his prescience, first in the mountains of Costa Rica in the early 1970s and then in his work with Mayan farmers in the tropical lowlands of Tabasco, Mexico, in the later 1970s. His approach was consolidated in 1997 with the publication of the first edition of this textbook, entitled *Agroecology: Ecological Processes in Sustainable Agriculture*. Anticipating the subsequent growth in universities and colleges of the new vision of agroecology, the Gliessman book has come to loom large in educational circles. We have used it frequently in our own teaching. In its three and, now, four editions, it has been and remains the go-to textbook on the subject. Each edition has encompassed new topics and remained intellectually fresh, reflecting the truly dynamic nature of the field. The current edition is no exception. In the spirit of "passing the torch," this new edition includes the insights of two coauthors, Ernesto Méndez and Victor Izzo, both of whom are located within the intellectually vibrant and evolving discipline of agroecology. Together, the authors represent three generations of agroecological researchers.

It seems to be true that every new intellectual discipline requires a foundational textbook. *Agroecology: The Ecology of Sustainable Food Systems* is that work. In this fourth edition, it offers the best and most comprehensive foundation so far.

John Vandermeer and Ivette Perfecto
Ann Arbor, Michigan

Preface 1

As I was completing my graduate studies in ecology many years ago, I had two choices. One was to take an academic position at a university studying the dynamics of vegetative succession in fields following abandonment of farming in the Midwest United States. The focus was on how nature recovered from the disturbance of farming. The other was to move to an isolated part of southern Costa Rica and try my hand at being a vegetable and coffee farmer. The goal there was to use my ecological knowledge to farm organically in a tropical region with more than 250 inches of annual rainfall. I ultimately decided on the latter, and my journey of finding ways to apply ecology to agriculture began.

It wasn't until I became a teacher in a department of ecology at a small college of tropical agriculture in the lowland Mexican state of Tabasco that the direction for my journey took shape. To teach ecology to young agronomists, I quickly realized that I needed to put ecology in an agricultural context. This context was all around me in the traditional Mayan farming systems, whose caretakers had inherited a long history of farming with nature rather than against it. Thus began my personal intercultural transformation, in which Mayan farmers—and many of the students from Mayan communities who I was supposed to be teaching—became my teachers. Together, we created something we began to call *agroecología*.

My journey then took me to the interdisciplinary Environmental Studies Program at the University of California at Santa Cruz. There I began teaching agroecology and established the Agroecology Program. This enabled the development of undergraduate experiential learning programs, international intensive courses in agroecology, the establishment of a non-profit organization working collaboratively with communities in Central America and Mexico, an endowed chair in agroecology, a graduate program emphasizing agroecology, an undergraduate major in agroecology, and now, a Center for Agroecology.

The three previous editions of *Agroecology* reflect the road traveled during this journey. The first edition (1997), with its cover showing the traditional three sisters agroecosystem of the Mayan farmers, reflected both the ecological and cultural co-evolution of farming systems. The book's three levels of transition to sustainability focused on how farms could move away from intensive industrial management to the redesigning of the agroecosystem using agroecological concepts and principles.

The second edition (2007) acknowledged that agroecology is really the ecology of the entire food system, a concept reflected in the collage of images on the cover that show how people were central to sustainability, from the farm to the table. We added a fourth level in the transition process where alternative food networks once again connected the growers of food with the people who eat it, and the ultimate goal was to develop agroecology as a force for change.

The third edition (2015) went beyond the farm and the market to the entire agri-food landscape, a thematic expansion represented on the cover by the agroecological farm of Roberto Jimenez in the mountains of southern Costa Rica. The farm integrates the ecological and social components of food and farming systems presented in the book. As a reflection of the importance of this kind of integration, we expanded the agroecological transition model to include a fifth level of transition focusing on the need to bring about a paradigm shift that challenges us to imagine how to grow and distribute sufficient, healthy, fair, and culturally appropriate food to everyone.

This new edition is the next phase in the journey. In it, we insist that all three domains of agroecology must be present—science, practice, and action for social change. Agroecology is as much about farming sustainably as it is about the social movement for transformative change that brings a fair and sustainable food system to everyone. Agroecology is about an agriculture that no longer exploits natural resources or human resources. Transformative change has become even more urgent as we face climate change, a pandemic, and the widening gap between the privileged few and the rest of us. We must continue to confront the economic and political power of those who control the current food system, and together build the alternative system that will take its place. It gives me hope that over the years of my agroecological journey, I have seen culture coming back into agri-*culture* and taking important steps away from only being agri-*business*.

My agroecological journey has been long enough for me to witness generational change. At my own farm that I share with my partner Roberta (Robbie) Jaffe, we welcome past students who bring their children to participate in our wine grape and olive harvests in the age-old community experience of sharing in the bounty at the end of the season. Former students are now involved in multiple levels of the change process, from farming to policy development and everything in between as teachers, farmers, consumers, researchers, policymakers, civil society advocates, and others, embracing agroecology as it has become a global force for transformative change in food systems. This generational change is also reflected strongly in the three co-authors I have invited to join me—Ernesto Méndez (former graduate student and co-director of University of Vermont Agroecology Institute), his colleague at UVM Victor Izzo, who leads the academic programs of the Institute, and Eric Engles, who after serving as the editor of the first three editions, now brings his background in social science to the author team. We added another new generation in tapping Andrew Gerlicz, a graduate student in agroecology at UVM, as the book's editor.

I am very appreciative of Alice Oven, Senior Editor in Life Sciences at CRC Press/Taylor & Francis Group, who has provided incredible support and ensured that this new edition came about. Following in the footsteps of Alf and Ruth Heller, who provided the key financial support for the first three editions, Alec and Claudia Webster of the Webster Foundation generously provided the essential funding for the intensive work this completely revised new edition has required. Additional supplementary funding was received from sources at the University of Vermont: the College of Agriculture and Life Sciences, the Gund Institute for Environment, and the Environmental Program. Finally, I am most grateful for the support I continue to receive from my life partner, Robbie Jaffe, as we have shared the agroecological journey.

As I pass the three-quarters of a century mark in my own life journey, it gives me great satisfaction to see agroecology become a leader in the movement for the transformation to socially just and ecologically sustainable food systems. We have constructed a foundation in farmer knowledge and practice backed by the science of agroecology and built upon it a movement dedicated to the goals of equity, sovereignty, and justice. It is rewarding to see this progress. As I spend time with my grandchildren, my hope is that the path of agroecology will widen so they can experience the kind of food system this book envisions.

Steve Gliessman
Condor's Hope Ranch
New Cuyama, California

Preface 2

We are grateful to Steve Gliessman for inviting us to participate in developing this textbook and making it a process of knowledge co-creation involving three generations of agroecologists. The field of agroecology has evolved a great deal since the first generation of agroecologists in the academy (Steve Gliessman prominent among them) began grappling with ways to further include the social sciences, engage more deeply and equitably with indigenous knowledge, and expand the scale of agroecology to food systems. We are grateful to have been able to continue this work of deepening and broadening the field by embracing transdisciplinarity, engaging with different knowledge systems, and bringing participatory action research, co-learning, equity, and justice into the mainstream of what agroecology does.

As dedicated educators who have been teaching agroecology for well over a decade, we are acutely aware of the key role that education plays in transforming entrenched systems. We view this textbook, and the wealth of knowledge it provides, as similar to the many practices and tools that agroecological farmers use each day in their fields and on their farms. Though this book can't be used to turn soil or plant seeds, it can inform practices and help to shift the mindsets of students, farmers, and policy-makers, while also establishing greater legitimacy for agroecology as an alternative to the industrial agricultural model.

This new edition comes at a critical time in the evolution of the agroecological movement within higher education and other educational spaces. Since the last edition, we have witnessed and contributed to a rapid growth of academic courses and majors focused on agroecology and sustainable agriculture. The momentum is only building, as new agroecology programs emerge each year on university campuses throughout the world. We are excited and hopeful that agroecology is entering its exponential growth phase as a pedagogical approach and social movement.

We would like to extend our gratitude toward the various people who have helped to make this new edition a reality. First, we thank the many generations of indigenous farmers and traditional land stewards who have come before us. Without their efforts to save and guard their tangible and embodied knowledge, there would be little foundation on which to build the current movement. Second, we thank the Agroecology and Livelihoods Collaborative (ALC) and all of the beautiful minds within that community, especially those of Scott Lewins, Martha Caswell, Colin Anderson, Nils McCune, Nell Carpenter, and Gabriela Buccini. From the coffee agroecology group, we thank Janica Anderzén, Alejandra Guzmán Luna, and Rigoberto Hernández Jonapá. There are many others from the ALC community who have also contributed, and we thank them all for joining us in critical and supportive co-learning. Without their shared experience, support, and deep knowledge none of our contributions would have been possible. Third, we acknowledge the important contributions of the many farmers who we have learned with over the years, including John Hayden, Nancy Hayden, Hilary Martin, Dylan Zeitlyn, Andy Jones, Corie Pierce, Brandon Bless, Christa Alexander, Becky Maden, Rachel Stievater, S'ra Desantis, and Ava Murphey. Fourth, we thank other agroecology colleagues with whom we have had the fortune to work and collaborate, including colleagues from the Collaborative Crop Research Program (CCRP), El Colegio de la Frontera Sur (ECOSUR) in Chiapas, Mexico, the Center for Agroecology Water and Resilience (CAWR) in the United Kingdom, the People's Agroecology Process, the Agroecology Research-Action Collective (ARC), the Universidad Internacional de Andalucía (UNIA), the Community Agroecology Network (CAN), Food for Farmers, the Caribbean Agroecology Institute, the Intervale Center, and many others. Fifth, we are grateful for the financial backing provided by the Webster Foundation and several units at the University of Vermont, including the College of Agriculture and Life Sciences, the Gund Institute for Environment, and the Environmental Program.

Finally, none of this could have been accomplished without the love and patience of our close and extended families. For Vic this is his partner Carolina and son

Nico. Carolina, an accomplished grower and garden educator, provided constant consultation and intellectual support throughout the entire process, while Nico consistently reminded him to always stay curious and remember to hold sacred our time on this land. For Ernesto, this extends to his siblings, nephews, and nieces, and those who came before, who have provided unconditional love and support in El Salvador and beyond. Ernesto is grateful to his life partner Karen Nordstrom, who shares with him the joys and challenges of their life journey with love, support, and authenticity. Ernesto's son Adriel and daughter Sofia inspire him to make this world and its food systems more just and sustainable for generations to come.

V. Ernesto Méndez
Victor Izzo
Burlington, Vermont

Authors

With graduate degrees in Botany and Ecology from the University of California, Santa Barbara, **Stephen (Steve) R. Gliessman** has accumulated more than 50 years of teaching, research, and production experience in the field of agroecology. His international experiences in tropical and temperate agriculture, small-farm and large-farm systems, traditional and conventional farm management, hands-on and academic activities, non-profit and business employment, and organic farming have provided a unique combination of experiences and perspectives to incorporate into this book. He was the founding director of the University of California, Santa Cruz, Agroecology Program, one of the first formal agroecology programs in the world, and was the Alfred and Ruth Heller Professor of Agroecology in the Department of Environmental Studies at UCSC until his retirement in 2012. He is the co-founder of the non-profit Community Agroecology Network (CAN) and currently serves on its board of directors. He is the editor of the international journal *Agroecology and Sustainable Food Systems* and dry farms organic wine grapes and olives with his wife Robbie in northern Santa Barbara County, California.

V. Ernesto Méndez is professor of Agroecology and Environmental Studies at the University of Vermont's (UVM) Environmental Program and Department of Plant and Soil Science, where he also co-directs the Agroecology and Livelihoods Collaborative (ALC) with Martha Caswell. With degrees in Crop Science, Tropical Agroforestry, and Agroecology, he focuses his research and teaching on agroecology, agri-food systems, participatory action research (PAR), coffee agroecology, transdisciplinary research approaches, and social justice. At UVM he is also a faculty member of the Food Systems Graduate Program, fellow and steering committee member of the Gund Institute for Environment. He has more than 25 years of experience working with smallholder farmers and Indigenous communities in Latin America and collaborating in agroecology efforts across the world. He has authored or co-authored more than 60 peer-reviewed articles and chapters and edited three books. Ernesto was born and raised in El Salvador and maintains deep connections, in life and work, with his Central American roots.

Victor M. Izzo is an agricultural entomologist and Lecturer of Agroecology and Environmental Studies in the Plant and Soil Science Department and Environmental Program at the University of Vermont. He also serves as the Education Coordinator of the Agroecology and Livelihoods Collaborative (ALC) and is the co-founder of the Vermont Entomology and Participatory Action Research Team (VEPART), also housed within the Department of Plant and Soil Science. With degrees in Chemistry, Bioscience, and Plant and Soil Science, Vic brings a broad perspective to his work as an agroecologist and teacher. Whether it is a high school classroom in Mexico City, a Master Gardener workshop on a New England farm, or an agroecology course on a university campus, he is always looking to create innovative learning communities built on trust, empathy, and the co-production of knowledge. When he is not in a classroom or on a farm, Vic is with his partner Carolina and son Nico tending to their many gardens and indulging in their respective culinary traditions of Italy and Mexico.

Eric W. Engles is a freelance editor, independent scholar, photographer, and naturalist. With experience in the natural sciences, a graduate degree in Sociology, and recognized achievement in the arts, he has developmentally edited more than two dozen books published by academic presses in fields ranging from environment and history to art and behavioral sciences. He has always tended a home garden, and the current two-decade gardening endeavor, in the foothills of the Sierra Nevada, supplies him and his wife Lisa with much of their food.

Recommendations for Using This Textbook

Reflecting the breadth of agroecology itself, this text has content that could find a home in many different disciplines—agriculture, ecology, soil science, rural sociology, economics, and history, to name the most relevant. Courses using this text could be located in any one of these disciplines, as well as multi- or transdisciplinary programs such as environmental studies or agroecology. How the text is mapped to the course curriculum will depend in part on the course's disciplinary identity and purpose. Potential modes of customization include leaving out some chapters, changing the order in which they are read, and giving greater emphasis to some topics by adding supplementary material. We have designed the book with these possibilities in mind.

Students' prior experience and knowledge in both ecology and agriculture will also determine how the text is used. The chapters in Sections I and II are intended to build a foundation for understanding the more complex topics covered in the chapters of Section III. Intensive study of Chapters 1–9, therefore, is recommended for readers with minimal college-level science training.

Readers with extensive background in the natural sciences, conversely, could read Chapters 3–9 selectively before turning their attention to the remainder of the text. Readers with advanced training in both ecology and agriculture, including advanced undergraduates, may want to pursue this strategy as well, supplementing the text with additional materials that provide more extensive literature review and reports on global food system sustainability issues.

The text can be used in either a one-quarter or one-semester course, but the rate at which material is covered will depend on the instructor, the students, and the curriculum. Ideally, a laboratory section will complement the lecture section of any course using this textbook, allowing hands-on experience with many of the concepts underlying ecological management of agroecosystems.

Suggested readings and a list of Internet resources at the end of each chapter provide further materials for the curious reader. The questions following each chapter are open-ended, designed to encourage the reader to consider the ideas and concepts presented in the broader context of environmental and social sustainability.

The concepts and principles in this text can be applied to agroecosystems anywhere in the world. Just as a farmer must adjust to local and changing conditions, readers of this book are challenged to make the necessary adaptations to apply its contents to their own situations. This might include finding locally appropriate examples and case studies in the research literature, working with local farmers to connect principles to actual practices, and participating in alternative social networks and movements for transformative change.

SECTION I

Pathway to agroecology

As the science of connections among living things, ecology affords a way of looking at agriculture that immediately expands its scope well beyond tilling, sowing, cultivating, harvesting, and marketing. In "agro-ecology," we move from a narrow concern with farming practices to the universe of interactions among crop plants, soil, soil organisms, insects, insect enemies, environmental conditions, and management actions, and beyond that to the effects of farming systems on surrounding natural ecosystems. Expanding this to a global scale, we see agriculture as the most land-intensive human activity on the earth, which leads us to consider the overall effects of farming on the ability of the earth to support its populations of humans and other living things. Examining human beings as a particular population, the ecological perspective then encourages us to look into the social world—at such topics as human food consumption patterns, the unequal distribution of food, and the economics of food production—knowing that at this level insight must come from fields of knowledge outside of ecology.

From this broadest of perspectives, agriculture can be seen as a key factor—perhaps *the* key factor—in the

Diverse agricultural landscape in the Karst region of southwest China. Production of both annual and perennial crops occurs in small, intensively managed fields close to where people live. The surrounding natural ecosystems remain relatively intact.

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intensifying crisis confronting humankind. Agriculture is not only a major cause of this crisis, it is also an arena full of potential solutions. The most basic goal of this section is to introduce readers to this expansive way of thinking about agriculture.

The first chapter of this section describes the many harms to soil, resources, ecosystems, and people brought about by the way we produce food today and discusses what it will mean to produce food more sustainably and in accord with principles of social justice. In this way, the chapter constructs an overall context for everything we will consider in this text. Chapter 2 then describes the many movements—in addition to agroecology—that have arisen over the last century or more to challenge, or at least provide an alternative to, the dominant system of industrial agriculture described in Chapter 1. Finally, Chapter 3 sketches the foundations of the agroecosystem—the fundamental unit of sustainable food production—and places the agroecosystem in the context of the larger food system. With an understanding of the stakes involved in how we humans grow our food and knowledge of the agroecosystem concept, the reader is prepared to explore the many layers of understanding that make up agroecology.

1

The case for fundamental change in agriculture

Judged by a variety of measures, agriculture, considered on a global scale, posted a long streak of extraordinary successes beginning shortly after World War II. During the latter half of the 20th century, yields per hectare of staple crops such as wheat and rice increased dramatically, food prices declined, the rate of increase in food production generally exceeded the rate of population growth, and chronic hunger diminished. This boost in food production was due mainly to scientific advances and technological innovations, including the development of new plant varieties, the use of fertilizers and pesticides (produced cheaply with cheap oil), and the growth of extensive infrastructures for irrigation, all of which contributed to the development of what we call *industrial agriculture*.

Although agriculture on a global scale has more recently struggled to maintain the ever-improving trends for yield increases, food-price reductions, and hunger diminishment that it achieved in the 20th century, it remains extraordinarily productive, providing abundant food for a large proportion of the world's people. Because industrial agriculture has done a superb job of "delivering the goods," many people in the developed and developing worlds have come to take food for granted. When supermarkets are always stocked with a cornucopia of fresh and packaged foods, people don't usually think much about what it takes to get the food onto the shelves. In historical perspective, this is really an unprecedented situation. Ever since *Homo sapiens* arose some hundreds of thousands of years ago, most humans have had to put the source of their next meals at the top of their list of concerns. But while having a relative abundance of food is a good thing compared to its opposite, it has tended to de-sensitize us to food issues, to make those of us with good access to food un-critical about how food comes to be.

Ironically, this is precisely the time in our species' history when we need to be taking stock of our food system with a more critical eye than ever before. Just because industrial agriculture is able to create food abundance in the present doesn't mean it will be able to do so over the long term. Indeed, it's time we came to the realization that industrial agriculture's productivity comes at a steep price and that the bill is already coming due. To create the food productivity that we take for granted today, the industrial system of food production is sacrificing the basic foundations of agriculture—fertile soil, available moisture, amenable climate, nutrient cycling, genetic diversity, and the ecosystem services of natural systems (pollination being one example). These prerequisites of food production can take only so much abuse before they begin to fail, putting at risk the food supply of tomorrow.

Another way of describing the situation is that the industrial agriculture model that dominates agriculture today is at the core of a fundamental contradiction: the techniques, innovations, practices, and policies that constitute industrial agriculture, and which have played the largest role in increasing agricultural productivity, have also undermined the basis for that productivity. They have overdrawn and degraded the natural resources upon which agriculture depends. They have created a dependence on non-renewable fossil fuels, the use of which is the primary cause of climate change. And they have helped to forge a system that concentrates ownership of food-system infrastructure in the hands of a few, while taking it away from farmers and farmworkers, those who are in the best position to be stewards of agricultural land. In short, the contradictions inherent in our industrial agriculture-dominated system of food production make it unsustainable—it will eventually collapse if it continues as the dominant form of agricultural production because it deteriorates the conditions that make agriculture possible.

Industrial agriculture also shares responsibility for many of the biggest social, cultural, and economic challenges of our time. It is the keystone of a global system of food distribution and consumption that plays a fundamental role in maintaining inequality within and between countries, denying food security to large numbers of people worldwide, and making diseases and disorders related to food *over*consumption one of the most serious and costly public health problems in the developed world.

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At the same time, our world food system is terribly ill-equipped to face a variety of worsening threats, most notably the emergence and redistribution of agricultural pests and diseases, economic shocks, rising costs for all the physical factors of production (land, water, energy, inputs), and climate change. Increasingly, experts are raising red flags about the ability of agriculture worldwide to adapt to an earth on which droughts, heat waves, and extreme weather events become commonplace and the entire biosphere undergoes major shifts.

Although how we feed ourselves is among humankind's weightiest issues, there is a conspicuous lack of consensus on the need to transform industrial agriculture, and the food system it supports, into something less harmful to human society and the planet's life-support systems. A large number of experts—policy analysts, economists, scientists, researchers, and even some business leaders—agree with the rough outlines of the view just presented (e.g., IPES-Food 2016; González de Molina et al. 2019). They believe that the industrial methods that dominate the world food system today are causing great harm to people, ecosystems, and the biosphere and cannot (and should not) be sustained. But as numerous and authoritative as they are, these voices of concern are often drowned out by those who predict productivity increases into the distant future and advocate for intensification and further dissemination of the very same harmful methods and technologies singled out by critics of industrial agriculture.

The causes of this crucial difference of opinion will be addressed in the chapters of the final section of this text (Section V). In the meantime, we encourage readers to entertain the critical perspective with which this chapter began and be open to the possibility that the world food system, as productive as it is at the moment, does in fact undermine the foundations of food production, comes at great costs to human society, and needs to be replaced by something fundamentally different.

The first step in this direction is to take a broad and critical look at the practices of present-day industrial agriculture—that is, to examine the largely hidden costs associated with the remarkable yields we've been extracting from the world's agricultural lands.

PRACTICES OF INDUSTRIAL AGRICULTURE

Industrial agriculture is built around two related goals: the maximization of production and the maximization of profit. These goals give agriculture a striking resemblance to the manufacturing processes that occur in factories. In both cases, elements of production are reduced to their simplest forms, processes are mechanized so that they can be brought under the full control of human operators, and efficiency of output in relation to input crowds out any other goals. Although this form of agriculture is often called *conventional* to distinguish it from so-called *alternative* agriculture, its factory-like nature suggests that it is more accurate and descriptive to call it *industrial agriculture*.

Figure 1.1 **Plowing a field**. The tractor is pulling a modified moldboard plow, which cuts into the soil, lifts it, and turns it at least partly upside down. This kind of tillage is used less today than it was several decades ago, but it is still in common use around the world.

In pursuit of maximum production and profit, a host of practices have been developed in industrial agriculture without regard for their direct social and environmental costs or their unintended, long-term consequences. Seven basic practices—intensive tillage, monoculture, irrigation, application of inorganic fertilizer, chemical pest control, genetic manipulation of domesticated plants and animals, and "factory farming" of animals—form the backbone of modern industrial agriculture. Each is used for its individual contribution to productivity, but as a whole, the practices form a system in which each depends on the others and reinforces the necessity of using all in concert.

Intensive tillage

Industrial agriculture has long been based on the practice of cultivating the soil completely, deeply, and regularly. The purpose of this intensive cultivation is to loosen the soil structure to allow better drainage, faster root growth, aeration, incorporation of crop residues, and easier sowing of seed. Cultivation is also used to control weeds. Under typical practices—that is, when intensive tillage is combined with short rotations—fields are plowed or cultivated several times during the year, and in many cases this leaves the soil free of any cover for extended periods. It also means that heavy machinery makes regular and frequent passes over fields.

Intensive cultivation tends to degrade soil quality in a variety of ways. Soil organic matter is reduced as a result of accelerated decomposition and the lack of cover, and the soil is compacted by the recurring traffic of machinery. The loss of organic matter reduces soil fertility and degrades soil structure, increasing the likelihood of further compaction and making cultivation and its temporary improvements even more necessary. Intensive cultivation also greatly increases rates of soil erosion by water and wind.

Beginning in the 1990s, some farmers began to move away from intensive tillage and substitute various kinds of no-till practices. These involve leaving crop residue on the surface and sowing seeds using a tractor-pulled drilling machine or planting directly into a surface sod. Less intensive reduced-tillage systems were also developed. When these practices proved successful, reducing costs and conserving soil, more farmers adopted them. By 2017, an estimated 21% of U.S. cropland was under no-till farming (Creech 2017). In other countries, the proportion of cropland not being intensively cultivated varies greatly, from negligible to more than 80% in some countries of South America (Kassam et al. 2015).

One reason why no-till farming has seen this relatively strong uptake is that by itself it is entirely compatible with the other practices of industrial agriculture. To trade intensive tillage for no-till, a farmer mainly needs to invest in new farm machinery. Using no-till systems within the framework of industrial agriculture generally means applying herbicides for weed control and often using more fertilizer to compensate for the stranding of nutrients in the crop residue on the soil surface. In this form, switching to no-till farming can be seen as trading one set of problems for another.

However, many farmers—not just those practicing ecological or organic agriculture—have been incorporating practices into their no-till or reduced-tillage systems that successfully eliminate the need for additional inputs. These practices include planting cover crops and using roller crimpers, solarization (tarping), and animal integration to control weeds and to terminate cover crops. The expansion of this kind of whole-system no-till farming is one of the bright spots in agriculture today, even though intensive tillage remains the dominant practice.

Monoculture

Over the last century, agriculture all over the world has moved relentlessly toward specialization. Farming once meant growing a diversity of crops and raising livestock, but now farmers are far more likely to focus on one crop or product—corn for livestock feed, for example, or hogs. In crop agriculture, specialization means monoculture—growing only one crop in a field, often on a very extensive scale (Figure 1.2). Monoculture allows more efficient use of farm machinery for cultivation, sowing, weed control, and harvest, and it can create economies of scale with regard to purchase of seeds, fertilizer, and pesticides. Monoculture is a natural outgrowth of an industrial approach to agriculture, where labor inputs are minimized and technology-based inputs are maximized in order to increase productive efficiency. Monoculture techniques mesh well with the other practices of modern agriculture: monoculture tends to favor intensive cultivation, application of

Figure 1.2 **Monoculture of corn**. Nothing but corn plants, with nearly identical genomes, cover vast areas of land. The goal of industrial-style monoculture is to exclude all other life forms.

inorganic fertilizer, irrigation, chemical control of pests and weeds, and specialized plant varieties. The link with chemical pesticides is particularly strong; vast fields of the same plant are more susceptible to a devastating attack by specific pests and diseases and require protection by pesticides. Many of the same problems occur when farmers plant large areas to organic monocultures.

Application of synthetic fertilizer

The spectacular increases in yields of the last half of the 20th century were due in large part to the widespread and intensive use of synthetic chemical fertilizers. In the United States, the amount of fertilizer applied to fields each year increased rapidly after World War II, from 9 million tons in 1940 to more than 47 million tons in 1980. Although worldwide use of synthetic fertilizers increased most rapidly between 1950 and 1992, continuing increases in their application since that period has brought total world consumption of synthetic fertilizer beyond the 200-million-metric-tons mark (FAO 2015a).

Produced in large quantities and at relatively low cost using fossil fuels, atmospheric nitrogen (N_2), and mined mineral deposits containing phosphorus (P), fertilizers can be applied easily and uniformly to crops to supply them with ample amounts of the most essential plant nutrients. Because they meet plants' nutrient needs for the short term, fertilizers have allowed farmers to ignore long-term soil fertility and the processes by which it is maintained.

The mineral components of synthetic fertilizers, however, are easily leached out of the soil. In irrigated systems, the leaching problem may be particularly acute; a large amount of the fertilizer applied to fields ends up in streams, lakes, rivers, and oceans, where it causes **eutrophication** (excessive growth of oxygen-depleting plant and algal life). Fertilizer can also be leached into groundwater used for drinking, where it poses a significant health hazard.

Use of nitrogen-based fertilizer is furthermore a major problem for the atmosphere. Its application stimulates soil microbes to produce large quantities of nitrous oxide (N_2O), an extremely potent greenhouse gas. Moreover, the production of the ammonia that is basis of most fertilizer manufacture requires extremely high temperatures and pressures and therefore consumes enormous amounts of natural gas, releasing an estimated 1.5% of all greenhouse gas emissions (Wang et al. 2018).

Irrigation

An adequate supply of water is the limiting factor for food production in many parts of the world. Thus, supplying water to fields from underground aquifers, reservoirs, and diverted rivers has been key to increasing overall yield and the amount of land that can be farmed. For the most part, however, irrigation is employed not to make land productive, but to make it *more* productive. Only about a fifth of agricultural land worldwide is irrigated, but this land produces about two-fifths of the world's food supply (FAO 2011). To generate this considerable increase in yield beyond what would otherwise be the case, irrigated agriculture uses tremendous volumes of water.

Irrigated agriculture uses so much water in part because it uses water wastefully. Approximately half of the water applied to crops (more in some places) is never taken up by the plants it is intended for. Instead, this water leaks from pipes, evaporates from the soil surface, or drains out of fields. Some wastage of water is inevitable, but a great deal of waste could be eliminated if agricultural practices were oriented toward conservation of water rather than maximization of production. For example, crop plants could be watered with drip irrigation systems and production of water-intensive crops such as rice and almonds could be shifted away from regions with limited water supplies.

The amount of water used in irrigation is an issue of importance because many parts of the world face increasingly critical water shortages. Not only is the supply of water inadequate for agriculture, but often for people and industry, too. In addition, irrigation can exacerbate soil erosion and the buildup of salts, and the infrastructures necessary for getting irrigation water to the fields—dams, aqueducts, pipelines, and pumping—are responsible for serious environmental problems ranging from overdrafting, water table decline, ground subsidence, and saltwater intrusion to destruction of aquatic and riparian habitats.

Chemical pest and weed control

After World War II, chemical pesticides were widely touted as the new, scientific weapon in humankind's war against plant pests and pathogens. These chemical agents had the appeal of offering farmers a way to rid their fields once and for all of organisms that continually threatened their crops and literally ate up their profits.

Figure 1.3 **Irrigation of a field in Utah**. In many places around the world, irrigation is unsustainable because of aquifer overdrafting and diminished precipitation.

But this promise has proven to be false. Pesticides (i.e., insecticides, fungicides, and herbicides) can dramatically lower pest populations in the short term, but because they also kill pests' natural enemies, pest populations can often quickly rebound and reach even greater numbers than before. The farmer is then forced to use even more of the chemical agents. The dependence on pesticide use that results has been called the "pesticide treadmill." Augmenting the dependence problem is the phenomenon of increased resistance: pest populations continually exposed to pesticides are subjected to intense selection for pesticide resistance. When resistance among the pests increases, farmers are forced to apply larger amounts of pesticide or to use different pesticides, further contributing to the conditions that promote even greater resistance. Resistance to pesticides is exacerbated by the emergence of **cross-resistance** in pest populations, in which evolved resistance to one type of pesticide confers resistance to other, not necessarily related pesticides.

The metaphor of the "treadmill" is particularly apt because once a farmer gets on it, he or she finds it difficult to get off. With natural enemies eliminated from the system, ceasing to use pesticides is asking for serious crop damage. This is one reason why many farmers—especially those in developing nations—don't use other options, even though the problem of pesticide dependence is widely recognized. Even in the United States, the amount of pesticides applied to major field crops, fruits, and vegetables each year remains above 1 billion pounds per year, more than twice the level it was in 1962, when Rachel Carson published *Silent Spring* (U.S. EPA 2012). Pesticide resistance, the spread of insect pests and plant pathogens to regions where they hadn't previously existed, and the extensive use of genetically modified crops *designed* to be grown in concert with intensive application of herbicides (see below) are all factors driving the worldwide increase in the use of chemical pest and disease controls. Ironically, total crop losses to pests have stayed fairly constant for the past 40–50 years despite increasing pesticide use (Pimentel 2005; Oerke 2006; Savary et al. 2019).

Besides costing farmers a great deal of money, pesticides can have a profound effect on the environment and on human health. Worldwide, people working in agriculture, especially farmworkers and small-scale farmers, are regularly at risk of direct pesticide poisoning, and the ubiquitous presence of pesticides in water, soil, and food is implicated in increased incidence of cancer, reproductive and developmental disorders, and other maladies (Nicolopoulou-Stamati et al. 2016). Pesticides applied to fields kill beneficial insects and those essential to natural-system food webs, and they are easily washed and leached into surface water and groundwater, where they enter the food chain, affecting animal populations at every level and often persisting for decades.

Manipulation of plant and animal genomes

Humans have selected for specific characteristics among crop plants and domesticated animals for thousands of years; indeed, human management of wild species was one of the foundations of the beginning of agriculture. In recent decades, however, technological advances have brought about a revolution in the manipulation of genes. First, advances in breeding techniques allowed for the production of hybrid seeds, which combine the characters of two or more plant strains. Hybrid plant varieties can be much more productive than similar non-hybrid varieties and have thus been one of the primary factors behind the yield increases achieved during the so-called "green revolution." The hybrid varieties, however, often require intensive application of inorganic fertilizer to realize their productive potential as well as pesticide application (because they lack the pest resistance of their non-hybrid cousins). In addition, hybrid plants cannot produce seeds with the same genome as their parents, making farmers dependent on purchasing seed every year from commercial seed producers.

A new era began in the 1990s, when the first **genetically engineered** (GE) organisms began to be used at a commercial scale in agriculture. These organisms, also referred to as **transgenic** or genetically modified, were produced using recombinant DNA technologies. They contain genes from other organisms that give them useful traits they did not previously possess, such as virus resistance or longer shelf life for their fruit. Between 1996 and 2012, the area planted to genetically engineered crops worldwide increased 100-fold, from 1.7 million ha to over 170 million ha, making these "biotech" crops "the fastest adopted crop technology in the history of modern agriculture" (James 2012). Two types of genetically modified crops were primarily responsible for this dramatic growth: those engineered to be tolerant of herbicides and those containing genes directing the plants to produce the same insecticidal toxins produced by the bacterium *Bacillus thuringiensis* ("Bt crops"). Herbicide-tolerant crops are designed to be treated with herbicides—usually glyphosate—to kill weeds but not the crop plants; Bt crops protect themselves from herbivory, reducing the need for insecticides. Together, these crops now account for more than 90% of the acres planted to cotton, soybean, and corn in the United States (USDA 2020b).

In 2012, geneticists introduced a new and very powerful tool called CRISPR-Cas9 that makes it possible to modify an organism's genome very precisely—in essence, to "edit" its genes. With CRISPR, plant and animal breeders can deactivate genes, alter gene expression, and add single genes or small DNA sequences. This gene-editing technology has once again revolutionized agricultural breeding. Although the dominant GE crops today are still those produced using the older recombinant technologies, the use of gene editing is growing rapidly and has significant ramifications for the future of the world food system. There is widespread concern that these technologies are being deployed without adequate oversight, public engagement, and assessment of risk.

Genetic engineering in agriculture has been promoted as a biotechnology that can increase yields, address hunger and malnutrition, and reduce inputs. Its supporters claim it will reduce the use of pesticides, make irrigation less necessary, allow agriculture on soils too saline for normal crops, and raise the nutritional value of some crops. These claims have some validity, but, in practice, the GE crops in widest use today are those that ensure the highest profits for the agrochemical and seed conglomerates—mostly the Bt crops and glyphosate-resistant crops described above, and those that incorporate both traits.

In addition to enriching agribusiness alone, the spread of genetic engineering biotechnologies raises many concerns. One is the potential for the migration of modified genes into other populations, both wild and domestic, resulting in such problems as more aggressive weeds or the introduction of toxins into crop plants. This "genetic pollution" is much more worrisome than traditional chemical pollution because the migrated genes will generally persist and even increase in frequency, whereas most agricultural chemical pollutants will degrade after a certain period of time. Another concern is that increased use of transgenic crops will push farmers to abandon traditional cultivars, diminishing agrobiodiversity and increasing farmers' dependence on the transnational corporations owning the patents on the new organisms.

One of the most serious drawbacks of using GE organisms in agriculture is that they can easily lead to another version of the pesticide treadmill. Where farmers plant crops engineered to be tolerant of glyphosate application, many species of the weeds they try to control develop resistance to the herbicidal agent, creating "super weeds." By 2019, scientists had already identified 51 pernicious agricultural weeds exhibiting resistance to glyphosate (Heap 2020). When faced with glyphosate-resistant weeds, farmers are forced to apply more concentrated herbicide more frequently or to add in other herbicides that have a different mode of action and are often more toxic (Baucom 2019). Bt crops have a similar problem. They have the virtue of reducing pesticide use when they are first introduced, but insect pests are developing resistance to Bt toxins, causing farmers to bring back the insecticides they used in the past in order to preserve the efficacy of Bt technology (Tabasknik & Carriére 2017). Moreover, the large amounts of Bt toxin produced by Bt crops cause the toxin to appear in ever higher amounts in animal feed, human food, and the environment. These problems reveal that GE technology functions mainly to support, and compensate for the failures of, the other unsustainable practices of industrial agriculture.

Smart farming

Technological advances in computing, imaging, robotics, networking, data processing, and artificial intelligence have allowed some of the larger, well-capitalized farming operations to virtually eliminate human labor and judgment from agriculture. By setting up remote sensing equipment, flying drones equipped with cameras and other imaging devices over their fields, and mounting sensors on their tractors, they can acquire real-time data on soil moisture, nutrient levels, average crop height, and other important variables (Figure 1.4). Feeding these and other data into advanced software systems, they can determine the necessary inputs and project the ideal harvest dates. To apply the inputs, they deploy robotic sprayers and injectors. When it comes time to bring in the harvest, other robots go into the fields to perform that work as well.

While few farmers have applied all these technologies together, their use is growing, and to many they represent the future of agriculture. Proponents tout them as more efficient and the key to realizing the productivity increases necessary to feed the world's growing population. From the perspective of sustainability, however, robots, drones, artificial intelligence, and other forms of digitalization are logical extensions of the industrial model, the latest means of transforming farming into precisely controlled production of agricultural commodities. They may help solve certain problems, but they lend the practices of industrial agriculture a stronger aura of inevitability.

Figure 1.4 **Farmer prepares to fly a drone**. Drones are being used for imaging, remote sensing, and application of pesticides.

Factory farming of animals

Worldwide, diets have incorporated steadily increasing amounts of meat and animal products. The rising demand for animal-based food has made it increasingly profitable to produce meat, eggs, and milk in large-scale, industrialized operations driven by the goal of bringing these food products to market at the lowest possible unit cost. The animals in these **confined animal feeding operations** (CAFOs) are typically crowded so tightly they can barely move, given antibiotics to prevent the spread of disease, and fed highly processed soy- and corn-based feed supplemented with hormones and vitamins. Even though they are completely dependent on crop agriculture for the production of feed, CAFOs are isolated—spatially and functionally—from the fields in which the feed grains are grown.

Factory-farm livestock production is another manifestation of the specialization trend in agriculture. In many ways, factory farming is for pigs, cattle, and poultry what monoculture is for corn, wheat, and tomatoes. Livestock raised in the crowded conditions of CAFOs are more susceptible to disease, just as monocropped corn plants are to pest damage, and both require chemical inputs (pharmaceuticals for livestock and pesticides for crops) to compensate. Both factory farming and monoculture encourage the use of organisms bred or engineered for productive efficiency and dependent on the artificial conditions of the industrial process.

Factory farming is criticized by animal-rights groups as cruel and inhumane. Laying hens and broiler chickens are routinely de-beaked to keep them from pecking each other; hogs are often kept in pens so small they can't turn around; beef cattle commonly suffer slow and painful deaths at the slaughterhouse.

There are many other reasons to be critical of the industrial approach to raising livestock. CAFOs, for example, have serious impacts on the environment. Disposal of the

Figure 1.5 **A confined animal feeding operation in California's Central Valley**.

massive concentrated amounts of manure and urine generated by the confined animals is a huge problem, usually dealt with by treating the wastes in large anaerobic lagoons that can leak nitrates into surface streams and groundwater and allow ammonia to escape into the atmosphere. This problem arises because CAFOs, by their very nature, cannot recycle nitrogen within the system, as is the case on non-industrialized farms where animals and crop plants are raised together and some form of free-ranging is part of the management approach. Thus, nitrogen becomes a problematic waste product instead of a valuable plant nutrient.

Factory farming of animals is also responsible for an increasing share of the water used in agriculture. Confined operations use a great deal of water for cooling the animals and flushing their wastes—water generally not needed in other animal production systems, at least not in the same large quantities. A more indirect way that factory farming of animals has resulted in increased water use is that it has enabled much of the growth in animal production worldwide, and more animals being raised for food means more animals drinking water to stay hydrated. Each animal can drink a surprisingly large amount of water every day. A hog, for example, can consume up to 8 gallons/day (Marks & Knuffke 1998). And water for drinking, cooling, and flushing waste doesn't exhaust all the water requirements in raising livestock. Factoring in the water needed to grow the biomass fed to animals, animal-derived food requires at least twice as much water to produce as plant-derived food, and usually much more. The difference between the amount of water needed to grow calorie-equivalent amounts of plant food and animal food can be extreme. For example, it takes only 1 L of water to grow a kcal of potatoes, but 10.2 L to produce a kcal of beef (Mekonnen & Hoekstra 2012). If we look at protein alone, the ratio is even more skewed: on average, producing 1 kg of animal protein requires about 100 times as much water as producing 1 kg of grain protein (Pimentel & Pimentel 2003). By allowing a great expansion in the scale of this type of food production, factory farming of animals has contributed not only to unsustainable water use but also to a variety of social and environmental harms including production of large amounts of the potent greenhouse gas methane.

THE CONSEQUENCES OF INDUSTRIAL AGRICULTURE

The practices of industrial agriculture all tend to compromise future productivity in favor of high productivity in the present. The ways in which industrial agriculture puts future productivity at risk are many. Agricultural resources such as soil, water, and genetic diversity are overdrawn and degraded. The global ecological processes on which agriculture ultimately depends are altered. The social, political, and economic conditions conducive to resource conservation are weakened and dismantled. In economic terms, these adverse impacts are called **externalized costs**. Because their consequences can be temporarily ignored or absorbed by society, in general, they are excluded from the narrow cost-benefit calculus that allows industrial agricultural operations to continue to make economic sense.

An important feature of industrial agriculture's externalized costs is that they have serious consequences both for the future and the present. These "unsustainable" aspects of industrial agriculture aren't problematic just because they are unsustainable—because they will one day cause the system to collapse—but because they are causing, in the present, real human suffering and irreparable damage to the ecological systems on which we rely (Food Tank 2015). They are also problematic because when they do begin to pull industrial agriculture into a state of crisis, agriculture won't be the only part of human society that will be impacted.

Soil degradation

Degradation of soil can involve salting, waterlogging, compaction, contamination by pesticides, decline in the quality of soil structure, loss of fertility, loss of organic matter, and erosion by wind and water. It is a serious problem all over the world. In 2015, the FAO estimated that 33% of the earth's land is highly or moderately degraded, with the majority of this land in areas with high poverty rates (FAO 2015b). Although it is possible to restore degraded soil, the trend is clearly in the opposite direction. Estimates vary considerably, but there is general agreement that the amount of valuable agricultural land lost to soil degradation worldwide runs into the millions of hectares per year (e.g., World Congress on Conservation Agriculture 2005).

The cause-effect relationship between industrial agriculture and soil degradation is direct and unambiguous. Intensive tillage at an extensive scale, combined with monoculture and short rotations, leaves the soil exposed to the erosive effects of wind and rain. Soil organic matter content takes a double hit from industrial practices because any erosion that occurs takes away the organic-matter-rich upper layers of soil first and because intensive tillage greatly accelerates the loss of organic matter through decomposition. Where irrigation is used, the applied water joins or replaces rainfall as a direct cause of surface erosion of agricultural soil.

Agricultural land that is not lost to production altogether due to severe erosion or salinization becomes increasingly less fertile when it is managed in a way that does not prioritize soil conservation and the continual replenishment of organic matter. Such land is kept productive by the artificial means of adding synthetic fertilizers. Although fertilizers can temporarily replace lost nutrients, they cannot rebuild soil fertility, replace lost organic matter, and restore soil health; moreover, their use has a number of negative consequences, as discussed above.

Since the supply of agricultural soil is finite, and because natural processes can't come close to renewing or restoring soil as fast as it is degraded, agriculture cannot be sustainable until it can reverse the process of soil degradation. Current agricultural practices must undergo a vast change if the precious soil resources we have remaining are to be conserved for the future.

Overuse of water and damage to hydrological systems

Fresh water is becoming increasingly scarce in many parts of the world as industry, expanding cities, and agriculture compete for limited supplies. A clean, fresh, and sufficient supply of water has become a major issue not just for agriculture, but for all of human society (Pearce 2006; FAO 2012, 2018). Some countries have too little water for any additional agricultural or industrial development to occur; municipal water systems in water-stressed regions across the globe are periodically running out of drinking water. To meet demands for water in many places, water is being drawn from underground aquifers much faster than it can be replenished by rainfall, and rivers are being drained of their water to the detriment of aquatic and riparian ecosystems and their dependent wildlife. Many of the world's major rivers—including the Colorado, Ganges, and Yellow—now run dry for part of the year as a result of upstream diversions and climate change-related reductions in rainfall and snowmelt.

All sectors of society have placed rapidly increasing demands on freshwater supplies in recent decades, but agricultural purposes account for the lion's share of the demand—about 70% of water use worldwide (FAO 2018). As discussed earlier in this chapter, most of the water used in agriculture goes to irrigate crops, but an increasing share is claimed by factory farming operations meeting rising demand for meat. In both cases, changes in methods and priorities could significantly reduce agriculture's water use, freeing up more for other human uses and for natural ecosystems.

In addition to using a large share of the world's fresh water, industrial agriculture has three major kinds of impacts on regional and global hydrological patterns and the aquatic, riparian, and marine ecosystems dependent on them. First, by drawing such large quantities of water from natural reservoirs on land, irrigation-intensive agriculture has caused a massive transfer of water from the continents to the oceans. A 2012 study concluded that an observed sea-level rise of 0.77 mm/year between 1961 and 2003, about 42% of the total rise, was due to the transfer of water from on-land storage basins to the sea. Most of this transfer is due to the tapping of underground aquifers for irrigation (Pokhrel et al. 2012). Moreover, the amount of water that agriculture causes to be moved from the land to the oceans is only increasing as more land is brought under irrigation.

Second, where irrigation is practiced on a large scale, agriculture brings about changes in hydrology and microclimate. Water is transferred from natural watercourses to fields and the soil below them, and increased evaporation changes humidity levels and may affect rainfall patterns. These changes in turn significantly impact natural ecosystems and wildlife.

Third, the dams, aqueducts, and other infrastructure created to make irrigation possible have dramatically altered many of the world's rivers, causing enormous ecological damage. Rivers that once provided valuable ecosystem services to human society cannot do so anymore—their wetland, aquatic, and floodplain ecosystems can no longer absorb and filter out pollutants or provide habitat for fish and waterfowl, and they can no longer deposit the rich sediment so important for restoring the fertility of agricultural soils in floodplain areas.

Agriculture's large and growing use of water will only grow more serious as a fundamental issue facing humankind. As the demand for water increases, the guarantee of an adequate supply becomes less and less assured because climate change is reducing mountain snowfall, melting high-altitude glaciers, increasing the frequency of droughts, causing salinization of groundwater in coastal areas, and degrading the ecosystem processes that help purify water. If industrial agriculture continues to use water in the same ways, our rivers will become increasingly crippled and regional water crises will become increasingly common, shortchanging the environment, marginalized peoples, and future generations as well as limiting irrigation-dependent food production.

Pollution of the environment

More water pollution comes from agriculture than from any other single source (FAO 2017a). Agricultural pollutants include pesticides, herbicides, other agrochemicals, fertilizer, animal wastes, and salts.

Pesticides and herbicides—applied in large quantities on a regular basis, often from aircraft—are easily spread beyond their targets, killing beneficial insects and wildlife directly as well as poisoning farmers and farmworkers. The pesticides that make their way into streams, rivers, and lakes—and eventually the ocean—can have serious deleterious effects on aquatic ecosystems. They can also affect other ecosystems indirectly. Fish-eating raptors, for example, may eat pesticide-laden fish, reducing their reproductive capacity and thereby impacting terrestrial ecosystems. Although persistent organochloride pesticides such as DDT—known for their ability to remain in ecosystems for many decades—are being used less in many parts of the world, their less-persistent replacements are often much more acutely toxic.

Figure 1.6 **Key component of California's vast State Water Project**. One of the largest of its kind in the world, the project collects water from the state's northern watersheds and redistributes it to more arid zones in the southern part of the state, using a network of 21 dams and more than 700 miles of canals, tunnels, and pipelines. Although about 70% of the project's water goes to urban and industrial uses, it is connected to and forms an important part of other water systems in the state that primarily provide irrigation water to farms. Systems such as this have dramatically altered streams and hydrologic function.

Pesticides also pose a significant human health hazard. They spread throughout the environment by hydrological, meteorological, and biological means, entering our bodies through our food, our drinking water, and sometimes the air we breathe. In one study of 72 river and stream sites distributed across the United States, five or more pesticides were detected in 88% of the samples and only 2.2% of samples had pesticide concentrations below the detection level (Covert et al. 2020). Another study (Wu et al. 2010) found that the herbicide atrazine, which is used very commonly for corn production, was present in 75% of all watersheds and 40% of the drinking water wells in corn producing regions of the United States, and estimates that over 33 million people in the United States have been exposed to atrazine in their drinking water. If all the drinking water sources in the United States at risk for pesticide contamination were properly monitored for the presence of harmful agents, the cost would be well over US$15 billion (Pimentel 2005).

Fertilizer leached from fields is less directly toxic than pesticides, but its effects can be equally damaging ecologically. In fresh water and marine ecosystems, it promotes the overgrowth of algae, causing eutrophication and the death of many types of organisms. Nitrates from fertilizers and livestock manure are also a major contaminant of drinking water in many areas. When nitrates enter aquifers, they are not easily removed, and frequently alternative drinking water sources are not available. Due to this kind of contamination, many people in agricultural regions are exposed to nitrate levels in excess of established safe thresholds and as a result have an increased risk of cancer and reproductive disorders. Rounding out the list of pollutants from croplands are salts and sediments, which in many locales have degraded streams, helped destroy fisheries, and rendered wetlands unfit for bird life.

Where factory farming has become the dominant form of meat, milk, and egg production, animal waste has become a huge pollution problem. Worldwide, farm animals produce an estimated five times more waste than do humans (Berendes et al. 2018). The large size of feedlot and other factory farming operations poses challenges for the treatment of these wastes. As noted above, the wastes are typically treated in large anaerobic lagoons not well suited to protection of the environment. Some of the nitrogen from the wastes leaks out of the lagoons and into underlying aquifers, adding large quantities of nitrates to the groundwater and eventually to rivers. Even more nitrogen from the wastes converts to ammonia and enters the atmosphere, where it combines with water droplets to form ammonium ions. As a result, the rainwater downwind of livestock

Figure 1.7 **Spraying pesticide in a soybean field**. Most pesticides are persistent in the environment and find their way into groundwater, rivers, lakes, reservoirs, and the ocean.

feeding operations often has extremely high concentrations of ammonium ions. Although most treated animal waste is ultimately applied to fields as fertilizer, the phosphorus and nitrogen it contains are beyond useful levels for most crops. Furthermore, factory farms often have so much waste to get rid of that they apply more treated waste to fields than the soil can accommodate, and do so year-round, even at times in the crop cycle when fields and crops are unable to absorb it. The excess nitrogen and phosphorus find their way into streams, rivers, lakes, and the local drinking water supply.

Through all these various avenues, tons of nitrogen and phosphorus from animal waste and inorganic fertilizer make their way into waterways and then into the oceans, creating large "dead zones" near river mouths. More than 50 of these dead zones exist seasonally around the world, with some of the largest—in the Chesapeake Bay, Puget Sound, and Gulf of Mexico—off the coast of the United States.

Destruction of natural habitat

Farming entails the conversion of native vegetation—the habitat for native species of insects, birds, mammals, and other animals—into land intensively managed by humans. That is the nature of agriculture and the price of supporting large populations of human beings on the earth. But different forms of agriculture have vastly different impacts on native vegetation and natural habitat. As we will discuss in Chapter 18, land managed by humans for food production has the potential to support healthy populations of beneficial insects, birds, and other vertebrates and invertebrates, serving in this regard as a reasonable substitute for the natural habitats that once existed on the land. In contrast, the practices of industrial agriculture described above combine to make most cropland in many areas essentially worthless as wildlife habitat. Intensively tilled monocultures of genetically uniform crops fertilized with inorganic fertilizers can serve as a habitat for very few animals except insect pests, and in attempting to control these pests with pesticides, industrially oriented farmers ensure that other insects are eliminated as well. More recently, the development of herbicide-resistant crop varieties has allowed farmers to escalate their war against weeds to a new level, creating vast stretches of agricultural landscape with no refuges for beneficial insects and no food plants for migrating populations of butterflies.

Industrial agriculture supports a drive to convert as much natural habitat as possible to farmland because more land in production generally means more profit. More often than not, farmers expand their areas of production not to grow more food for people, but to grow more corn and other agricultural commodities for biofuel production and animal feed. In the United States, conversion of additional land to corn production has been directly linked to federal subsidies for biofuel production.

The effects of eliminating natural vegetation and reducing the habitat value of agricultural land may be slow to accumulate, but there is little doubt that they may become severe. Some of the effects will be felt directly by agroecosystems, as pollinators such as European and native bees become scarce and reductions in populations of natural enemies of insect pests make farmers more dependent on pesticides. But even more worrisome are the larger-scale effects, which include precipitous declines in biological diversity, deterioration of ecosystems that provide farmers and other humans with critical ecosystem services (such as water purification, buffering of floods, groundwater recharge, and erosion control), and a reduction in the ability of terrestrial ecosystems to absorb and store carbon.

Dependence on external inputs and nonrenewable resources

Industrial agriculture has achieved its high yields mainly by increasing agricultural inputs. These inputs comprise physical factors of production such as irrigation water, fertilizer, pesticides, and processed feed and antibiotics; the energy used to manufacture these substances, to run farm machinery and irrigation pumps, and to climate-control animal factories; technology in the form of hybrid and transgenic seeds, new farm machinery, and new agrochemicals; and knowledge in the form of the expertise needed to use and manage these inputs. These inputs all come from outside the agroecosystem itself; their extensive use has consequences for farmers' profits, use of nonrenewable resources, and the locus of control of agricultural production.

The longer industrial practices are used on farmland, the more the system becomes dependent on external inputs. As intensive tillage and monoculture degrade the soil, continued fertility depends more and more on the input of fossil-fuel-derived nitrogen fertilizer and other nutrients. As industrial systems strive to eliminate all organisms except for a single variety of crop plant, natural controls on pest outbreaks and weeds are lost and the systems depend more and more on chemical pesticides.

Agriculture cannot be sustained as long as this dependence on external inputs remains. First, the natural resources from which many of the inputs are derived are nonrenewable and their supplies finite. Second, dependence on external inputs leaves farmers, regions, and whole countries vulnerable to supply shortages, market fluctuations, and price increases. In addition, excessive use

Figure 1.8 **Farm equipment in California's San Joaquin Valley**. Mechanization is inseparable from industrial agriculture's dependence on external inputs. Equipment is needed to level, rip, and cultivate soil, plant seeds or transplant seedlings, apply fertilizers, spray pesticides, irrigate, and harvest crops.

of inputs has multiple negative off-farm and downstream impacts, as noted above.

The most notable of external inputs in industrial agriculture is fossil fuels. The dependence of industrial agriculture on fossil fuels has become so extreme—they are critical for everything from manufacture of nitrogen fertilizer to transport of food from one side of the globe to the other—that food prices have become correlated directly with energy prices. Dependence on fossil fuels is also a major reason why agriculture is one of the biggest contributors to greenhouse gas emissions. Although agriculture's dependence on an input that will eventually be used up is a cause for concern, a continued flow of fossil fuels has been guaranteed for the medium term by the development of new extractive technologies such as "fracking" and the exploitation of deeper off-shore oil sources. The same thing cannot be said, however, for another critical external input: phosphorus. Mineable deposits of phosphorus-rich minerals—the sole source of this important macronutrient in synthetic fertilizer—exist in meaningful quantities in only a few places in the world and may be used up in a matter of decades.

Production of greenhouse gases and loss of carbon sinks

As an economic sector, agriculture is the third largest contributor to greenhouse gas emissions worldwide, behind transportation and the burning of fossil fuels for power and heat. Although it is impossible to grow, process, and distribute food without releasing carbon dioxide and other greenhouse gases into the atmosphere, our present food system makes a much larger contribution to climate change than it would if organized according to agroecological principles. The geographic and economic separation between farmers and consumers ensures the burning of large quantities of fossil fuels to distribute and transport food; input-intensive monoculture requires that fossil fuels be used to produce and distribute inorganic fertilizers, pesticides, and other inputs and that farmers be dependent on fossil-fuel-consuming field equipment. Further, industrial agriculture's primary focus on the maximization of yield and profit gives farmers little motivation to use fossil-fuel energy and the inputs derived from it efficiently. It is common, for example, for farmers to apply excess nitrogen fertilizer, much of which ends up as nitrous oxide, a greenhouse gas.

The food system's focus on production of meat and dairy products is a major reason why agriculture produces so much greenhouse gas. A large proportion of agriculture's total greenhouse gas emissions come from the digestive systems of the world's livestock in the form of the potent greenhouse gas methane. Livestock are also responsible for much of agriculture's emission of carbon dioxide and nitrous oxide. The nitrous oxide comes from bacterial processing of the nitrogen in livestock manure; the carbon dioxide comes from the rapid decomposition of crop residue in the tilled fields used to produce livestock feed. Altogether, livestock production chains are estimated to be responsible for 14.5% of anthropogenic greenhouse gas emissions (Gerber et al. 2013).

In addition to producing greenhouse gases, industrial agriculture exacerbates climate change by reducing the ability of the biosphere to hold carbon in a fixed, organic form. At any particular moment, a significant portion of the carbon in circulation—that is, not locked away in geologic structures below the surface—is not in gaseous form in the atmosphere, but present as dissolved CO_2 in the oceans and in organic or mineral form in earth's terrestrial ecosystems. This latter "sink" of carbon is largely made up of vegetative biomass and the microbial biomass, humus, and organic and mineral carbon of the soil. Industrial agriculture involves practices (described in the first part of this chapter) that reduce the storage capacity of both of these terrestrial carbon sinks. Much of this reduction in carbon storage capacity occurs in the clearing of large tracts of woody vegetation—much of it tropical rainforest—for pasture land and for growing livestock feed, palm oil, and biofuel feedstock. Additionally, intensive tillage, application of inorganic fertilizer, and a strong reliance on annual crops dramatically reduce the ability of agricultural soils to sequester and store carbon because they reduce the soil's biological activity and expose its organic matter to depletion by erosion, chemical degradation, and bacterial respiration.

In these many ways, industrial agriculture makes a significant contribution to climate change, thereby playing a role in making much of the earth less hospitable to agriculture in any form.

Loss of agrobiodiversity

Throughout most of the long history of agriculture, humans generally increased the genetic diversity of crop plants and livestock wherever agriculture was practiced. People were able to do this both by continually recruiting wild species and their genes into the pool of domesticated organisms and by selecting for a variety of specific and often locally adapted traits through selective breeding of those species. This process resulted in two levels of agrobiodiversity: greater numbers of species being used for food (worldwide and regionally) and greater genetic variety within those species. In the last 100 years or so, however, both levels of diversity in domesticated plants and animals have declined.

At the species level, the decline is the result of agriculture narrowing its focus to just a handful of crop and livestock species—those with high yield potential and other traits that make them good fits for industrial agriculture. Although more than 6,000 different plant species have been grown for food around the world, fewer than 200 of them now contribute significantly to food production, even at a national level. Only nine species currently account for 66% of total world crop production (FAO 2019a).

As a result of a similar kind of narrowing within species, many locally adapted varieties of plants and breeds of animals have been largely abandoned (FAO 2019a, b). A surprising number have become extinct and a great many others are heading in that direction. Even though modern breeding programs are continually releasing new varieties for use in production, the loss of older varieties occurs at a greater rate, leading to a net reduction in diversity. According to one account, about 75% of the genetic diversity that existed in crop plants has been lost over the past century (Nierenberg & Halweil 2004; FAO 2010). At the same time, the genetic bases of most major crops and livestock species—the relatively few species we now depend on—have become increasingly uniform, with only a handful of varieties accounting for the bulk of production. This loss of varietal and genetic diversity within crop species is referred to as **genetic erosion**.

The loss of agrobiodiversity has occurred mainly because of industrial agriculture's emphasis on short-term productivity gains. When highly productive varieties and breeds are developed, they tend to be adopted in favor of others, even when the varieties they displace have many desirable and potentially desirable traits. Genetic homogeneity among crops and livestock is also consistent with the maximization of productive efficiency because it allows standardization of management practices.

For crop plants, a major problem with increasing genetic uniformity is that it leaves each crop assemblage, as a whole, more vulnerable to attack by pests and pathogens that acquire resistance to pesticides and to the plants' own defensive compounds; it also makes crops more vulnerable to changes in climate and other environmental factors. These are not insignificant or hypothetical threats. Every year, crop pests and pathogens destroy an estimated 30%–40% of potential yield (Savary et al. 2019). Plant pathogens can evolve rapidly to overcome a crop's defenses, and global commerce and genetically uniform farm fields allow these new virulent strains to spread rapidly from field to field and continent to continent.

Throughout the history of agriculture, farmers—and more recently, plant scientists—have responded to outbreaks of disease by finding and planting resistant varieties of the affected crop. But as the size of each crop's genetic reservoir declines, there are fewer and fewer varieties from which to draw resistant or adaptive genes. The importance of having a large genetic reservoir can be illustrated by example. In 1968, greenbugs attacked the U.S. sorghum crop, causing an estimated $100 million in damage. The next year, insecticides were used to control the greenbugs at a cost of about $50 million. Soon thereafter, however, researchers discovered a sorghum variety that carried resistance to the greenbugs. No one had known of the greenbug resistance, but it was there nonetheless. This variety was used to create a hybrid that was grown extensively and not eaten by greenbugs, making the use of pesticides unnecessary (Royer et al. 2015). Such pest resistance is common in domesticated plants, "hiding" in the genome but waiting to be used by plant breeders. As varieties are lost, however, the valuable genetic reservoir of traits is reduced in size, and certain traits potentially invaluable for future breeding are lost forever. A broader issue is that agricultural systems with narrowed genetic bases are less effective in integrating with and supporting the function of natural systems and thereby helping to create multifunctional landscapes (see Chapter 18).

Figure 1.9 **Chayote, an edible member of the squash family from Central America**. Chayote squash, easy to grow in gardens and very prolific, is an example of one of the many plants around the world that is under-utilized as a food source. The fruits are not the only portions of the plant that are edible and nutritious—the tuberous roots can be eaten like potatoes and the shoots and leaves used in stir-fries. Its vining habit allows it to be grown in tight spaces and in combination with other crops.

Increasing vulnerability to disease is also a serious concern for domesticated animal species as they lose their genetic diversity, but perhaps more serious is increased dependence on methods of industrial food production. Livestock breeds that are not adapted to local conditions require climate-controlled environments, doses of antibiotics, and large amounts of high-protein feed.

Loss of the most knowledgeable land stewards

Accompanying the concentration of agriculture into large-scale monocultural systems and factory farms has been a dramatic decline in the number of farms and farmers, especially in developed countries where mechanization and high levels of external inputs are the norm. From 1920 to the turn of the century, the number of farms in the United States dropped from more than 6.5 million to just over 2 million, and the percentage of the population that lived and worked on farms dropped below 2%. Data from the 2019 U.S. Current Population Survey showed that only 0.6% of the employed civilians in the United States list their occupation as "farmer or rancher" (U.S. Census Bureau 2019).

In developing countries as well, rural people who work primarily in agriculture continue to abandon the land to move to urban and industrial areas, which will hold an estimated 68% of the world's population by 2050 (United Nations 2018). There are now far more people in the world whose livelihoods are non-agricultural than there are people who grow food, and this gap continues to widen over time.

Besides encouraging an exodus from rural areas, large-scale commodity-oriented farming tends to wrest control of food production from rural communities. This trend is disturbing because local control and place-based knowledge and connection are crucial to the kind of management required for sustainable production. Food production carried out according to the dictates of the global market, and through technologies developed elsewhere, inevitably severs the connection to ecological principles. Experience- and place-based management skill is replaced by purchased inputs requiring more capital, energy, and use of non-renewable resources. Farmers become mere instruments of technology application, rather than independent decision-makers and managers.

In less-developed countries, the growth of large-scale export agriculture has an even more ominous effect. Elites in these countries have, for a long time, gained control of land through various and often illegal means to increase production of export crops. More recently, however, the growing value of agricultural land in less-developed countries has attracted international investors, who have been buying it up at a rapid pace in a process called "land grabbing," turning farmland into a valuable and sought-after financial asset. In the decade between 2000 and 2010, more than 203 million ha of land in less-developed countries were the object of sale or lease negotiations (Anseeuw et al. 2012). The majority of these land deals were made for the express purpose of growing export crops—biofuels, in particular—and will contribute nothing to the production of food supplies in the countries in which they are located. In nearly all cases, realizing investors' plans means removing the people living on and farming the land, often violently and usually without consultation or compensation (Geary 2012). Speculative investment in agricultural land by large transnational funds such as TIAA continues, further undermining the once-stable relationship between local farmers and their land and, with it, local farming knowledge and ability (Fairbairn 2020).

Increasing vulnerability and risk

The size, scale, integration, and technological sophistication of the world food system tend to give the impression that it can easily resist the environmental vagaries—droughts, floods, cold snaps, pest infestations, diseases—that have plagued farmers since humans took up agriculture thousands of years ago. But this impression is a false one: industrial agriculture has actually made itself extraordinarily vulnerable to extreme weather events, climatic shifts, pests and diseases, and economic and political disruptions.

A central cause of this vulnerability is the practice of monoculture, especially when it is combined with the planting of genetically uniform crops. Planting the same variety of a single crop across a wide geographic area virtually assures that when nature serves up conditions hostile to that crop's development—a late spring frost, a severe drought, an extreme weather event—the damage will be widespread. When the damage is caused by drought, the effects are intensified by the dependence on synthetic fertilizer, because years of providing crop nutrition solely through chemical means have dramatically lowered the soil's moisture-holding capacity through depletion of its organic matter. As noted above, monoculture and genetic uniformity also dramatically increase vulnerability to pests and disease. A virtual sea of host organisms, all with their natural resistance bred out of them, is the perfect opportunity for a fungus, virus, or insect to vastly improve its reproductive success in a very short time span. Further exacerbating the problem is the inherent risk of depending on only three crops—corn, rice, and wheat—for more than half of the world's food.

Climate change assures that industrial agriculture's vulnerability (or, put the other way, its lack of resilience) will increasingly become a matter of serious concern. Climate change is likely to increase the frequency and severity of droughts and floods, to increase the incidence of extreme cold and heat, to reduce the mountain snowfall on which many regions rely for irrigation water, and to allow pests and diseases to move to regions where they were formerly excluded by winter cold. An earth beset by a warming climate needs exceptionally resilient agroecosystems, not the opposite.

Because of its interconnected nature, the world food system is also vulnerable to social, political, and economic factors that have no direct connection to climate, weather, or the environment. Increases in the price of oil, trade agreements, unilateral governmental actions, human disease pandemics like COVID-19, and disruptions in the world economy are among the many factors that may have important effects on food prices, supply chains, and distribution systems. In this realm, however, it is necessary to clarify who bears the brunt of the "vulnerability." Industrial agriculture has become so deeply integrated into the world economic system, which is controlled by a relative handful of elites, that it is not industrial agriculture itself that is vulnerable so much as it is the world's food consumers and smallholder farmers.

Figure 1.10 **Storm damage in a corn field**. Due to the effects of climate change, droughts, heat waves, unprecedented flooding, and severe storms are becoming increasingly common all over the world, resulting in crop loss and financial hardship for farmers. Industrial farming practices have increased agriculture's vulnerability to these kinds of events.

HARMFUL EFFECTS ON SOCIETY OF THE CURRENT FOOD SYSTEM

We have argued that industrial agriculture undermines the resources and conditions necessary for its own continuation into the future and, on that basis alone, must be replaced with a form of agriculture less dependent on fossil fuels, external inputs, and technology and less harmful to soil, natural systems, and the biosphere. But when we look at the food system as a whole—that is, at food distribution and consumption as well as food production, and at the social and economic systems within which these activities are embedded—we begin to see many other reasons to press for fundamental change in the way we humans feed ourselves.

A gulf between growing food and eating it

The relationship between people and food changed in a fundamental way many millennia ago with the invention of agriculture. When large amounts of surplus food could be grown, stored, and transported, the conditions were in place for a separation in time and place between the act of procuring food and the act of eating it. Individual humans had previously directly gathered or hunted their own food or knew the people who did so; now, once agriculture had taken hold, only some people grew food while others concentrated on other economic activities.

The separation between growing food and eating it increased over the span of human history in a somewhat linear fashion, with increasing numbers of traders, brokers, and merchants inserting themselves between farmers and much of the remainder of the population. When urban populations swelled and industrial agriculture began to dominate after World War II, however, the gap between farmers and the people who became known as "consumers" suddenly grew much wider and much deeper. The number of linkages between the grower of the food and the person who consumed it reached a point where the social as well as the geographic distance between them was so great that the act of eating became completely divorced from the basic agricultural acts of growing or raising the food. Not only did most consumers lose all awareness of plowing, sowing, reaping, milling, slaughter, and butchery, but they had no reason to even consider these basic facts of food creation. Food became something you bought at the grocery or supermarket, nicely packaged and presented.

This situation may not seem like something to be critical of. We get to enjoy an amazing cornucopia of foodstuffs at relatively low prices without having to dirty our hands in the soil or witness the killing of animals. Like many things that sound good on the surface, however, it comes with a price.

A global food system designed to accommodate and encourage demand for diverse, palate-pleasing, convenient food brings with it a variety of negative consequences for consumers:

- **Food is less fresh**. Because much of the food we eat must travel a long distance to get to us, it isn't particularly fresh. Even produce, shipped rapidly by air or truck, often under refrigeration, is often picked before it's ripe.
- **Food is less nutritious**. When surviving transport and storage is the major consideration, the breeding (or genetic engineering) process that produces the seeds is likely to have sacrificed taste and nutritive content. In addition, food that must survive long-distance transport and storage is subjected to a variety of processes—overcooking, drying, freezing, vacuum-packing, pasteurization, irradiation—that tends to remove its nutrients.
- **Food is less healthy**. Packaged and processed foods have added preservatives and a variety of other added ingredients—such as salt, sugar, and fats—that are linked to obesity, cancer, and other health problems. Most produce contains detectable levels of pesticides.
- **Food is standardized and homogenized**. Regional and cultural differences in cuisine and diet are slowly disappearing with the homogenization of the food supply. Fast-food chains insure that a burger purchased in Tokyo is virtually identical to one bought in Chicago. Related to this is the loss of place-based identity. The regional foods that define the places we live in are either being lost or overly hyped as marketing tools.
- **Food is emptied of meaning**. When food consumption is completely detached from the processes that got it to our tables, when we lose all connection with

Figure 1.11 **Supermarket shelves**. Much of the food to be found on supermarket shelves around the world is standardized, highly processed, not fresh, and full of unhealthy ingredients. The abundance and diversity give the impression that the food system is set up to satisfy consumers' every need.

Figure 1.12 **Unhealthy food**. Most donuts are fried in palm oil and sugar glazes are often added to the already-sweet rings of cooked batter. Few "foods" are less healthy than donuts. Around the world, much of the food that's consumed by non-rural people contributes to metabolic disease and weight gain while supporting unsustainable agricultural practices like monoculture and conversion of tropical forest to palm plantations.

the people who grow our food and with all the biological and social facts of the food's existence, eating is stripped of much of the context and meaning it has had since the long-ago origins of the human species.

Negative impacts on human health

Agribusiness corporations spend huge sums manipulating consumer tastes and behaviors in a variety of ways, taking advantage of hard-wired human desires for fatty foods and sweets and the often-frenetic lifestyles adopted by those chasing after higher status and living standards. As a result, people have become obsessed with food as a product and with the act of consuming it. In addition to supporting the systematic erasure of food's origin and path to the supermarket shelf that we just discussed, this fetishization of food has contributed to the rise of metabolic disorders as one of the most serious public health problems in much of the developed and developing world.

Immersed in a cultural context that makes eating a matter of pleasure rather than the satisfaction of nutritional needs and presents them with an array of palate-pleasing foods high in fat, salt, and sugar, many people consume far more calories than they need. Food overconsumption has made obesity and metabolic disorders like Type 2 diabetes far more common in many countries than they have ever been before. The prevalence of these conditions constitutes what many consider a public health emergency because they lower life expectancy and contribute to higher rates of cancer, heart disease, and stroke. In 2016, 39% of adult men and 39% of adult women worldwide were considered overweight and 11% of men and 15% of women were classified as obese (WHO 2020). These statistics represent what is approximately a doubling of obesity rates since the late 1980s (WHO 2013). Although increasingly sedentary lifestyles are partly to blame, a major reason for the increase in obesity and metabolic disorders is an increase in consumption of the kinds of foods that industrial agriculture is most strongly geared to producing—sugar- and fat-laden, energy-dense, and processed.

Encouraging unhealthy diets is only one way that industrial agriculture impacts the health of humans worldwide. By using antibiotics in livestock production, expanding agriculture into formerly wild landscapes, and increasing contacts between humans and wild and domestic animals, agriculture has greatly increased the likelihood of infectious agents moving from animals to humans. Such pathogens are called zoonotic. The virus that causes COVID-19 is only one of the zoonotic pathogens to emerge as a threat to human health in recent years. A review of the literature showed that since 1940 more than half of all the zoonotic diseases that have affected humans were able to jump the species barrier because of food system-related factors (Rohr et al. 2019).

Distressed rural communities

One of the central dynamics of the rise of industrial agriculture has been to substitute tractors (and other inputs) for people. On a global scale, this has meant a shrinking of the rural population and a reduction in the number of people who can be called farmers—who, as we point out above, are the people traditionally conceived of as stewards of the land. The particular manifestations of the trend toward larger farming operations and industrial practices vary by country and region and depend on the degree of integration into the global food system, but all over the world smaller-scale farmers are taking the biggest hit. These growers are becoming increasingly marginalized while those with large operations claim an increasing share of the benefits—and become more like factory managers than farmers.

In developed countries like the United States, smaller-scale farmers have little power against the advancement of industrial agriculture. Smaller farms cannot afford the cost of upgrading their farm equipment and technologies in order to compete successfully with the large farm operations. Moreover, the increase in the share of the food dollar going to distributors and marketers, coupled with cheap food policies, has left many farmers in a tightening squeeze between rising production and marketing costs and declining returns. As a result, many can't afford to stay on the land. Larger farmers often buy out their smaller neighbors, and when agricultural land is adjacent to rapidly expanding urban centers, there is an incentive instead to sell farmland at the inflated value it has as urban land.

In the developing world, many countries still have very substantial rural populations, which is why half of the world's people still depend on farming for their livelihoods. In some parts of the world, such as much of South Asia, over 70% of the people are farmers, for example. However, the industrialization of agriculture in these countries is putting these rural people at an increasing disadvantage. Seeking to follow the example of developed countries, or pressured by them, their governments implement policies that subsidize food imports, prioritize the production of export crops, and welcome international agribusiness corporations and foreign land ownership. Without the support they need from the state, challenged to get fair prices for their crops, and often pushed off the land, small-scale farmers in the developing world are struggling to survive. Their situation is made more critical by external factors like climate change.

As a result of these and other dynamics, rural people—once able to feed themselves adequately *and* sell surplus food to city-dwellers—now make up the most food-insecure group worldwide. It is estimated that 80% of the world's hungry live in rural areas (Mikhail 2012). And as more and more rural smallholders are pushed off the land, they migrate to cities, where they become dependent on others for their food and face uncertain prospects for employment.

The marginalization of farming and farmers has serious social and demographic consequences for rural communities. Rural farm communities are in decline around the world. Once thriving assemblages of people from all walks of life, livelihoods, and outlooks, today they are increasingly aging and depopulating. In 2017, less than 1% of the U.S. population was made up of full-time farmers, and of those, farmers over 65 years old outnumbered those under 35 more than four to one (USDA 2019). In many developing countries, farmers and their families are leaving rural areas and their farms in alarming numbers, forced out by increasingly untenable circumstances or attracted to opportunities, imagined or real, in cities or in other countries. In addition to contributing to problems such as hunger, unemployment, and migration pressure, the marginalization of farmers leaves the countryside with fewer people willing and able to care for and manage the land sustainably.

Global inequality

Despite increases in productivity and yields, hunger persists all over the globe. The Food and Agriculture Organization of the U.N. estimated that 8.9% of the world's population—or more than 678 million people—were chronically undernourished in 2018 (FAO 2020). With increasing frequency, spikes in global food prices, major droughts, and political upheaval create even more hungry people. In 2020, the COVID-19 pandemic presented an additional challenge to food security. In that year alone, Feeding America projected that the United States annual food insecurity rate would increase by 4.1 percentage points for the overall population and by 4.9 percentage points for children, such that nearly one in four children would now be at risk (Feeding America 2020).

There are also huge disparities in calorie intake and food security between people in developed nations and those in developing nations, and between rich and poor regardless of how developed a country may be. People faced with chronic food insecurity have poorer health, less power to improve their life circumstances, and shorter life expectancies than people with access to adequate and nutritious food. At the beginning of the 21st century, the world reached a dubious milestone: the number of overweight people (about 1.1 billion) grew roughly equal to the number of underweight people (Gardner & Halweil 2000). This statistic indicates that the unequal distribution of food—which is both a cause and a consequence of global inequality—is the real cause of hunger, not inadequate food production.

Since hunger, poverty, and inequality existed before the rise of industrial agriculture in the latter half of the 1900s, one could argue that global inequality has causes unrelated to industrial agriculture. While some causes are indeed separate, it is also true that industrial agriculture perpetuates and accentuates existing relationships of inequality. It does this because it is designed to generate profits for the owners of agribusiness concerns and because the process of wealth generation depends on increasing its control of land, farmers, resources, markets, and distribution networks and on reducing labor costs. The inevitable result is the enrichment of some groups and some countries at the expense of others.

Developing nations too often have moved away from local food systems and now grow food mainly for export to developed nations, using external inputs purchased from the developed nations. While the profits from the sale of the export crops enrich small numbers of elite landowners, many people in the developing nations go

Figure 1.13 **Migrant workers picking strawberries**. Poorly paid for physically demanding work, these laborers often struggle to feed their families while the fruit they pick is enjoyed by people in more fortunate circumstances.

hungry. In addition, those with any land are often displaced as the privileged seek more land on which to grow export crops.

Besides causing unnecessary human suffering, relationships of inequality tend to promote agricultural policies and farmer practices that are driven more by economic considerations than by ecological wisdom, cultural preference, and long-term thinking. For example, subsistence farmers in developing nations, displaced by large landowners increasing production for export, are often forced to farm marginal lands. The results are deforestation, severe erosion, and serious social and ecological harm. As long as industrial agriculture is based on technology originating in the developed world, relies on external inputs accessible only to those with capital, and exists primarily to generate wealth for elite strata, the practice of agriculture will perpetuate and exacerbate inequality. In turn, inequality will remain a barrier to broader societal sustainability.

THE PATH TOWARD FOOD SYSTEM TRANSFORMATION

If it is possible to sum up the foregoing discussions in a single sentence, it's that a food system dedicated to the maximization of production and profit can't help but damage both the health of the environment and the health of society. The inevitable conclusion that flows from this contention is that our current industrial agriculture-based food system needs to be reclaimed by an agroecological system that works with, instead of against, natural ecosystems and supports the well-being of all people. This requires changes so fundamental that they warrant the term *transformation*.

Those who advocate transitioning from our current food system to another call for a variety of different qualities in the system toward which we should deliberately move. One is *sustainability*—the ability to exist or be maintained into the future. When it came into wide use following the release of the Brundtland Report in 1987, the term *sustainability* referred to human impacts on the planet's life support systems. Development (i.e., human economic activity) was considered sustainable if it did not damage the resources, cycles, and living elements of the natural world and thereby compromise the ability of future generations to meet their needs. Since that time, the meaning of the term has expanded greatly to include how human society impacts itself and its members, not just the natural world on which humans depend. For many people, sustainability now refers to all desired aspects of a society, such as equity, fairness, food security, and economic security. Although we advocate that the food system must be transformed into one that is consistent with these people-oriented goals as well as the health of natural systems, we have concerns that relying on this broad definition of sustainability may be inadequate. One reason is that many people restrict their understanding of sustainability to its narrower, original meaning as pertaining to human impact on natural systems. A second reason is that calling for a food system that supports the health and well-being of people is most fundamentally a moral imperative, to be fought for in the present, and secondarily a matter of sustaining society into the future. If we stake out a broad definition of *sustainability* inclusive of social, cultural, and economic concerns and do nothing more than that, then the essential meaning of the word itself—able to be sustained—may undermine that sense of a present, moral imperative.

Another quality that people want to strive for in transforming agriculture and the food system is *social justice*, which is defined in different ways but usually refers to fairness or equality in the distribution of rights, opportunities, wealth, privileges, and power. Pursuing the goal of social justice in the food system addresses issues not directly covered by the narrow, ecologically based definition of sustainability, including food insecurity, hunger, poverty, wealth inequality, landlessness, race- and gender-based bias, and unequal exposure to the consequences of climate change. The sense of a moral imperative is inherent in the term.

There are other desirable qualities for a food system intended to displace the current one. It should enable and encourage optimal human health, vibrant and prosperous communities, and the realization of human potential. It should discourage conflict between nations and social groups. It should make human societies more resilient in the face of the challenges that will come about in a world that's simultaneously warming and filling with more people.

No single term can capture all of these characteristics. In this text, we attempt to indicate the key qualities of what we want to move toward by using the phrase *just and sustainable*. In general outline, a just and sustainable food system is one that

- conserves, regenerates, and revitalizes soils, ecosystems, and biodiversity;
- works to mitigate climate change and help human societies adapt to it;
- uses freshwater resources in ways that simultaneously meet the needs of people, natural systems, and the future;
- guarantees equality of access to appropriate agricultural practices, knowledge, and technologies and enables local control of agricultural resources;
- eliminates hunger, ensures food security in culturally appropriate ways, and guarantees every human being a right to adequate food; and
- removes social, economic, political, and race- and gender-based injustices from food systems and the structures they help support.

The role of agroecology in helping to bring about this kind of food system is not to prescribe specific practices and arrangements. Rather, agroecology contributes principles, concepts, and strategies that must form the foundation of any system of food production, distribution, and consumption that can make a legitimate claim to being a more ecologically sound, sustainable, and just successor to the one based on industrial agriculture. These principles, concepts, and strategies are more oriented toward offering a design framework for sustainable agroecosystems than they are prescriptions or blueprints for the construction or management of actual agroecosystems, and they don't dictate the specifics of an entire world food system.

Figure 1.14 **Farmers' Market in Santa Cruz, California**. A variety of fresh, seasonal, locally grown fruits and vegetables is being sold. Farmers' markets express and support many of the characteristics of a just and sustainable food system.

Transforming agriculture in a fundamental way—putting it on a sustainable path—is going to be a tremendous challenge. A basic assumption of this textbook is that agroecologists can hope to meet this challenge only if we approach it on three different fronts simultaneously (Wezel et al. 2009; Gliessman 2018).

First, we require more diverse and better knowledge of the ecological relationships among domesticated agricultural species, among these species and the physical environment, and among these species and those of natural systems. This need is satisfied by agroecology as a science, which draws on modern ecological knowledge and methods, as well as those from indigenous cultures, to derive the principles that can be used to design and manage sustainable agroecosystems.

Second, we require effective and innovative agricultural practices, on-the-ground systems that work in the present to satisfy our food needs while laying the groundwork for the more-sustainable systems of the future. Satisfying this need is agroecology as practice, which values the local, empirical knowledge of farmers and the sharing of this knowledge, and which undercuts the distinction between the production of knowledge and its application.

Finally, circumstances demand fundamental changes in the ways that humans relate to food, the economic and social systems that determine the distribution of food, and the ways in which food mediates the relationships of power among populations, classes, and countries. Serving this need is agroecology as a movement for social change, which not only advocates for the changes that will lead to food security for all, but also seeks knowledge of the means by which these changes can be activated and sustained.

Although each of these dimensions of agroecology is critical, the bulk of this text is dedicated to the science of agroecology. In presenting this material, the text highlights the practical dimension by giving examples of how the science can be successfully applied. The social-change aspect of agroecology is fully explored in Section IV, after the reader has absorbed the full suite of ecological principles and practices that form the foundation of sustainable food systems. Focusing on this aspect of agroecology at the end of the text is not an indication of its secondary importance. If agroecologists and others seeking to put agriculture on a more sustainable basis fail to consider the ideas discussed in Sections IV and V, their efforts are likely to be for naught.

FOOD FOR THOUGHT

1. How does the holistic approach of agroecology allow for the integration of ecological soundness, economic viability, and social justice?
2. Why has it been so difficult for humans to see that much of the environmental degradation caused by industrial agriculture is a consequence of the lack of an ecological approach to agriculture?

3. What common ground is there between agronomy and ecology with respect to sustainable agriculture?
4. What are the issues of greatest importance that threaten the sustainability of agriculture in the town or region in which you live?
5. What is the meaning of the concept that people "have a right to food"?

INTERNET RESOURCES

Agroecology in Action
agroeco.org
Led by agroecologist Miguel Altieri, Agroecology in Action promotes the integration of agroecological knowledge and technologies into practice while building a deeper understanding of the complex long-term interactions among resources, people, and their environment.

Food and Agriculture Organization of the United Nations
fao.org/agroecology
The agroecology knowledge hub of FAO where experiences from around the world are shared and promoted in an effort to catalyze dialogue and cooperation globally for the scaling out and scaling up of agroecology.

Food First: Institute for Food and Development Policy
foodfirst.org
Food First is a non-profit think-tank and "education-for-action center" focused on revealing and changing the root causes of hunger and poverty around the world.

FoodPrint
foodprint.org
FoodPrint is a consumer campaign intended to help people make food choices that reduce their impact on natural systems.

Union of Concerned Scientists—Food and Farms section
ucsusa.org/food
UCS combines independent scientific research and citizen action to develop innovative, practical solutions and to secure responsible changes in government policy, corporate practices, and consumer choices. Its Food & Agriculture program focuses on the science behind sustainable agriculture as the direction for the future.

Worldwatch Institute
worldwatch.org
A nonprofit public policy research organization dedicated to informing policymakers and the public about emerging global problems and trends, and the complex links between the world economy and its environmental support systems. Food and farming are key support systems they monitor.

RECOMMENDED READINGS

Altieri, M.A. 1995. *Agroecology: The Science of Sustainable Agriculture*. 3rd ed. Westview Press: Boulder, CO.

An important pioneering work on the need for sustainability and a review of the kinds of agroecosystems that will help lead us toward it.

Berry, W. 2009. *Bringing it to the Table: On Farming and Food*. Counterpoint Press: Berkeley, CA.

An eloquent collection of essays by a master farmer and writer that clearly outlines the ethics and culture of human connections to the land and agriculture.

Douglass, G.K. (ed.). 1984. *Agricultural Sustainability in a Changing World Order*. Westview Press: Boulder, CO.

Proceedings of a landmark symposium that helped define the trajectory for future work on the interdisciplinary nature of agricultural sustainability.

Funes-Monzote, F.R. 2008. *Farming Like We're Here to Stay: The Mixed Farming Alternative for Cuba*. Wageningen University: Wageningen, Netherlands.

A motivational account of the remarkable effort to develop food self-sufficiency as a response to economic crisis in Cuba, and the grounding of this response in the concepts of agroecology.

Gliessman, S.R. & M.E. Rosemeyer. 2010. The Conversion to Sustainable Agriculture: Principles, Processes, and Practices. Advances in Agroecology Series. CRC Press/Taylor & Francis Group: Boca Raton, FL.

The framework for the conversion of food systems to sustainability.

Goodman, D., M. DuPuis, & M.K. Goodman. 2011. *Alternative Food Networks: Knowledge, Place and Politics*. Routledge: London.

A critical review of the growth of alternative food networks and their struggle to defend their ethical≈and aesthetic values against the standardizing pressures of the corporate mainstream with its "placeless and nameless" global supply networks.

Guzmán-Casado, G., M. González de Molina, & E. Sevilla-Guzmán 1999. *Introducción a la agroecología como desarrollo rural sostenible*. Ediciones Mundi-Prensa: Madrid. (In Spanish).

A pioneering description of agroecology as a social movement focused on sustainable rural development, with a strong emphasis on the European model.

Herren, H. & H. Benedikt. 2020. *Transformation of our Food Systems: The Making of a Paradigm Shift.* Zukunftsstiftung Landwirtschaft (Foundation on Future Farming): Berlin, Germany; and Biovision: Zurich, Switzerland.

Termed the IAASTD+10, this important book shows how it is no longer time for "business as usual." Published on the 10th anniversary of the IAASTD report of 2009, it calls attention to how the past decade has not seen the progress needed in food system change, why this has happened, and the bold steps needed for a new paradigm to take charge.

Jackson, W., W. Berry, & B. Colman (eds.). 1986. Meeting the Expectation of the Land. Northpoint Press: Berkeley, CA.

A collection of contributions from a diverse set of experts, designed to inform the general public of the people- and culture-based elements that are needed to make the transition to a sustainable agriculture.

Kimbrell, A. (ed.). 2002. The Fatal Harvest Reader: The Tragedy of Industrial Agriculture. Island Press: Washington, DC.

An important collection of essays that vividly portray the devastating impacts of the current industrial agricultural system on the environment, human health, and farm communities, and present a compelling vision for a healthy, humane, and sustainable agriculture for the future.

Mendez, V.E., C.M. Bacon, R. Cohen, & S.R. Gliessman. 2016. *Agroecology: A Transdisciplinary, Participatory, and Action-oriented Approach*. CRC/Taylor & Francis Publishers: Boca Raton, FL.

A comprehensive collection of chapters that defines the agroecological approach to sustainability as a transdisciplinary, participatory, and transformational set of actions.

Perfecto, I., J. Vandermeer, & A. Wright. 2010. Nature's Matrix: Linking Agriculture, Conservation and Food Sovereignty. Earthscan: London, UK.

By linking landscape ecology with diversity theory, this book shows the incredible value of sustainable peasant agriculture as a positive force for biodiversity conservation and food sovereignty.

Philpott, T. 2020. *Perilous Bounty: The Looming Collapse of American Farming and How We Can Prevent It*. Bloomsbury Publishing: New York.

Vandermeer, J.H. 2011. *The Ecology of Agroecosystems*. Jones & Bartlett Publishers: Sudbury, MA.

An excellent source of information on the application of ecological concepts and principles in the scientiic study of agroecosystem design and management.

Wezel, A., S. Bellon, T. Dore, C. Francis, D. Vallod, & C. David. 2009. Agroecology as a science, a movement and a practice. A review. *Agronomy for Sustainable Development*, 29, 503–515.

Defines the three areas of focus for agroecology, with historical background on the development and application of each area.

Wise, T.A. 2019. *Eating Tomorrow: Agribusiness, Family Farmers, and the Battle for the Future of Food*. The New Press: New York.

A powerful critique of modern agricultural technology that shows that the world already has the tools to feed itself with agroecology and local knowledge, but food systems have to escape the control of industrial corporate agriculture first.

2

Alternatives to industrial agriculture

Regenerative agriculture, certified organic, permaculture, and biodynamic farming are among the many different systems of growing and raising food that exist today and represent themselves as alternatives to the dominant system of industrial agriculture described in Chapter 1.

Each alternative system has its advocates, devotees, and practitioners. Many promote their chosen system with singular passion, often claiming that it is the best solution to the problems presented by industrial agriculture and the best path to sustainability. Often all the different systems seem to be competing with each other for adherents. It can be a bewildering situation for anyone whose goal is to support the transformation of the food system. Which of these systems should I have faith in?

Despite their competitive and brand-building marketing efforts, the alternative agriculture systems have a great deal in common, at least on the surface. Most obvious is their shared opposition to, or critique of, industrial agriculture. They also share a grounding in ecological concepts and a belief that farmers should work in concert with nature rather than in opposition to it. From this perspective, all the alternative systems may have legitimate claims to be serious alternatives to industrial agriculture.

Looking under the surface, it's possible to recognize important differences among the different alternative systems. One way they can be differentiated is to look at how they organize and disseminate their methodologies. Some use a formulaic or *recipe-based approach* in which each decision a farmer might make is directly prescribed. This approach is typically paired with an established set of rules and certifications codified by some form of reference or governing organization. Others put forward a set of fundamental principles that farmers can apply as they see fit. Alternative systems that use this *principles-based approach* prioritize the ability of farmers to pick and choose their own suite of inputs and practices according to their particular context.

Many other differences among the alternative systems emerge if we examine them from an historical perspective. When we see them as *movements* that arose in particular historical circumstances, in response to certain challenges, we build a deeper understanding that allows us to better evaluate their potential contributions to challenging the dominant industrial food system and transforming it into one that is sustainable and just.

RESPONSES TO THE INDUSTRIALIZATION OF AGRICULTURE IN THE EARLY 20TH CENTURY

Industrial agriculture has its roots in the period of overall industrialization that occurred mostly in Europe and North America during the 19th century. During the latter part of that century, farms grew somewhat larger, on average, and production methods became more intensive as farmers were called upon to feed a growing and increasingly urban population. In the beginning of the 20th century, change came more rapidly with increased mechanization based on fossil-fuel power, the development of technologies like refrigeration that allowed food to be more easily stored and transported, and the invention of the Haber–Bosch process, which allowed the large-scale manufacture of synthetic nitrogen fertilizer.

The relatively quick rise of industrial farming methods was a major cause and consequence of massive social changes and disruptions. In both the United States and many countries of Europe, societies that had always been largely rural and agrarian rapidly transformed into urban societies. Fewer people made livings as farmers and fewer people grew their own food. Cities rather than rural towns became the centers of social, cultural, and political life. Some farmers prospered, but for others it was a time of crisis.

It was in this historical context that the first alternatives to industrial agriculture emerged. Farmers and intellectuals who envisioned the future saw trends that to them were deeply disturbing. Agriculture was turning its back on nature, relying on synthetic chemicals, losing respect for the soil, and abandoning the ethic of stewardship. They feared these trends could only lead to disaster.

What these critics of early industrial agriculture advocated was in many ways a return to the practices, principles, and attitudes that they saw being abandoned. In this sense, they founded their goals and recommendations on what we now call traditional agriculture—those small-scale systems of food production that had been developed in place over many generations of practice and

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observation. In the United States, traditional agriculture in turn had much to owe to the agriculture practiced by the indigenous people whose land European colonists appropriated and to the African people captured and brought to the New World to work as slaves on farms and plantations.

Biodynamic agriculture

Biodynamic agriculture is often regarded as the first modern "organic" agricultural approach. Derived from the works and theories of the controversial Austrian philosopher and scientist Dr. Rudolf Steiner during the early 1900s, biodynamic agriculture grew significantly in the latter part of the last century. More than 600,000 acres are currently under biodynamic production worldwide.

Steiner formally introduced the biodynamic "philosophy" in the summer of 1924 during a series of eight lectures delivered for a select group of farmers in the small village of Koberwitz, Germany (now Kobierzyce, Poland). A staunch opponent of "chemical" agriculture and the emerging industrial agriculture model, Steiner proposed his biodynamic system as a "holistic" alternative that represented a more sustainable vision for agriculture. Steiner saw each farm or garden as an "integrated, whole, living organism… made up of many interdependent elements: fields, forests, plants, animals, soils, compost, people, and the spirit of the place." This integrated vision of the agroecosystem would allow biodynamic practices to be applied at various scales and in different contexts.

A variety of basic principles are derived from the holistic philosophy at the root of biodynamic agriculture. Since the farm is like an organism, it must be self-sustaining and produce its own animal feed and manure. Pest outbreaks and diseases are symptoms of ill health and must be addressed through attention to the whole farm system. Despite the centrality of these principles, biodynamic agriculture leans heavily on the use of strict recipe-based practices and an extensive certification process. Farmers wanting to be certified as biodynamic practitioners are required to use nine "biodynamic preparations" as field sprays, inoculants, or composts. These mixtures, made from plants, minerals, and animal manures, must be prepared in very specific ways. Preparation 502, for example, is made up of the flower heads of yarrow (*Achillea millefolium*) packed into a stag's bladder. Another preparation is cow manure packed into a cow's horn. Biodynamic farmers are trained to align their applications and associated practices (e.g., seeding, harvesting, fertilizing) with specific spiritual, metaphysical, and celestial cycles.

Critics of biodynamic agriculture claim that many of its methods lack any empirical basis. This critique may be well-founded, as few of the biodynamic preparations have been rigorously evaluated in controlled studies. However, in most of the field studies comparing the agricultural yields and ecological performance of conventional, biodynamic, and organic methods, biodynamic and organic methods outperform conventional methods equally well. These findings suggest that the biodynamic preparations, at the very least, are not hindering the performance of the methods. It is no surprise, then, that biodynamic agriculture is often considered a progenitor of organic agriculture.

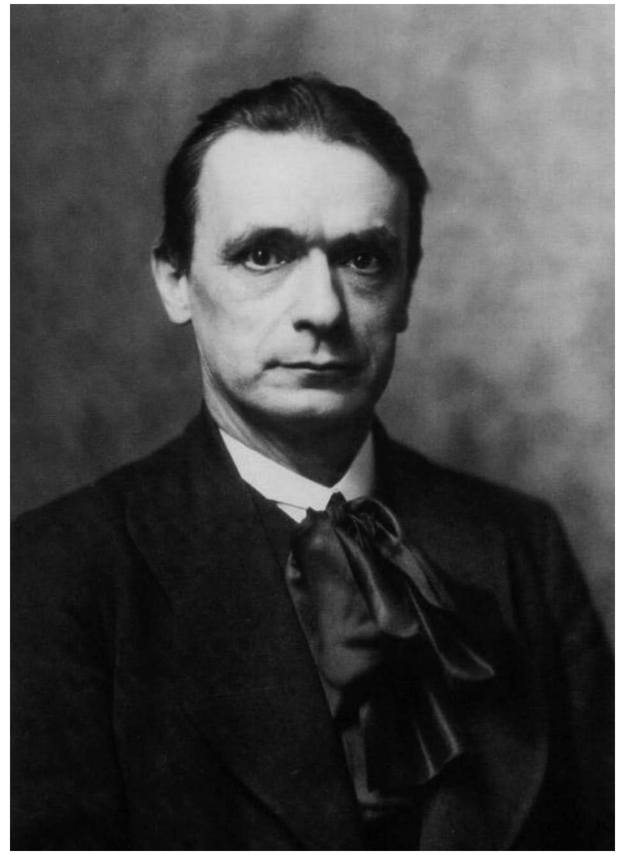

Figure 2.1 **Rudolph Steiner**. Steiner's writings and lectures on agriculture became the basis for the Biodynamic system.

Organic agriculture

Though the origins of modern organic agriculture are difficult to pinpoint, founding credits are often given to traditional farmers on the Indian subcontinent and the associated work of the British botanist Sir Albert Howard. While working as an agricultural adviser in India during the early 20th century, Howard recognized that the industrial agricultural techniques he had been instructed to promote throughout the region seemed to be less effective than the soil-focused holistic practices already being employed by the Indian farmers he was sent to "help." This realization led Howard to reconsider his production-focused view of agriculture and adopt a more systems-based approach to farming where long-term soil health took precedence over short-term yields. During his 25-year tenure at the Indore Experiment Station in India, Howard developed a deep appreciation for soil and composting ecology, and it was here that he articulated his most celebrated agroecological concept, "the law of the return." Howard described the law of the return in his treatise *An Agricultural Testament* as the general principle of closing the nutrient loop by reducing the potential loss of organic matter stemming from harvesting and cultivation. Using an array of natural farming practices such as composting, cover cropping, and animal integration, nutrients and organic matter are actively returned to the soil to maintain long-term fertility. This closed-loop process represented a stark rebuttal of the linear input-heavy systems being promoted by Howard's colleagues beginning in the late 1800s.

The dissemination of Howard's work throughout much of the Western world inspired a number of researchers and farmers dedicated to what eventually became known as organic farming. One particular acolyte, Jerome Irving Rodale, played a critical role in the early growth and expansion of organic farming in North America. During the late 1940s, inspired by the writings of Howard and his own personal health struggles, Rodale established the Soil and Health Foundation, later to become the Rodale Institute. Focusing much of its effort on testing and promoting organic farming techniques, the Rodale Institute became a hub of information and support for farmers interested in adopting more holistic methods of production free of synthetic fertilizers and pesticides. Over the next 40 years, the Rodale Institute helped to establish organic farming as perhaps the most popular alternative to conventional industrial agriculture.

During the early days of the Rodale Institute and the burgeoning organic agriculture movement, most farmers selected and applied their chosen farming methods using a principles-based approach focused mostly on soil health and the reduced usage of synthetic pesticides and fertilizers. Although a diverse array of traditional farming methods (e.g., cover cropping, composting) were used on many of these farms, the rejection of chemical methods emerged as the unifying characteristic for self-identified organic farmers.

Early regenerative agriculture

The American agricultural scientist and inventor George Washington Carver was an early promoter of farming practices designed to "regenerate" degraded land so that it could be used for agricultural production. During his time as a resident professor at the Tuskegee Institute in the late 1800s and early 1900s, Carver explored various farming practices that could build soil organic matter and fertility. He actively promoted the most promising techniques and crops to the poor black farmers he saw as his main constituents.

The preeminent African American scientist of his day, Carver was very sensitive to the struggles of black farming communities. He understood and acknowledged that most African American farmers, systematically disenfranchised and segregated by so-called Jim Crow laws, had access to only the least valuable and most degraded farmland. Additionally, because extension services and other farming resources were generally not available to them, these farmers often had limited capacity for building and maintaining fertility on their farms. It became Carver's mission to counteract these disadvantages by assisting and educating these resource-poor farmers. He was particularly interested in studying low-cost/low-input farming practices and novel crop varieties (e.g., peanuts and sweet potatoes) that could succeed on marginal and degraded land. Farming techniques such as cover cropping, crop rotation, and the use of nitrogen-fixing crops (e.g., peanuts) for rebuilding soil fertility became the cornerstones of his research program.

To disseminate this knowledge, Carver pioneered innovative teaching methods that allowed him to educate farmers directly on their land about regenerative practices. Using a mobile classroom known as the Jesup Agricultural Wagon (named after the benefactor who provided the funds for its construction), Carver traveled around to farms and community spaces to provide demonstrations of soil science phenomenon, crop varieties, and farming techniques. This "Farmer's College on Wheels," as it was called by Booker T. Washington, became tremendously popular, reaching an average of about 2,000 people per month.

Unlike Steiner, Howard, and Rodale, Carver did not strive to reclaim and re-value farming practices that were being overtaken by the rise of industrial agriculture. Instead, he was responding to race-based inequities that were the legacy of slavery and decades of segregationist policies. Whereas Steiner, Howard, and Rodale wanted to thwart the degradation of soil they knew would come with industrial farming, Carver was dealing with the reality of already-degraded soil. And yet, Carver's solutions—ecologically based methods of building soil organic matter and fertility—were largely the same as those promoted by his more privileged white contemporaries. As one of the original developers of regenerative methods, Carver should be celebrated as a founder of what is now known as regenerative agriculture. But his contributions, like those of most African American farmers and agricultural scientists, have been largely forgotten.

Conservation agriculture

During the mid-1940s, on the heels of the Dust Bowl, perhaps the greatest ecological catastrophe of the 20th century, many North American farmers and scientists openly questioned the long-term viability of conventional agriculture. They developed a particularly critical view of the moldboard plow and the use of excessive tillage practices. With suffocating dust storms still vivid in their memory and the reality of eroded land and depleted soil often facing them directly, growers and agronomists in the Midwest and across the globe began to advocate for a

Figure 2.2 **George Washington Carver in a field at the Tuskegee Institute**. Photograph made by Frances Benjamin Johnston in 1906, the same year that the Institute's Jesup Agricultural Wagon was completed and began its mobile educational mission. Carver is holding a chunk of soil.

form of agricultural management less dependent on tillage and other methods of soil disturbance.

The 1943 publication of *Plowman's Folly* by agronomist Edward Faulkner helped to crystalize the prevailing anti-tillage sentiments and present the primary soil health principles supporting no-till and low-till management. "The truth," wrote Faulkner, "is that no one has ever advanced a scientific reason for plowing." When it is recognized that "plowing is wrong," he claimed, "the whole gamut of theory we have evolved concerning the growing of crops will be brought into focus for examination."

Though Faulkner's work brought no-till agriculture back into the collective consciousness of the global farming community, actual adoption of no-till practices remained limited for many years. They began to be more widely adopted in the United States in the 1960s and spread to Brazil in the 1970s. By the 1990s the benefits of no-till practices were widely enough recognized that uptake expanded greatly around the world. At the same time, the no-till strategy was combined with other practices and repackaged as conservation agriculture. In this form, it established itself as an internationally accepted agricultural approach dedicated to reducing soil erosion and maintaining soil health.

Conservation agriculture is loosely defined as an agricultural system that minimizes soil disturbance while maximizing soil coverage and encouraging on-farm biodiversity. The system is based on three basic principles:

- **Minimum soil disturbance.** If the soil is tilled at all, the disturbed area must be less than 15 cm wide or make up less than 25% of the cropped area.
- **Permanent soil organic cover.** To reduce soil erosion and maintain soil organic matter, the soil is always covered with a cover crop, a cash crop, or an organic mulch.
- **Diversified crop rotations.** To reduce the build-up and the sequestering of pests and disease pathogens within the field, at least three different crop species are rotated through.

Conservation agriculture's strict focus on supporting healthy soils and reducing soil erosion separates it from the more multifaceted alternative systems discussed in this chapter. Since conservation agriculture does not prohibit the use of synthetic herbicides but does limit tillage, many practitioners of conservation agriculture terminate their cover crops with herbicides. As a result, conservation agriculture is often criticized for its association with chemical agricultural products and services. In addition, many of the farmers themselves recognize that herbicide use promotes problems like herbicide resistance and reduced soil biodiversity. However, in recent years, with conservation agriculture gaining in popularity and governmental support, new farming implements have been developed that allow practitioners to terminate cover crops and cash crops without using chemicals and without significant disturbance of the soil surface. The implements that have gained the widest use are known as roller crimpers (Figure 2.3). Some conservation agriculture farmers are also exploring methods like solarization, in which plastic tarps are used to generate

Figure 2.3 **A roller crimper**. The action of the blades knocks down a cover crop and "crimps" the plants' stems, transforming the crop into a thick, weed-suppressing mulch. Many roller crimpers are designed to be pushed in front of a tractor so that a device behind the tractor can part the flattened mat of stems, drop seeds, and cover them with soil. (Photo courtesy of Rodale Institute.)