Stephen L. Young · Francis J. Pierce
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Foreword

Since the dawn of agriculture, man has struggled with controlling species competitive to their crops. Many technologies and strange machines have been developed to kill or retard weeds that have often used lots of cheap energy. These days energy is not so cheap, and the indiscriminate distribution of off-target chemicals have caused widespread problems to economics and the environment as well as a detrimental public perception.

The main change in recent years has been the realization that it is very difficult to create the ability to distinguish between crop and weed species by embedding it in a chemical formulation, where it is lethal to the weed and benign to the crop and environment. These days we have a different approach by embedding the "smarts" into the applicator. It is much easier (but still not trivial) to recognize weeds from crops and carry out an "intelligently targeted input" of chemicals or energy only onto the weeds, thus significantly reducing the inputs by, in one case, 99.9 % by volume when using spray microdots. This can be reduced to zero chemicals when we use physical weeding.

Our aim in developing these technologies is to work out the minimum amount of energy that is needed to control weeds and, by extension, the minimum amount of energy that we introduce to the natural environment to turn it into production agriculture. We are at last glimpsing what I suggest is tertiary development where these technologies actually use the smallest amount of energy to kill a weed. The first example of this is using machine vision to identify the meristems of weeds and then steer a low-power laser to heat up the meristem until the cell walls rupture, thus forcing the weed to become dormant.

It might seem like science fiction, but the day where robots and smart machines are working 24/7 in our fields tending our crops is not that far off. This book goes a long way in describing the reality of weed control and the future of farming.

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Preface

In both conventional and organic cropping systems, there is an immediate need to apply the latest technologies to improve the efficiency and economics of management while reducing the impacts. Never before has there been such pressure on farmers globally to produce more with less and reduce inputs in cropping systems. The main purpose of this book is to provide the current state of automation for weed control in cropping systems, which demonstrate how being more precise in our applications is possible now and into the future.

By bringing together biologists and engineers working in the same field, ideas can be stimulated on ways to change current weed management for the better. After many discussions, some lengthy, between the editors back in early 2009, a group was formed and a paper was written. The former met at Washington State University's Center for Precision Agricultural Systems and was composed of engineers, biologists, industry representatives, and local growers with one goal: strategize new ways to use automation to control weeds in organic vegetable crop production systems. I wrote the paper that was published in *Weed Science* on the use of automation for weed control in organic cropping systems, which was also a call for broader participation by the weed science community.

As a group, we wrote a proposal for the USDA SCRI program. At the same time, I organized a symposium for the 2010 Weed Science Society of America annual meetings on automation and machine guidance systems for weed control in cropping systems. The speakers presented information and research on current weed management techniques, automated mechanical and chemical weed control, market readiness of robotics and automated weed control, and international advancements in automation for weed control. The interest from the audience was limited to a small but enthusiastic group of weed scientists. Obviously, more awareness and education on this topic was needed on a wider context, which is what solidified my interest in the topic of automated weed control and fuelled my passion for completing this book.

From the group that met back in 2009, the speakers at the 2010 symposium, several other respected individuals, and my colleague, Dr. Fran Pierce, we have assembled the first book focused solely on automation and weed control in cropping systems. The main themes of this book are (1) weeds in conventional and organic production systems, (2) advancements in technology and current weed control practices, (3) applications of automated weed control in cropping systems, (4) economics of organic and conventional production systems, and (5) global trends and future directions for automated weed control. The objectives are to (1) provide the first complete resource on automation and robotic weed control in conventional and organic cropping systems for the student, researcher, and grower, (2) shift the paradigm that precision technology and cropping systems cannot fit into a single, streamlined production system, and (3) stimulate thoughts and ideas for broader application of new engineering solutions to traditional agricultural-based problems, such as weed control.

The production of a book of this magnitude could have profound impacts on current and future cropping systems across the globe. To date, no other resource exists on this important and rapidly advancing topic of automated weed control. In the near future, a new approach will be needed for managing weed pests, especially with the challenges of weed resistance to herbicides; off-site movement of soil, fertilizers, and chemicals; an increasingly non-agrarian public; labor shortages; economies in recession; and the continued rural to suburban land use conversion.

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Thanks to Maryse Elliot, my publisher, for approaching me with the idea of writing the book.

Last but not least, I thank my wife for supporting me even during the many sleep-deprived days spent working after hours to complete what seemed to be at the time an insurmountable task.

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Chapter 1
Introduction: Scope of the Problem—Rising Costs and Demand for Environmental Safety for Weed Control

Stephen L. Young, Francis J. Pierce, and Pete Nowak

Abstract Many organic and conventional producers rank weed control as their number one production cost. For organic producers particularly, weed control has become increasingly important as organic production has increased its market share. In conventional systems, herbicide resistance, off-target movement, and increased regulations have left many growers with few alternatives. Added to this is an increasing demand from the public for a safer and more sustainable supply of food. This chapter addresses the problems of mechanized agricultural systems to set the stage for the introduction and adoption of more advanced technology to meet the needs of growers and satisfy the desires of consumers.

1 Timeless Weeds

> *Autonomous robotic weed control systems hold promise toward the automation of one of agriculture's few remaining unmechanized and drudging tasks, hand weed control. Robotic technology may also provide a means of reducing agriculture's current dependency on herbicides, improving its sustainability and reducing its environmental impact.*
> *Slaughter et al. (2008)*

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While biblical Adam was promised thorns and thistles as part of his punishment (Genesis 3:18), Timmons (1970) review states that few agricultural leaders or farmers became interested in weeds as a problem until about 1200 A.D. One can correctly imagine, however, that from the development of primitive forms of agriculture, weeds have presented a formidable challenge for food, feed, and fiber production. Our ancestors recognized weeds as limiters of desirable plants, sources of health problems, and degraders of aesthetics over a broad range of environments. But what are weeds? Weeds are most simply defined as "[a] plants out of place." A more poetic description was provided by Ralph Waldo Emerson who declared that "a weed is a plant whose virtues have not yet been discovered." Indeed, the ongoing search for genetic materials from plants that may prove to be beneficial confirms the need for a flexible perspective in managing those plants we call weeds.

2 The Number One Pest Problem

In both early and modern agriculture, weeds clearly rank as the primary pest problem. Today, weeds plague even the most advanced and progressive farming operations regardless of their management approach, whether organic, conventional, or sustainable. Holm and Johnson (2009) state that "throughout the history of agriculture, more time, energy and money have been devoted to weed control than to any other agricultural activity." In the USA, the vast majority of crop acres are treated with herbicides (Gianessi and Reigner 2007) accounting for about two-thirds of the pesticide expenditures for US farmers in the late 1990s (Donaldson et al. 2002). Today, the development of herbicide-resistant weeds is the major concern for farmers relying on chemical weed control, while in organic production systems, the cost and effectiveness of hand removal of weeds is a concern due to expenses, labor availability, and, in large-scale systems, the social acceptability of employing large numbers of migrant labor. Farmers are increasingly facing environment and economic consequences of emerging weed management challenges, restrictions on the availability and effectiveness of chemicals, changing government policies, and dynamic markets that can reward or punish depending on how weeds are managed.

There is no immunity to weeds and the problems they cause, whether for a large farmer or a typical home gardener. Without continued and focused management and control efforts, a low or an apparent nonexistent weed population can very quickly get out of hand with direct (e.g., lower yields) and lasting (e.g., soil weed seed bank) effects. Because weed impacts are significant and have been passed on through countless generations, there is a continually evolving array of the types and numbers of different approaches for controlling weeds. In commercial cropping systems these options are vast and include the categories of mechanical, chemical, biological, and cultural control.

3 Management: Then and Now

Prior to the development of herbicides, weeds were largely a management challenge that was addressed with planning and the use of high amounts of disturbance. Crop rotation was important, and whatever new ground was available was used once the "old" location had become too infested with weeds. The movement between and to new land parcels was, in itself, a type of rotation, although not what is typically practiced today.

Early day cropping systems relied on routine disturbances to reduce weed pressure. The use of cultivation was important for disrupting weed growth and could be applied in the simplest of forms. Unfortunately, early day cultivation could not be applied selectively, except in rows, and bare soil, which resulted in high amounts of erosion, was common in many fields. In the Midwest, the Dust Bowl of the early 1900s was caused by excessive tillage, as the prairie sod grasses were eliminated in favor of annual cropping systems. When Lowdermilk (1939) wrote his report on the demise of ancient civilizations due to excessive erosion, the cultivation of weeds in irrigated cropping systems was identified as a likely culprit. As noted earlier, weeds are timeless, and as we have to relearn again and again, the various forms of disturbance used to manage weeds may have significant consequences that ripple across both time and space.

With the invention of 2,4-D in the 1940s, weed control changed dramatically. The agricultural chemical revolution (i.e., the substitution of inorganic fertilizers and manufactured chemicals to replace manure, humus, and various forms of pest control) following WWII gave growers the ability to selectively manage weeds in cropping systems with chemicals designed to kill on contact or through movement within the plant. Later, new herbicides were developed that provided total, selective, or partial control of weeds, which gave growers great flexibility in managing weeds in their crops. These innovations also brought about an important change in the indigenous knowledge associated with weed management. Prior to the introduction of these chemicals, growers had to accrue a system of knowledge on multiple dimensions of weed control: what to do, when and how to do it, and what observations are needed to guide decisions. The increased ease associated with dependence on chemical control also meant less knowledge was required for managing cropping systems. Knowledge of weed ecology became less important, and a grower could focus on other important management aspects, including fertility, marketing, or crop selection.

Currently, the most relied upon techniques for controlling weeds in conventional cropping systems are the use of cultivation and herbicides. The invention of herbicide-resistant (HR) crops has allowed for a quick application of a single herbicide sprayed over the entire field to control weeds without harming the crop. The simplicity of this system has actually led to the emergence of HR weeds. The use of a single herbicide that is applied repeatedly in one season at high rates on mature weeds is a recipe for resistance, which occurs when an individual plant or population responds to intense selection pressure. In addition, growing the same crop each year and using the same weed management program only exacerbates the problem. Add these 'incorrect' management strategies together across large acreages and only time is needed for HR weeds to start appearing in grower fields, which they now have. Today HR weeds are a very significant problem, one that keeps increasing in size and scope, as we continue to fail in understanding that any new technology is a double-edged sword—there are many benefits, but mismanagement can lead to major problems.

In organic and some conventional cropping systems, the use of cultivation remains a heavily relied upon management tool for controlling weeds. The ability to systematically move through a field and physically disturb weeds has been one of the most relied upon control tools for centuries because there is no guess work and virtually all of the risk is eliminated. Large-scale operations use this tool because equipment manufacturers have created a wide range of implements appropriate for these operations. While the same range of equipment may not be available to small-scale growers, they have a greater capacity to respond to smaller or sudden changes than larger growers because they have an intimate relationship with their crops and fields. This type of knowledge or familiarity with the dynamics of weed ecology is extremely difficult at large scales, and since HR weeds are an increasing problem, scientists are looking to other forms of innovation to address this situation. One of the promising developments is automated and targeted weed control, a theme that is addressed in the remainder of this book.

4 Costs, Costs, Costs

All forms of modern-day weed control have costs associated with them. Some accrue to the grower, others to workers who may be exposed to chemicals, and still others to environment and society on the whole. Yet the lack of weed control diminishes yields and profits, thus resulting in an ongoing balance by growers to limit risk by falling somewhere between an 'insurance level' and minimal level of control that will minimize the impact of weeds. In conventional systems, the exposure to chemicals by those who have to make the applications is a safety risk that is costly in terms of health and finances. Although some cases are suspect, there are links between health problems and the application of pesticides in crop production systems. In addition, the locations where chemicals are manufactured are "no shining stars" of environmental excellence either, but the same could be said for fertilizer manufacturers and their various distribution points.

Not only are applicators and manufacturers vulnerable to the ramifications of handling toxic chemicals, but the environment itself suffers from any level of chemical application. Weeds suffer, which is desirable from a production standpoint, but it is debatable, often on a site-specific basis, as to whether yield benefits justify potential harm to humans and surrounding ecosystems. Non-HR crops suffer from misapplications and even HR crops have been debated as to whether they are completely suitable for the environment. Off-target movement (e.g., drift, runoff) of chemicals has numerous effects on animals, insects, birds, and fish,

Fig. 1.1 Organic onion field in eastern WA, USA with a hand-weeding crew. Every other pair of onion rows has already been hand weeded and cultivated (Photos courtesy of Rick Boydston, USDA-ARS)

although all chemicals face rigorous testing mandated by EPA (in the USA) prior to commercial sales. Nevertheless, this testing does not prevent an off-label application made by mistake or in the wrong circumstance. The debate surrounding the accounting for benefits and costs is not new and has been with us with the emergence of each new form of weed management. While Rachel Carlson may have been a lone voice when she issued the warning associated with the use of chemicals in her book Silent Spring, today there are hundreds of books and reports on how we have allowed HR weeds to become a major agricultural issue (Beckie 2006; Beckie et al. 2006; Beckie and Tardif 2012; Bhowmik 2010).

In organic systems, similar costs to the environment can occur if an over-reliance on cultivation is used. The continued disturbance of the soil leads to excessive erosion by means of both wind and water. Since weed control can be more difficult in these systems, it could be argued that excessive weeds that are left uncontrolled are also polluting the environment. Probably, this is one of the main reasons why there are so few large-scale commercial organic farm operations. For those companies that are successfully producing organic crops, one of their biggest inputs is manual labor, a significant economic cost to the grower, and one that challenges the notion of a sustainable system due to these social dynamics (Fig. 1.1).

The costs for weed control, other than to the environment and applicator, can range from minimal to financially devastating. In many countries, manual labor is used to control weeds because it is cheap and plentiful. Most often, in these situations, other challenges exist that relate to growing, processing, or delivery of crops to market. In locations where labor is not widely available, costs are reduced by using chemical weed control because it is relatively cheap and easy to use.

Increasingly, the environmental costs of weed control are being evaluated, not just by scientists but by the public, along with the financial costs that can escalate for companies and growers trying to expand their market in the organic area.

Whether mechanical, chemical, cultural, or biological, the goal of weed management should be to reduce or eliminate weeds and limit disturbance as much as possible because weeds most often thrive in disturbed systems.

5 The Need for Change

Crop production is most often conducted on a field scale, and in most cases, inputs are applied at rates averaged for an entire field using equipment that spans multiple crop rows. The needs of individual plants, including weeds, can change dramatically over very short distances. There are obvious requirements of plants, such as nutrients and water, and more subtle requirements, such as light, air, and microbial interactions. In most conditions, plants must compete for resources, which end up diminishing their overall growth and development.

We also know that the strategies that growers use to manage weeds vary between growers, and between and within fields (Riemens et al. 2010). This means standardized or uniform approaches to weed management using emerging technologies are likely to fail in the same way that indiscriminate use of innovative HR products has led to HR weeds. Managing variation in biological systems has to be balanced with managing variation in the social systems or the differences between growers. This may mean targeted communication efforts that address key misperceptions while highlighting the benefits of weed management strategies based on an understanding of the grower situation (Wilson et al. 2009). Increasing the adoption of a dynamic and appropriate management strategy has to be the objective associated with the emergence of new technologies (Hammond et al. 2006).

The potential for new management strategies, a theme of this book, can be found by beginning with an understanding of a commonality of all current weed management strategies. Weeds in production systems often occur in patches of various sizes or as individuals growing among crop plants, yet they are managed in a way that is similar to the crop, large-scale and uniform. A combination of control methods, such as chemical, mechanical, and cultural, is used at different times of the season or over several seasons in most cropping systems, but rarely are single weed plants targeted. Weeds, like crop plants, are not managed at the individual plant scale.

The development of machine-guided technologies for precision weed control has advanced rapidly in recent decades. Technological advancements specific to weed control have been made in many areas, including mechanical, chemical, thermal, and electrical. The first published report of selective spot herbicide application technology was by Lee et al. (1999), who developed a prototype system with microcontroller actuated-specific solenoid valves, delivering liquid to the spray ports, based on the machine vision-generated weed map and robot odometry. Several other weed control tools have been investigated for use in combination with robotic systems, including flame weeding, hot water, organic oils, and high-voltage electrical discharge.

With rapid advances in sensors and guidance technology, potentials for weed control are changing dramatically. By using technologically equipped machinery that can target individual weeds in real time, there is no limit to the number of control tools for use in the field at any one time. The advances in the biological systems engineering field are evidence that "given enough time, an engineer [really] can build anything." Biological research and the latest technological developments in weed control have the potential to radically change the current research approach to weed control and help significantly reduce environmental impacts (e.g., drift, off-target movement) and the high cost of inputs and labor. The potential for developing these precision weed management techniques is real, but challenges remain to do so in a cost-effective manner. Other questions related to scale neutrality or making these innovations available for both small and large operations remain to be addressed.

If it were possible to control weeds without disturbance, the environment would be better off, and growers would have more time to focus on the things that the invention of herbicides allowed for over 50 years ago. It is safe to say that if we could manage weeds without inputting toxins, causing erosion, and changing genetics, we would. Unfortunately, the population of the world continues to increase, yet the amount of arable land available for producing crops will not. Therefore, we need to get more precise in managing crop production and at the same time take steps to protect and limit damage to the ecosystems that ultimately support every single livelihood in every single culture that occupies every single part of the globe.

6 A New Resource

The remainder of this book has been written for the biologist and engineer; the expertise of both is needed to address the current challenges of protecting ecosystems and producing more food for future generations. The discrete and targeted control of weeds in cropping systems using advanced technology is a first step in addressing these challenges.

The six sections of the book include an introduction to the scope of the problem (this chapter) and organic and conventional cropping systems (Chap. 2) (first section). In the second section, a report on the latest advancements in the field of engineering (Chap. 3), a detailed description of weeds and their biology in cropping systems (Chap. 4), and a description of how engineering and weed biology have been combined and the field of biological engineering has advanced (Chap. 5) make up one of the most important sections of the book. In section three, three areas of automated weed control are the focus, including precision planting (Chap. 6), mechanical removal (Chap. 7), and chemical applications (Chap. 8). The fourth section expands the reader's view with examples from the Western Hemisphere (Chap. 9), Western Europe (Chap. 10), and Asia (Chap. 11), of the latest technology that is being used or under development. In the fifth section, the economics of automated weed control (Chap. 12), an industry perspective (Chap. 13), and the potential for automated weed control in underdeveloped countries (Chap. 14) are discussed at length. Finally, the last section (Chap. 15) provides prospects for the future of automation and weed control in precision agriculture.

No other book cuts across two different disciplines with detail and thoroughness to inform readers on the current and provide insight into the future state of weed control. In addition, this book helps to inspire and bring together the next generation of biologists and engineers who are working in the areas of weeds and crop production systems.

References

Beckie H (2006) Herbicide-resistant weeds: management tactics and practices. Weed Technol 20:793–814

Beckie H, Tardif F (2012) Herbicide cross resistance in weeds. Crop Prot 35:15–28

Beckie H, Gill G, Singh H, Batish D, Kohli R (2006) Strategies for managing herbicide-resistant weeds. In: Handbook of sustainable weed management. Food Products Press, New York, pp 581–625

Bhowmik PC (2010) Current status of herbicide resistant weeds around the Globe. J Crop Weed 6:33–43

Donaldson D, Kiely T, Grube A (2002) Pesticides industry sales and usage, 1998 and 1999 market estimates. U.S. Environmental Protection Agency, Office of Prevention, Pesticides, and Toxic Substances, Office of Pesticide Programs, Washington, DC

Gianessi LP, Reigner NP (2007) The value of herbicides in U.S. crop production. Weed Technol 21:559–566

Hammond C, Luschi E, Boerboom C, Nowak P (2006) Adoption of integrated pest management tactics by Wisconsin farmers. Weed Technol 20:756–767

Holm FA, Johnson EN (2009) The history of herbicide use for weed management on the prairies. Prairie Soils Crops 2:1–10, http://www.prairiesoilsandcrops.ca

Lee WS, Slaughter DC, Giles DK (1999) Robotic weed control system for tomatoes. Precis Agric 1:95–113

Lowdermilk WC (1939) Conquest of the land through seven thousand years. U.S. Department of Agriculture's Soil Conservation Service, February 1948 S.C.S. MP-32. First published as USDA Bulletin No. 99. U.S. Department of Agriculture Natural Resources Conservation Service, 1939

Riemens MM, Groeneveld RM, Kropff MJ, Lotz LA, Renes RJ, Sukkel W, van der Weide RY (2010) Linking farmer weed management behavior with weed pressure: more than just technology. Weed Sci 58:490–496

Slaughter DC, Giles DK, Downy D (2008) Autonomous robotic weed control systems: a review. Comp Electron Agric 61:63–78

Timmons FL (1970) A history of weed control in the United States and Canada. Weed Sci 18:294–307

Wilson RS, Hooker N, Tucker M, LeJeune J, Doohan D (2009) Targeting the farmer decision-making process: a pathway to increased adoption of integrated weed management. Crop Prot 28:756–764

Section I
Agricultural Production Systems

Chapter 2
Current State of Weed Management in Organic and Conventional Cropping Systems

Alec F. McErlich and Rick A. Boydston

Abstract Crop losses due to weeds result in reduced yields and quality and increases in harvest costs. Weed management often requires major resource inputs to produce a successful crop. Herbicides are central to the conventional approach to weed management, and they have allowed the grower to reduce management priority, time, effort, and cost of managing weeds. Their use has at times come at a price such as herbicide-resistant weeds, environmental damage, reduced water quality, and loss of genetic diversity. Although growers use a combination of management practices to control weeds, differences between those used in conventional agriculture compared to organic production systems often vary widely in their implementation and relative importance. Approaches to weed management within an organic system revolve around implementing a range of techniques, often consecutively over the course of the cropping rotation. For both organic and conventional growers, weed management remains a significant impediment to optimizing crop yield, improving crop quality, and reducing the costs of production.

1 Introduction

Weeds are ubiquitous to most crops. Most agricultural soils contain millions of weed seed per hectare, and if left unmanaged, weeds greatly reduce crop yields by competing with the crop for nutrients, light, and water. Unlike most other agricultural

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pests, weeds are present every year in every field and require some degree of management for optimum crop yields and profitability. Weeds comprise the first stage of plant succession following soil disturbance and removal of native vegetation. From the time man first started manipulating crop plants to grow in designated areas rather than gathering food from nature, controlling competing vegetation became a primary task. Planting crops in rows facilitated cultivation and weeding options. Row spacing was largely based on the width of the particular animal or machine that would be used to cultivate the crop.

Crop losses due to weeds vary by crop, weed species, location, and farming system (Bridges 1992; Swinton et al. 1994). Weeds can directly reduce crop yields, reduce crop quality, and increase harvest costs. Weeds not only compete for nutrients, light, and water but can also harbor pests (nematodes, insects, pathogens) of the crop reducing potential yields and quality further (Boydston et al. 2008). Weeds can also reduce the value of the harvested crop such as lowering protein levels in grain and decreasing fruit or seed size. The presence of weeds in the harvested crop may also lower the value of the crop. Jointed goat grass (*Aegilops cylindrica*) in wheat (*Triticum aestivum*) seed, puncture vine (*Tribulus terrestris*) burs and nightshade (*Solanum* sp.) berries in green peas (*Pisum sativum*), nightshade stains on beans (*Phaseolus vulgaris*), and horseweed (*Conyza canadensis*) oil distilled with peppermint (*Mentha piperita*) oil are examples of weeds contaminating and lowering the value of the harvested crop. A Canadian survey of crop losses due to weeds in 58 commodities reported average annual losses of $984 million due to weeds (Swanton et al. 1993). Lentil (*Lens culinaris*) and cranberry (*Oxycoccus* sp.) crops had the greatest percent yield loss due to weeds (25 %), whereas the major crops of corn (*Zea mays*), soybean (*Glycine max*), hay, wheat, potato (*Solanum tuberosum*), canola (*Brassica napus*), and barley (*Hordeum vulgare*) had the greatest monetary value losses.

Most fields are infested with multiple weed species which interact resulting in a combined effect on the crop. Crops vary in their ability to compete and tolerate weeds. Soybean yield was reduced more by weeds than corn yields in previous studies (Swinton et al. 1994). Onions (*Allium cepa*) lack a competitive crop canopy to shade weeds and are susceptible to nearly total crop loss due to uncontrolled weeds (Williams et al. 2007).

2 Changing Consumer Attitude Toward Food

The publication of Rachel Carson's book *Silent Spring* in 1962 is seen by many as the beginning of the modern organic era in the USA. It undoubtedly created a consciousness of environmental issues and food production practices of the time. An increasing consumer awareness of production practices, pesticide residues, food safety, human health, animal welfare, and food quality is largely

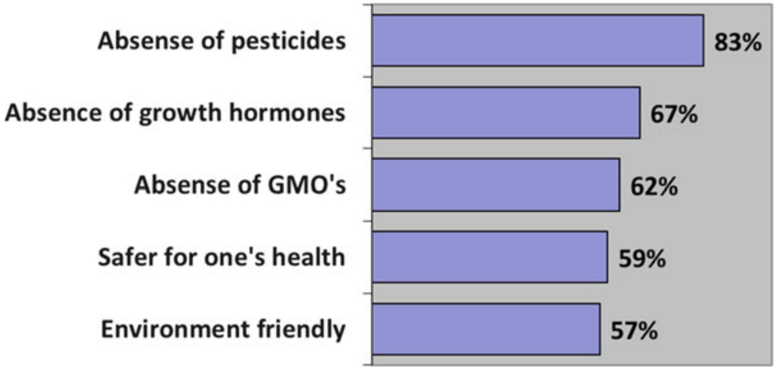

Fig. 2.1 Top five US consumer properties associated with "organic" (Abbrev. from Hartman 2007)

responsible for the increased demand for organic foods (Fig. 2.1). A recent survey of US consumers revealed that nearly two-thirds believe foods are less safe due to chemical use during production and processing (Anon 2010). An increasing number of consumers associate healthy food consumption with improved personal health and wellness. Food is seen as a first step to treating and preventing health problems (Hartman 2010).

Global consumer demand for organic foods continues to increase particularly in Western markets. The higher price of organic foods is often cited as a major reason why consumers avoid buying organic products (Stolz et al. 2011; Sadek and Oktarani 2009). This has led some consumers to seek not only organic foods, but also items labeled as locally sourced, eco-friendly, third party audited, socially responsible, and products produced within sustainable production and processing systems, a trend now termed by many as "beyond organic." Many food and supermarket companies have established production guidelines or require third-party audits of suppliers as part of standard procurement contracts. Third-party verification of production practices is often used to show consumers that a product is produced to set standards by affixing the audit organization logo to the product packaging. Independent third-party verification of production systems is an increasingly common practice within the food industry and has led to an upsurge in the number of various eco-labels worldwide. Examples from the USA are shown in Fig. 2.2. Food and agriculture companies have expanded their corporate social responsibility (CSR) reporting to include not just financial and regulatory information but also measures taken to address sustainable growth, environmental impact, equitable employment policies, and social issues (Martinez 2007).

Organic	Reduced Pesticides	Socially Responsible	Eco Friendly	Sustainable	Animal Welfare
USDA	NutriClean	Fair Trade Certified	RainForest Alliance	Food Alliance	Certified Humane
Canada Organic	Protected Harvest	ProTerra	Salmon Safe	Non GMO Project	Animal Welfare
Demeter	Certified Naturally Grown	Certified Fair Labor	Approved Dolphin Safe	LIVE	American Grassfed
BioGro			Bird Friendly		

Fig. 2.2 Examples of third party food certification labels found in US markets

3 Organic Agriculture

The organic principles involve recognition of the values diversity and natural systems bring to the relationships associated with our use of the planet's resources, crops, and animals to produce food, fiber, and materials. The International Federation of Organic Agricultural Movements (IFOAM) expresses these principles under four core headings of Health, Ecology, Care, and Fairness.

The four principles of organic agriculture as defined by IFOAM (IFOAM 2005) are

- Health—organic agriculture should sustain and enhance the health of soil, plant, human, and planet as one and indivisible.
- Ecology—organic agriculture should be based on living ecological systems and cycles, work with them, emulate them, and help sustain them.
- Fairness—organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities.
- Care—organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.

3.1 Definitions

The International Federation of Organic Agricultural Movements (IFOAM) defines organic agriculture as "a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with diverse effects. Organic agriculture combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and good quality of life for all involved."

The early history of organic movement is provided by Conford (2001) and Kristiansen and Merfield (2006). Standards defining the methods by which organic producers operated were first developed in Europe in the 1940s. By the 1970s certification using third-party agencies began to occur, replacing the internal audit systems used by the earliest standards organizations. Today public and private third-party certifiers play a key role to ensure standards are adhered to in all aspects of production through to the customer. Legal definitions and regulations in many counties ensure organic label claims are substantiated by third-party audit programs. A number of countries, including the European Union, USA, Japan, and Canada, have defined "organic" within law and only certified operations may use this term. Seventy-six countries now have some form of organic regulation in statute (Huber 2011). While standards worldwide may differ to some degree, largely in response to local needs and practices, ongoing efforts are underway to establish equivalency agreements in order to harmonize certification and facilitate international trade. As part of the 1990 Farm Bill the US Congress passed the Organic Foods Production Act (OFPA) to enable establishment of the US National Organic Standards. These standards went into effect in April 2001 and are regulated and enforced by the National Organic Program (NOP) of the Agricultural Marketing Service, US Department of Agriculture (USDA).

3.2 World Production

As consumer demand for organic products has increased, so has the land area under organic production. Increasing distribution via mainstream retailers has also driven market growth. Demand from the larger organic market countries of North America, Asia, and Europe has led to an increasing international export trade from African and Latin American countries. Demand for warmer climate crops such as coffee, and the need for counter season supply, has allowed an increasing number of producers in these countries to supply export markets. The rapid consumer demand for organic products in the USA caused periodic product shortages due to supply limitations (Dimitri and Oberholtzer 2009) and as a result led to an increased need for imported products.

The world total area under organic production (agricultural and nonagricultural [beekeeping, wild harvest, forestry, aquaculture, grazed nonagricultural land] production areas combined) reached 80 million hectares in 2010 (Willer and Kilcher 2012). The land area under organic agricultural production increased by 22 % in the 5-year period from 2005 to 2009 and had reached 37.2 million hectares in 2009 (Willer and Kilcher 2011). By 2009, the worldwide number of organic producers totaled 1.8 million, a 400,000 increase from the previous year (IFOAM 2010).