Integrated weed management for sustainable agriculture

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Weeds have received a lot of attention, but they have never been respected or understood well. The fact that many people earn a living and serve society by working to control and manage them is often greeted with amusement if not outright laughter. Even scientific colleagues who work in other esoteric disciplines find it hard to believe that another group of scientists could be concerned exclusively with what is perceived to be as mundane and ordinary as weeds.

No agricultural enterprise or part of our environment is immune to the detrimental effects of weeds. They have interfered with human endeavors for a long time. In much of the world weeds are controlled by hand or with a hoe. A person with a hoe may be as close as we can come to a universal symbol for the farmer, even though most farmers in developed countries no longer weed with, or even use, hoes. For many, the hoe and the weeding done with it, symbolize the practice of agriculture. The battle to control weeds, done by people with hoes, is the farmer’s primary task in much of the world.

Weed science is vegetation management — the employment of many techniques to manage plant populations in an area. This includes dandelions in turf, poisonous plants on rangeland, and weeds in soybeans. Weed scientists attempt to modify the environment against natural evolutionary trends.

Weed science is not a panacea for the world’s agricultural problems. The problems are too complex for any simple solution and students should be suspicious of those who propose simple solutions to complex problems. In fact, the hope should be not to solve but to diminish, not to cure but to alleviate. The work of the weed scientist is fundamental to solving problems of production agriculture in our world. Weeds have achieved respect among farmers who deal with them every year in each crop. Weeds and weed scientists have achieved respect and credibility in academia and the business community. The world’s weed scientists are and will continue to be in the forefront of efforts to feed the world’s people.

In weed science movements occur, directions change, and progress results. Some movements are called bandwagons with words and phrases that define and identify them. Each movement makes its contribution to the parade of ideas and contributes to the general cacophony of competing ideas, which, one hopes will yield a harmonious new paradigm. Some ideas assume a position at the head of the line. Integrated weed management (IWM) has assumed a position of centrality and leadership. The concept of integrated pest management (IPM), particularly in entomology, can be traced to the late 1800s when ecology was recognized as an essential foundation for scientific plant protection. If integrated IWM systems are to succeed, changes in weed management systems will be required. The direction and scope of changes will determine their success.

There is a risk that integrated weed management may only be another bandwagon, but it makes so much sense that it is likely to endure. It is not perfect but it is better than anything else we have. The evidence in this book is sufficient to demonstrate that weed management systems for crops are incomplete. They are developing, but research gaps exist. Present weed management is dependent on herbicides. Integrated weed management systems that are sustainable over time will emphasize putting components of weed control together. Even casual observation of the presently dominant capital, energy, and chemical dependent agriculture demands answers to questions about the system’s sustainability. In view of the rapid appearance of herbicide resistant weeds,
continued dependence on herbicides, and emphasis on short-term solutions, does not seem sustainable. The system that now dominates US and other industrialized, developed country agriculture emphasizes production in monocrop plant communities. Many argue that this kind of agriculture cannot achieve what all regard as a proper goal: sustainability. Weed science has been focused on control technology rather than understanding why and how weeds compete so well. Integrated weed management is widely promoted by weed scientists, but it is not widely practiced.

It is likely that successful integrated weed management systems will have to be developed within the opportunities and constraints of agricultural industrialization. Industrialization, is a process whereby agricultural production is structured under the pressure of increasing levels of capital and technology that allow management systems to integrate each step in the economic process to maximize efficiency of capital, labor, and technology. An inevitable question is whether this process is compatible with, and capable of achieving a sustainable agriculture. Some believe the answer is yes, others believe that the industrializing forces of consumer desires and demands, prescription agricultural products, molecular biology, and the changing nature of farming combine to make industrialization inevitable. Many argue that modern industrial agriculture built on and dependent on scientific knowledge is the only way to feed the 9 billion people expected by 2050 and the possible 11 billion by 2100. They argue that if the dominance of energy, chemical and capital dependent agriculture is not drastically changed, the 9 billion will not be fed, because the system is not sustainable. The result of the debate will affect weed science.

Integrated weed management should not limit its focus to weed control. To be successful, the focus must be the total vegetation complex or better, habitat management rather than weed control in a year in a crop. Perhaps it is most correct to say that industrialization should, although it may not, change the scale of concern. Sustainable integrated weed management systems should extend concern to environmental quality and future generations. These are large scale concerns. Small scale concerns such as how to control weeds in a crop in a year have dominated but future agricultural systems will require major changes. Environmental concerns demand large scale thought. Small scale thought suffices for individual concerns. Large thoughts are needed for large systems. Everything needs to be integrated to have a complete crop management system. It won’t be easy to do. It is necessary.
Introduction

Since settled agriculture began weeds have been and remain a significant obstacle to increased yields and to feeding a growing world population. Without effective weed management productive, profitable agriculture is not possible. Weed control has relied heavily on the use of herbicides which account for the majority of pesticide use in countries such as the US. However, herbicides suffer from a number of disadvantages, including environmental effects, effects on other species, residues in food and the environment. Weed scientists are aware of and dealing with these concerns as well as herbicide resistance among ever more weed species and the effects of invasive species.

These problems are being addressed by the development of integrated weed management (IWM) systems which include herbicides as part of a broader array of cultural, mechanical and biological methods of control. The chapters in this book review research on IWM directed toward developing sustainable methods of weed management. The volume summarises the latest research on the principles and methods of IWM. Chapters also assess the current challenges facing the use of herbicides, and provide a detailed review of the range of cultural, physical and biological methods of control available for IWM.

Part 1 Weeds

The focus of the first part of the volume is on the ecology of weeds. Chapter 1 addresses the relationship between weed ecology and the population dynamics of weeds, exploring the reasons for abundance of weeds and the effect of weed distribution on overall populations. The chapter examines the ‘target transitions’ approach to weed control, a technique based on targeting weeds at key life stages. It also examines the place of weeds within on-farm ecosystem communities and agroecosystems, and includes a detailed case study on efforts to mitigate the invasive potential of a bioenergy crop species.

Chapter 2 builds on the themes of Chapter 1 by focussing on weed-plant interactions. Crops or desired plant species co-occur with undesired species which are then classed as weeds. This human-imposed classification is based on the perception that there is an interaction that results in some negative effect of the weed on the crop or desired species. Chapter 2 offers an evolutionary perspective on crop-weed interactions and examines the nature of shared resource pools between desired crops and weeds. The chapter addresses the effects of direct competition between weeds and crops for resources, the indirect effects of competition and the spatial and temporal dynamics of crop-weed interaction.

Complementing the themes of Chapter 2, Chapter 3 concentrates on the nature and effects of invasive weed species. An invasive weed exhibits a tendency to spread rapidly and occupy new niches. The chapter describes ten examples of situations in which invasive weeds directly affect agriculture. The chapter also examines the indirect effects of invasive weeds, and discusses how climate change and globalization interact to promote invasions. The chapter explores the potential contribution of IWM to managing and controlling weed invasions, describing the invasion process and its economic effects on agricultural commodities.
Part 2 IWM principles

The focus of the second part of the volume is on IWM principles, including surveillance, risk assessment and planning an IWM programme. The focus of Chapter 4 is on key issues and challenges in the field of IWM. In order to intensify agricultural productivity while at the same time enhancing ecosystem services, it is necessary to evaluate carefully how current weed management technologies are deployed, including herbicides and herbicide resistant crops. Herbicide chemistries and herbicide resistant crops have provided excellent technologies that have resulted in significant changes to the way weeds can be controlled. Chapter 4 highlights several key components that must form the basis for an effective IWM strategy, including tillage, the importance of understanding weed emergence relative to the crop, critical periods for weed control, crop morphology, row width, nutrient management and crop rotation.

Chapter 5 complements Chapter 4 by discussing ethical issues in integrated weed management. Without an appropriate ethical framework, research runs the risk of pursuing too narrow a focus and thus the wrong goals. As the chapter points out, agriculturalists must see agriculture in its many forms — productive, scientific, environmental, economic, social, political, and moral. It is not sufficient to justify all management activities on the basis of increased production. Other criteria, many with a clear moral foundation, should be included.

Chapter 6 develops the themes of Chapter 5 by examining surveillance and monitoring of weed populations. To implement IWM more effectively, it is necessary to determine the temporal and spatial distribution of weed populations in a field. Weed species tend to be patchy and this influences the ability to calculate average weed densities when conducting a survey. The chapter reviews current and evolving practices for scouting and mapping weed populations both during and across growing seasons. It considers the use of scouts on the ground, UAVs with cameras flying over the fields, and advanced software and computer-based tools to detect, identify, and record weed species. The chapter also discusses the use of regional and global scales to understand changes in the occurrence of herbicide-resistant or invasive weed populations, and includes case studies on how research has been used to improve practice.

Part 3 Using herbicides in IWM

The theme of the third part of the volume is on the role of herbicides in IWM. The focus of Chapter 7 is the challenge of site-specific weed management. Weeds vary in species and density across fields, but uniform management is typical. Chapter 7 reviews the definition and underpinnings of site-specific weed management, and discusses how information about weed spatial and temporal variability can be used to determine if weed management strategies should be varied by location. Building on Chapter 6, the chapter considers how data about weed distribution can be collected using satellites, aerial platforms, and unmanned aerial vehicles (UAVs), and then verified by scouting. The chapter reviews the advantages of site-specific weed management, as well as the major factors which stand in the way of its adoption.

Chapter 8 complements the themes of the preceding chapter by concentrating on the assessment of herbicides and minimisation of their environmental effects. Herbicides
are widely used to control weeds but they can have other effects on the environment. Herbicides can move from the site of application through spray drift, volatilization from surfaces, surface runoff or leaching to groundwater. Whether and how far a herbicide will move depends on the physical and chemical properties of the herbicide, the style of application, environmental conditions at the time of and after application, site topography, how tightly the herbicide is bound to soil components, and how quickly the herbicide is degraded. Environmental effects of herbicides include damage to sensitive plants in the environment, damage to aquatic organisms and alterations in microbial populations. Chapter 8 examines the sources and fate of herbicides in the environment, the different types of environmental effects herbicides may have, and the challenge of managing the environmental effects of herbicides.

Chapter 9 switches the focus from herbicides themselves to address trends in the development of herbicide-resistant weeds. Since the mid-1940s, herbicides have been the most cost effective and efficient method of weed control for agronomic crops. Today, herbicide-resistant weeds, in combination with a decline in industry discovery programs and a cessation in discovery of new herbicide sites of action, threaten the continued utility of herbicides. Weeds have evolved resistance to 160 different herbicide active ingredients (23 of the 26 known herbicide sites of action) in 86 crops and in 66 countries. Chapter 9 reviews the various kinds of herbicide-resistance, and then considers resistant weeds by site of action, crop, region and weed family. It considers the available strategies for managing herbicide-resistant weeds, but concludes that although herbicides are likely to remain the backbone of agronomic weed control for the next 30 years, their utility will steadily decline, and we need to begin working on new weed control technologies that will eventually replace herbicides.

Part 4 Cultural and physical methods for weed control

Chapter 10 reviews the development and use of crops resistant to herbicides such as glyphosate, glufosinate, imidazolinone (IMI) and sulfonylurea, as well as the development of multiple herbicide-resistant (HR), stacked-trait crops. Prudent use of HR crops potentially diversifies weed control by enabling use of herbicide tank mixtures, herbicide rotations, or sequential herbicide programs. Instead, as the chapter points out, the simplicity and convenience of glyphosate-based cropping systems using glyphosate-resistant (GR) crops has been over-exploited, with growers often relying on glyphosate only for weed control in GR corn, soybean, and cotton, for example. Over-reliance on HR crop technology over the past two decades, has led to rapid evolution of HR weeds because of massive selection pressure. As the chapter points out, HR crop technology alone cannot provide total weed control. HR crops must be integrated with other weed control tactics. It is best regarded as supplementary to other weed control methods that increase the diversity of weed control tactics. This highlights the need for IWM, a holistic approach that integrates different methods of weed control to manage weeds and maintain crop yields. Integration of HR crop technology with cultural, mechanical, chemical and biological tactics is critical in the management of herbicide resistance.

Chapter 11 develops the theme of non-herbicide-based weed control by examining cultural techniques for managing weeds. Widespread problems with herbicide-resistant
weeds, environmental contamination by herbicides, and soil degradation due to excessive cultivation have led to an increasing need for a wide array of cultural techniques to reduce weed population densities, biomass production, and competition against crops. Chapter 11 reviews cultural techniques whose efficacy has been demonstrated in particular farming systems. These include increasing crop population density; increasing crop spatial uniformity; altering planting date; transplanting; the choice of highly competitive and allelopathic cultivars; mulching; and soil fertility and moisture management. The chapter shows how, when used in particular combinations, the cumulative effects of cultural tactics may be substantial and can lessen the burden of crop protection placed on chemical and mechanical controls.

Chapter 12 addresses another non-herbicide based method of weed control, the use of crop rotations and cover crops to manage weeds. Crop rotation has been known for many years as an effective strategy for controlling weeds because it has a disruptive effect on weed populations. Cover crops are important additions to cash crop rotations because they suppress weeds during rotational periods when crops are absent and provide ecosystem services that enhance soil quality and fertility. The chapter describes current research on crop phenological diversity and management disturbance diversity, before suggesting new analytical frameworks for assessing the multifunctional properties and discussing the overall sustainability of cover crops and crop rotations.

Chapter 13 moves the focus from the efficacy of crop rotations against weeds to developments in physical weed control, examining the effects of tillage on weed populations and offering an overview of the methods of physical weed control. The chapter examines the tools for physical weed control and the effect of soil conditions on the effectiveness of these approaches. Addressing in particular the issue of weed-crop selectivity, the chapter examines some of the fundamental problems associated with cultivation and the challenges of weed control. It looks, for example, at how to achieve effective combinations of intra-row weeding tools such as torsion, finger and tine weeder. As the chapter shows, recent advances in GPS and camera-based guidance systems permit increasingly precise, close-to-the-row tool adjustment, even for slow-growing, direct seeded crops.

Continuing the theme of physical methods of weed control, Chapter 14 homes in on techniques of flame weeding. Flaming as a vegetation control method began in the mid-1800s. It is based on utilizing heat for plant control, and has the potential to be used effectively for at least six agronomic crops (field corn, sweet corn, popcorn, sorghum, soybean, and sunflower) when conducted properly at the most tolerant crop growth stage. There has been increasing interest in integrating flame weeding with conventional cropping systems, and in locations where herbicide use is undesirable, such as in cities, parks, and other urban areas. The chapter reviews flame weeding requirements, the mechanism by which the technique reduces weeds, and the potential uses of flame weeding. The chapter also consider its advantages and disadvantages, including its potential environmental effects.

Shifting the focus of the volume to the effect of soil on weed control, Chapter 15 examines the potential of soil solarisation as a sustainable method for weed management. Solar heating of soils involves heating moist and mulched soil (with a transparent polyethylene film) for several weeks. The advantages of the technique include its nonchemical nature and its effective use in a wide range of agricultural areas worldwide. The chapter reviews the use of solarization in sustainable weed management, covering its mode of action, its effects on weeds, soil nutrients and pesticides, and the benefits and limitations of this
strategy. The plastic mulching technology required for solarisation is also discussed, along with the significance of the technique for integrated pest management.

Chapter 16 continues the theme of non-chemical techniques of weed control by focussing on weed management in organic crop cultivation. Managing weeds in organic production systems is critical to the economic success of organic farmers, as well as long-term ecological sustainability. Problems with weeds are a major reason why organic operations fail, or never get started. The chapter provides an overview of the range of tools and tactics that can be used to contend with weeds in organic systems and describes the integration of several tools and tactics. The chapter presents several organic farmer case studies to illustrate different types of weed management plans, and looks ahead to future trends in scientific research that will help organic farmers manage weeds while conserving and building soil resources.

Part 5 Biological methods for weed control

The fifth and final part of the volume surveys the available biological techniques for weed control. Chapter 17 examines the use of allelopathy and competitive crop cultivars for weed suppression in cereal crops. Due to the rise of herbicide resistance, diverse weed management tools are required to ensure sustainable weed control. The chapter focuses on competitive cereal crops and cultural strategies for weed management, including the use of weed-suppressive cultivars, post-harvest crop residues and cover crops for managing the weed seed bank and eventual weed suppression. It also addresses factors influencing the effect of allelopathy on weeds, including soil and environmental conditions, which limit or intensify the efficacy of allelochemicals. The chapter reviews the response of some weeds to secondary metabolites released by living cereal crops and/or crop residues (selectivity). The chapter recommends future research areas, aiming to address the knowledge gap regarding the fate of these compounds in the environment and their role in important physiological processes in both plants and microbes in the soil rhizosphere. Case studies are provided on the production of benzoxazinoids in cereal crops and the use of competitive cereal cultivars as a tool in integrated weed management.

Following on from the themes of Chapter 17, Chapter 18 offers an overview of bio-herbicides. Chemical control methods for weeds are widespread, but there are many invasive species for which these are not economically feasible. In addition, there are social, economic and political drivers towards reducing the overall use of pesticides. The chapter considers bioherbicides as an alternative method of weed control. It reviews the use of products based on natural compounds derived from plants or microbes, the classical approach to microbial bioherbicide application, and the use of an inundative approach which applies an endemic pathogen applied in much greater quantity than would be found naturally. The chapter discusses the ways in which bioherbicides can be integrated into weed management programs and the institutional changes needed for biological control adoption.

Complementing Chapter 18, Chapter 19 focusses on the use of microorganisms in integrated weed management. Biological control of weeds by fungal pathogens, bacteria and viruses has been studied for more than three decades, with the aim of suppressing or reducing the weed population below an ecological or economic threshold. The chapter describes the role of biopesticides in weed control, historical accomplishments...
in biological weed control and recently registered pathogens. The chapter discusses new
discoveries currently under development, target weed control, and the role of screening
and fermentation technologies, as well as looking ahead to future developments in this
area.

Continuing the theme of microorganisms in more detail, Chapter 20 specifically explores
the use of bacteria in integrated weed management. Annual grass weeds are increasing
as a dominant weed species in the western United States, Canada and Mexico. Downy
brome, one of the most widespread, invasive annual grass weeds, negatively affects cereal
yields, reduces forage quality in grazing lands, degrades rangelands, and increases the
fire frequency of western lands. Based on case studies, the chapter reviews how naturally-
occurring bacteria can be screened to find those that suppress downy brome but do
not harm native plants and crops. The chapter describes how one such bacterial strain,
*Pseudomonas fluorescens* strain ACK55, was identified as able to reduce downy brome
root formation, root growth, and tiller initiation. The chapter discusses long-term field
trials in the western US, in which application of the bacteria resulted in almost complete
suppression of downy brome for three to five years after one application, when desirable
plants were present.

The final chapter in the volume, Chapter 21, moves discussion from microorganisms
to the use of insects in integrated weed management. Seed predation by insects is a
potentially promising approach to the regulation of weeds that could offset herbicide use
as part of integrated weed management. Using the example of carabid beetles, as the
most intensively studied grouping of insect weed seed predators, the chapter describes
the current state of knowledge in this subject area and highlights future research trends.
The chapter examines the interaction between weeds and predator communities and
assesses how fields and landscapes can be managed to enhance weed seed predation.
The chapter looks at the level of weed regulation that can realistically be expected from
this approach, and provides a detailed case study from the UK.
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