WEED SCIENCE AND MANAGEMENT

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Contents

Summary

The field of weed science is a relative newcomer to the agricultural arena. However, the innovations and developments that have stemmed from the research in this area have had a major impact on agricultural practices and productivity. With the introduction of the first selective herbicide onto the market, researchers ensured the continuation of the newly recognized science by demonstrating how significant herbicides could be in increasing producers' yields. Today, although chemical weed control plays a major role in weed management and remains a key element of weed science, research interests have become as diversified as any subset of sciences.

The goals of weed science remain the same, to identify and establish effective weed management strategies in order to reduce detrimental effects to agricultural crops; however, these practices now include a greater focus on sustainable agricultural and environmental conservation. Management strategies include an array of cultural practices and ideas that not only work to suppress weed populations but also help to preserve the environment.

Challenges, like herbicide resistance, force the researchers in this field to remain on the cutting edge of technology and lead to even greater developments associated with weed science. As with any science, the dynamic nature of weed science will continue to present future researchers with challenges that require innovative solutions that may once again revolutionize agriculture as it first did with the introduction of herbicides not so long ago.

1. Introduction to Weed Science and Management

1.1. What is a Weed?

Traditionally, a weed is defined as any plant growing where it is not wanted. This definition can apply to crops, native plants as well as non-native species. If it is considered to be a nuisance where it is growing, it can be termed a weed. However, weeds are not just unwanted species; they can have substantial negative impacts when they are present. Weeds can effectively compete with crop species, can lower yields, increase labor requirements and, ultimately, increase food costs for the consumer (Klingman and Ashton, 1975).

Competitive ability by weeds is determined by several plant characteristics. One of the most common traits of a weed species is its tendency to be an annual or biennial rather than a perennial; this allows the species a faster reproduction rate leading to a higher fecundity (Sutherland, 2004). Other characteristics that determine the "weediness" of a species is the ability to colonize under high sunlight and low soil moisture conditions. Plants that have capabilities of dealing with herbivory as well as plants that have allelopathic traits also tend to be better at out-competing surrounding plant species.

Some non-native species of plants are considered to be very weedy in nature. It is reported that some non-native plants can grow faster and bigger, increase reproduction rates, and can have increased survival rates when outside of their native habitat. This may be due, in part, to the loss of environmental checks that keep these plants in balance within their natural habitat. Genetic make-up also determines the ability of a plant to become weedy in nature; however, a genetic pattern has yet to be described (Ward *et al.*, 2008).

1.2. History of Weed Science

The science of weed control as we know it today is still in its infancy when compared to the other agricultural sciences. In fact, weed control received little attention or research efforts until the late 1800's and early 1900's even though man has been plagued by unwanted plants among cultivated fields since Biblical times. For centuries weed control has been accomplished as a byproduct of seedbed preparation. Even the modern hoe, which is synonymous with weed control, was specifically designed by Jethro Tull to break up the soil to make nutrients more readily available to the crop's roots (Timmons, 2005).

Other early methods of weed control include labor intensive hand hoeing and hand pulling of weeds as well as cultural practices, such as crop rotation. Although hoe-hands are rare in developed countries, hand removal of weeds remains the dominant form of weed control in many undeveloped nations. Rotation practices were largely replaced by monoculture systems and chemical weed control by the 1940's (Appleby, 2005); however, crop rotation has become an integral part of weed management in organic farming as well as integrated weed management practices in conventional farming systems. Until recently, research to understand weed populations and attempts to control weeds within a crop went largely untried and control of the weed was left in the hands of fate and some very tired farm workers.

Chemical weed control was first mentioned when describing the effects of mainly inorganic substances and their ability to offer some form of selective weed control. Some of the chemicals with herbicidal activity prior to the 1940's were salt, iron sulfate, sulfuric acid, and copper sulfate (Klingman and Ashton, 1975). Many of these compounds were used extensively in Germany, France, and the United States within specific areas, but until the 1940's, herbicides were not widely used as a form of weed control.

Weed science received a major boost as a valid scientific discipline with the synthesis of 2,4-D by R. Pokorny in 1941 and its subsequent commercial acceptance as an effective herbicide. Until this point, research was limited in funding as well as in interest by the scientific community; those who did dare tackle questions about weed control did so neither with the chance of recognition nor with insight from previous research. When 2,4-D appeared on the market, it offered users a cheaper option of weed control that could be applied at relatively low rates and in many agricultural settings (Ross and Lembi, 1999). The characteristics of 2,4-D offered hope that chemical weed control could revolutionize global food production, in turn, drawing a great deal of attention to weed control research.

The 1940's and 1950's saw an explosion of synthesized herbicides. By 1950, there were roughly 25 herbicides available for use (Timmons, 2005). By the late 1950's and

1960's, enough effective herbicides appeared on the market to ensure that chemical weed control was a viable replacement for hard labor mechanical weed removal. In the same manner, weed science was guaranteed a spot among respected subsets of agricultural sciences. In more recent years, weed scientists have been challenged to meet herbicide regulations to secure a safe environment for future generations. The researchers have responded with overwhelming success in the form of herbicides with low use rates, low environmental residual, and little to no non-target effects (Zimdahl, 1999). Glyphosate is an example of this technology; it was introduced during the 1970's and offered excellent weed control at these lower use rates (Ross and Lembi, 1999), and with little harm to the environment as indicated in the ranking of the World Health Organization (see also: *Land Use Management*).

In the 1980's and 1990's, herbicide introductions included new compounds at even lower rates than before, allowing for the total weight of chemicals being used to decrease even though herbicide use was on the rise. Weed science also saw the adoption of herbicide resistant crops in the 1990's. Although this technology offers an extraordinary opportunity to increase crop yield throughout the world, it has been met with scrutiny that today's weed scientists must research and overcome.

As weed science develops into a more mature science, it is assured a place among the most important areas of agriculture. However, this is the only constant within the field. Weed scientists will be faced with an ever changing landscape of problems to undertake. Today's weed researchers must be willing to explore the complex issues like herbicide resistance among weed species, effective herbicide use within conservation systems, organic herbicide use, implementation of integrated weed management and a score of other important issues within weed science. Not only must they be ready to face these issues, they must also remember that goals are of a global nature. In order to meet ever increasing food demands, weed scientists will not only have to keep an eye to the future, but also to the past since many nations still labor under these conditions.

1.3. History of Weed Management

As more and more researchers begin to explore the realm of weed science, new ideas and technologies have emerged that have drastically altered the approach to weed management. In early agricultural production, little weed control existed except through tillage and/or hand-hoeing. Agricultural mechanization efforts largely ignored weed control implements until 1914 when the rodweeder was introduced primarily for weed control (Timmons, 2005). During this time, one farmer could provide food for just six other people. As technologies improved, including weed management tactics, the number of people a single farmer could feed would see a sharp increase.

Until the 1940's, chemical weed control was practiced mainly in agricultural and non-crop situations in Europe. Some of these inorganic compounds, including: salt, sodium arsenate, carbon bi-sulfide, and petroleum oils, offered weed control but not at highly effective rates. This less than superior control, coupled with the large acreage available at the time in the United States, limited the American farmer's adoption of the slightly yield-increasing inorganic herbicides (Zimdahl, 1999). By the 1940's, however, much of the United States frontier had been settled and the population was ever increasing.

These factors made the timing of Pokorny's synthesis of 2,4-D in 1941 a major herbicide discovery rather than a passing novelty among heretofore uninterested farmers. The commercialization of the compound in 1945, which was relatively inexpensive, could be applied at low rates, had a broad area of uses, and was relatively well received by farmers, spawned an influx of interested developers into the herbicide arena.

By the 1960's, over 120 herbicides were available for weed management. At this time, however, public concern over health and safety issues with herbicides and herbicide residues led to growing pressure on chemical companies to develop herbicides with increased efficacy at lower rates, less residual, and less toxicological effects on non-target species. In 1974, when Monsanto introduced glyphosate to the market, the type of herbicide desired by government agencies and portions of the public had been achieved. Because of its non-selective nature, glyphosate was used mainly in non-crop situations or prior to crop planting in conservation tillage practices.

By the mid 1990's, weed control would once again receive a boost on par with that of the 2,4-D discovery when glyphosate-resistant soybeans were introduced in 1996 (Green *et al.,* 2008). This technology allowed for the use of a non-selective herbicide within a row crop setting without injury to the resistant crop. Introduction of other resistant crops on a large scale, as well as the sole dependence of some farmers on this herbicide, has inevitably produced glyphosate resistant weed biotypes.

This development has required the swift adaptation of weed management research and protocol. Most recently, chemical companies have worked to design an herbicide resistant crop that contains resistance to multiple non-selective herbicides. This feat would allow farmers greater flexibility in herbicide choice, reduce dependency on a single herbicide, and reduce selection pressure toward glyphosate-resistant weed species.

At a time when farmers face the potential loss of certain herbicides due to resistant issues, adoption of alternative weed control tactics has been touted by weed researchers as a means to control weed communities as well as to prolong the field life of certain herbicides. These alternative measures can include: biological agents, mulches, use of allelopathy, cover crops, crop rotation, and soil fertility manipulation. The combination of these weed control tools along with conventional chemical control might provide effective weed management while preserving important herbicide formulations for future generations.

Much advancement has been achieved in weed control since research began in earnest. These achievements have not come without complications and defeat, however, advancements have still been made and improved weed control methods have allowed farmers to witness dramatic increases in yield.

As the world's population continues to increase and agricultural land diminishes, it is imperative that the research in weed management progress with the changing agricultural needs to guarantee adequate food for ourselves and posterity.

2. Weed Biology

2.1. Characteristics of Weedy Plants

Many definitions have been proposed in an attempt to categorize weed species separately from other plant species. In general, weeds are just plants growing in unwanted areas that can often cause a negative impact on surrounding vegetation and/or the users of the land. Research into successful weeds has revealed a great distinction between weedy and non-weedy species. In most instances, weedy plants possess certain characteristics or properties that allow them to thrive and multiply in many different locations (Table 1).

A characteristic most often noted by all who study weeds is an ability of weed species to succeed in disturbed areas (Baker, 1974). These areas, which make desirable weed habitats, must also be used to sustain human food production and livelihoods. This age old battle between man and weeds is the crux of why we seek to understand the traits that give a weed a foothold in our lives.

Weeds, like all plants, require sunlight, nutrients, and water for life. In agricultural systems, desirable crops face competition by these weedy species for a limited quantity of these resources. In undisturbed systems, native weeds could not usually outcompete the whole of the natural vegetation; however, in cropping systems, disturbance and replacement of natural vegetation with predominantly one species allows a weed a chance to employ its “weedy” traits.

- Germination requirements fulfilled in many environments.
- Discontinuous germination (internally controlled) and great longevity of seed.
- Rapid growth through vegetative phase to flowering.
- Continuous seed production for as long as growing conditions permit.
- Self-compatible but not completely autogamous or apomictic.
- When cross-pollinated, unspecialized visitors or wind utilized.
- Very high seed output in favorable environmental circumstances.
- Produces some seed in wide range of environmental conditions; tolerant and plastic.
- Have adaptations for short- and long-distance dispersal.
- If a perennial, has vigorous vegetative reproduction or regeneration from fragments.
- If a perennial, has brittleness, so not easily drawn from ground.
- Has ability to compete inter-specifically by special means (rosette, choking growth, allelochemicals).

Table 1. General Characteristics of Weedy Species (adapted from Baker, 1974).

In contrast to many row crops, weeds are capable of rapid development from the seedling stage to the flowering stage. Not only do weeds produce seeds in a relatively short period of time, they can also produce large quantities of seeds within this brief period of time. In addition to seed production, weedy species are often capable of vegetative reproduction which allows continuation of the species even without seed dispersal.

Other traits that define species as successful weeds include highly effective seed dispersal mechanisms and long-lived viable seeds within the seed bank. This gives weeds the ability to infiltrate undisturbed regions and proliferate if the site becomes disrupted in the future.

Weed species not only have certain characteristics (allelopathy, e.g.) that allow them to compete other species, but they may also possess certain traits to dissuade damaging herbivory. Weeds have even adopted traits to defend themselves against the ever threatening human. Weed species have the ability to adapt, rather quickly, at a genetic level to environmental factors in order to achieve species continuation. This characteristic permits weeds to continue the battle against humankind by challenging our much relied upon herbicide arsenal.

When attempting to define what makes a weed successful, there will always be a core list of traits available; however, as time passes, we can only expect this list to expand. As our understanding about and control mechanisms of weeds grow and change, so too will the traits and abilities of weedy species develop. In this manner, both weeds and humans will continue their quest of domination over the other.

2.2. Weed Life Cycles

2.2.1. Life Cycle Stages and Life History

Control of major agronomic weed species requires an understanding of the weed's growth habits, its susceptible growth stages, and its reproductive abilities. Understanding a weed's life cycle provides the foundation of knowledge necessary to limit the impact of weeds in the agricultural arena.

The life cycle of a weed refers to the general growth, flowering, seed production, and eventual death of a plant. Categorization of all plants falls into one of three broad classes, or life histories: annual, biennial, or perennial. This classification is determined by the length of a plant's life cycle. Annual plants will germinate, grow, reproduce, and die within a year's time; biennials will take two years to complete their life cycles. The life cycle of a perennial will last three or more years.

Determining the life history of a weed establishes the weed control tactics used on a particular weed because its growth and reproduction will vary based upon its specific life cycle. Certain stages throughout the life cycle of a weed provide more advantageous times for successful control than others. Many agricultural weedy species have a propensity for being annuals; annual plants generally thrive on disturbed areas like cropping areas and have rapid vegetative, hence more competitive, growth from seed. With this in mind, understanding the strengths and weaknesses of the annual life cycle has been essential in establishing effective weed control strategies.

2.2.2. Soil Seedbank

Before a weed can germinate and grow, its seed must successfully reach and remain viable in the soil seed bank of a specific area. The soil seed bank contains seeds from previous weed generations within the region and, to a lesser extent, seeds that have been disseminated into the area. Time within the soil seed bank can present a relatively vulnerable stage in the life cycle of a weed. At this point, a seed is faced with predation and decomposition or conditions unfavorable for germination. If the seed remains viable until conditions improve, it may have a chance for germination or it may remain dormant within the seed bank for many seasons. It is at this point that farmers have historically used tillage as well as herbicides to reduce the number of weed seeds in the upper soil layer and to inhibit the growth of newly germinated seeds.

Because the soil seedbank experiences so many variables that affect the aboveground weed composition, a producer's understanding of weed seed characteristics and requirements for germination in his particular region and/or crop system remains essential in developing effective, sustainable weed control strategies. For example, a lot of species germinate quickly under conditions of light or distinct day/night temperature alternations after a period of winter cold. These seeds will germinate massively in early spring without or after a superficial tillage, but they can stay dormant one year more after a deep autumn tillage, and germinate a year later after a second deep tillage.

Other weed species may have viable weed seed remaining in the seedbank for 40 or more years after deep tillage (Ross and Lembi, 1999). Cultural practices, like tillage and crop rotation, and environmental factors, like light and cold requirements, can be manipulated or monitored in order to determine what weed species will emerge at a given time and location. Producers can use this knowledge of the seedbank to develop weed control plans for short-term as well as long-term strategies.

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Biographical Sketches

Jessica Kelton - After receiving a Bachelor's degree in Biology from Troy University, Jessica Kelton began pursuing a Master's degree in Weed Science with Auburn University's Agronomy and Soils department under the direction of Dr. Andrew Price.

Andrew Price - After receiving Bachelor's and Master's degrees in Plant and Soil Sciences from The University of Tennessee and a PhD in Crop Science from North Carolina State University, Andrew Price has worked at the USDA-Agriculture Research Service National Soil Dynamics Laboratory in Auburn, Alabama, where he has been conducting weed biology and management research in conservation agriculture systems. Dr. Price also serves as an affiliate faculty member at Auburn University. Research goals include the development of integrated farming technologies and strategies for managing weeds which increase adoption of conservation production systems that reduce economic risks and improve farm profitability; improve soil quality and productivity; reduce risks from short-term droughts; and enhance carbon storage.