LEGAL SOLUTIONS TO WICKED PROBLEMS IN AGRICULTURE: PUBLIC-PRIVATE COOPERATIVE WEED MANAGEMENT STRUCTURES AS A SUSTAINABLE APPROACH TO HERBICIDE RESISTANCE

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ABSTRACT

A weed is more than a plant in the wrong place. At best, it is an inconvenience or an unsightly blemish on a manicured landscape. At worst, it represents a threat to human existence by undermining the food supply. Efforts to mitigate the impact of weeds can have far reaching consequences—an ever-increasing herbicide treadmill tied to new genetically engineered crop varieties leading to further herbicide resistance, economic losses, and a cascading effect on environmental quality and human health. Shifting the strategy to public-private cooperative weed management structures that incorporate the principles of long-term sustainability, care of common pool resources, and community engagement can begin to unwind the wicked problem of herbicide resistance. The agricultural community solved a similar problem more than a century ago with the formation of drainage districts. Adopting a statutory scheme, modeled on existing drainage district law, for the establishment of cooperative weed management districts, could help to unravel this wicked problem of herbicide resistance.

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VI. RECOMMENDATIONS & CONCLUDING THOUGHTS 

I. INTRODUCTION

We are in the midst of what some call the biotechnology era, or the second “green” revolution.¹ There is no doubt that the development of herbicide-tolerant plant varieties has vastly simplified on-farm weed management. The herbicide glyphosate, commonly known by the trade name Roundup, is used on close to 100% of the nation’s soybean crops² and almost 85% of the corn crop.³ The prevailing weed management strategy for many farms is simply to spray copious quantities of glyphosate before, during, and sometimes after the growing season. Since 2001, glyphosate is the most widely used herbicide in the United States.⁴ But accompanying this ubiquitous use is the development of resistance to the technology.⁵ Resistance of some particularly nasty weeds with the potential to create serious economic and environmental harm is inevitable unless an alternative solution is enacted and embraced. Herbicide resistance is a wicked problem.

Wicked problems are dynamically complex, ill-structured, public problems with causes and effects that are difficult to identify and model; examples include terrorists, nuclear energy, healthcare, poverty, and crime.⁶ Moreover, these problems tend to be intractable and elusive due to the interaction of multiple social and political factors, as well as biophysical complexities.⁷ The wickedness arises not only from scientific complexity but also from multiple stakeholder perceptions of the problem and potential trade-offs associated with solutions and desirability of alternative outcomes.⁸ As a result, progress requires focused and intentional integration across multiple approaches to agricultural research and development.⁹

³ Id.
⁵ Id. at 357.
⁸ Batie, supra note 6.
⁹ Erich Jantsch, Towards Interdisciplinarity and Transdisciplinarity in Education and Innovation, in INTERDISCIPLINARITY PROBLEMS OF TEACHING AND RESEARCH IN UNIVERSITIES 97–121 (Léo Apostel et al. eds., 1972); Nicholas R. Jordan & A.S. Davis, Middle-Way Strategies for Sustainable Intensification of Agriculture, 65 BIOSCI. 513 (2015); Florin Popa et al., A Pragmatist Approach to Transdisciplinarity in
invasive plant species and the threat of herbicide resistance (“HR”). A problem such as weed herbicide resistance gives rise to a situation in which individual, on-farm practices affect common pool resources (i.e., resistance susceptibility), resulting in a trade-off between the immediate benefits of highly effective weed control through herbicide application coupled with HR crops, and the long-term efficacy of these management tools (i.e., herbicides and HR crops). Long term investments in sustainable practices can lower resistance susceptibility; however, the net benefit of these investments cannot be optimized piecemeal and require cooperation of multiple stakeholders at the landscape-scale.

The encroaching spread of Palmer amaranth (*Amaranthus palmeri*) in the United States serves as an example of this wicked problem with critical implications for economic and agricultural sustainability. Palmer amaranth is a robust, aggressive weed native to the southwest United States and northern Mexico. For years, Palmer amaranth has been creeping into other areas of the United States and has become one of the most significant invasive weed problems for cotton and soybean producers in the southeast. Recently Palmer amaranth has been found heading north throughout the United States and has been confirmed in Illinois, Indiana, Ohio, Michigan, and as far north as Pennsylvania. There are several characteristics that make Palmer amaranth different from other common weeds: it adapts and spreads quickly to new locations, it produces a large amount of seeds, it competes aggressively and grows two to three inches per day, and most importantly, it has evolved resistance to multiple herbicides, including glyphosate. Once an invasion has begun, farmers must timely spray foliar-applied herbicides before the plant is taller than four inches, which can occur less than ten days after emergence. If the emer-
gence is not detected in time, yield losses of 78% (soybean) and 91% (corn) can be attributed to Palmer amaranth.\(^\text{17}\)

Palmer amaranth expansion presents an immediate threat that requires proactive attention, yet farmers tend to rely on reactive and inadequate management techniques.\(^\text{18}\) Rather, a coordinated weed management scheme is needed for successful invasive management of these weeds. While the science is clear, the social dilemma of how to facilitate cooperative work between neighboring farmers within a geographic region is a significant and persistent hurdle to cooperative weed management formation and long-term success.\(^\text{19}\) Moreover, prior research found that the existing legal regime generally fails to regulate invasive plants, covering on average only 19.6% of the species considered invasive by scientific authorities.\(^\text{20}\) In light of this regulatory failure, it is even more crucial that individual farmers and landowners develop alternative strategies.

This Article investigates the wicked problems of invasive plant species and herbicide resistance, as well as the flawed regulatory regime currently in place, in order to develop a legal framework that facilitates public-private cooperative weed management partnerships. Legal documents alone cannot spur participation among stakeholders unless there is broad and sustained agreement that the proposed management strategies embedded in any agreement represent the best and most economical decision for their individual land/farming operation. There are several possible legal solutions that borrow from already-established frameworks for collective action problems, with varying governmental involvement designed to promote the use of private cooperative weed management partnerships. We discuss the benefits and risks of private action and/or state regulation and suggest a hybrid model of public-private engagement, whereby the state creates supporting structures for cooperative weed management partnerships to help untangle some of the evolving wicked problems facing agricultural sustainability with respect to herbicide-resistant weeds and pesticide usage.


II. SUSTAINABILITY AND THE WICKED PROBLEM OF HERBICIDE RESISTANCE

The term “sustainability” means that humanity has a responsibility to make sure new developments satisfy the needs of the present without compromising the ability of future generations to meet their needs. Additionally, the field of sustainability science has been defined as one that seeks to understand the interactions between nature and society and encourages those interactions on a more sustainable path. Where most scientific decisions are based on objective and hard evidence with little reference to one’s personal values, sustainability decisions must be informed by values, context, and a focus on social action. A key inquiry for sustainable decision-making is to determine the trade-offs between human well-being and the natural environment. If we decide that the environment outweighs human well-being, without compromising well-being, we must show deliberate, judicious, and transparent use of informed value-based judgments for the sustainable decision to gain legitimacy. Most of the time, sustainable decision-making is about striking a balance between the promotion of human development and well-being and the protection of the Earth’s life support systems. When the outcome is largely off-balance and there is no clear answer for what decision to make, we have a wicked problem—a problem typically associated with sustainability decision-making.

The hallmark of a wicked problem is that it is both dynamic and complex; it has innumerable causes that are difficult to describe and cannot be solved with a single right answer. Even explaining what the problem is depends on who you ask because different stakeholders involved will have different views and understandings of the complexity of not only the issue, but also what constitutes an acceptable solution. Conventional problem solving fails to tackle wicked problems, and solutions that solve one facet may exacerbate the overall problem by generating undesirable consequences. Often, the only
“end” to a wicked problem is when those working to solve it run out of resources including time, money, and energy, or when a solution has been reached that is good enough merely to avert the crisis. Additionally, solutions are often judged as better or worse rather than right or wrong. The only consensus on solving a wicked problem is that a feasible solution requires trade-offs among competing values and a multidisciplinary approach that involves collaboration and resource sharing. Science’s role, which is generally used for solving well-defined problems, is to come up with multiple options for solutions while other disciplines conduct a balancing analysis of economic, environmental, and social requirements to implement the science with accompanying policy.

Wicked problems are often discussed in contrast to so-called tame problems, which are problems with one clear solvable answer, such as a math equation or the structure of an unknown compound. For tame problems, it is clear when the problem has been solved. Rittel and Webber, who coined the term wicked problems, delineated ten questions for determining when a dilemma is a wicked problem or a tame problem. The assertion is that science was developed to deal

35. Rittel & Webber, supra note 7, at 160.
36. Id.
37. Id. at 161–64. In abbreviated form, the ten framing questions are: (1) there is no definitive formulation of the problem, which requires conceptualizing all of the possible solutions in order to describe the problem; (2) no stopping rule, meaning there is no criteria to determine when the solution has been found; (3) solutions are not true or false, but good or bad, thereby transferring judgment of the solution to the various stakeholders; (4) there is no way to test the solution and thus any solution will generate waves of consequences that may impose additional problems that outweigh the intended advantages of the solution; (5) there is only one attempt with each solution because there is little opportunity to learn by trial-and-error; (6) there is no way to know when or if all solutions have been identified or considered—additionally, there may be no solution; (7) each wicked problem is unique and possesses a distinguishing property of overriding importance, despite similarities with current and previous problems; (8) every wicked problem is a symptom of another problem and because of the cyclical natural, any resolution poses another problem of which the original problem was a symptom; (9) the causes of a wicked problem can be explained in numerous ways and the choice of the explanation determines the nature of the solution; and (10) the planner/problem solver has no right to be wrong, meaning unlike bench science in which a researcher is allowed to make a hypothesis that is later refuted, those proposing solutions to wicked problems are liable for the consequences of the actions they generate. See id.; see also Curran, supra note 28.
with tame problems, but wicked problems require more interdisciplinary participation.\footnote{Rittel & Webber, supra note 7.}

A wicked problem can be hard to define because many times the problem arises out of a presupposed solution to another wicked problem. For example, in order to propose a solution to the wicked problem of herbicide resistance and the resulting “superweeds,” we must first acknowledge that the wicked problem of herbicide resistance in agriculture was a consequence of a solution to the bigger wicked problem of genetic engineering for pest control, which was a solution to the bigger wicked problem of sustainability and food security.\footnote{Durant & Legge, supra note 33.} This is what Lang and Heasman refer to as “productionism,” whereby agricultural production focused on monocultures rather than diversity, which created a reliance on artificial inputs and energy-intensive engineering rather than the underlying delivery of societal goals such as health and food security.\footnote{Tim Lang & Michael Heasman, Food Wars 30 (2d ed. 2015).} It is important to understand the originating problems that led to herbicide resistance, starting from the overarching concepts and working our way down, before attempting to propose a solution.

As discussed at the beginning of this Part, sustainability is the balancing of human well-being with the needs of the natural environment. As the global population continues to increase, the question of how to feed that number is hotly debated. Many have grappled with how to sustainably use the land in a way that yields the most food while protecting the environment. The most popular solution in the United States is biotechnology, which many argue provides adequate, nutritious, safe, and environmentally benign food supplies.\footnote{Durant & Legge, supra note 33, at 311.} However, as the continued EU-U.S. dispute over the use of genetically modified (“GM”) foods displays, this solution for sustainable and secure food production is far from universal.\footnote{It is important to note that this Article is not debating the argument for or against GM foods, rather, this Article discusses the controversy surrounding GM to demonstrate that one wicked problem often creates another and in order to keep GM a sustainable option, other weed management practices must be adopted to better ecological sustainability and protect crop yields from HR weeds.} The U.S. approach was largely utilitarian and legal, basing legislation (or lack thereof) on a scientific process that found no difference between the final product, while the more hesitant EU approach embraced a consideration of consumers’ values and cultural views resulting in a regulation of the genetic engineering process rather than the end product.\footnote{Durant & Legge, supra note 33, at 312.}

The use of GM food was also touted as a way to increase yields, at lower costs to farmers, in a more environmentally benign way, which led to the next wicked problem—the rise and management of herbi-
cide resistance. 44 Agriculture’s overreliance on single-action pesticides in GM glyphosate-resistant cropping systems is accountable for an outbreak of glyphosate-resistant superweeds. 45 The introduction of GM crops resistant to glyphosate in the 1990s revolutionized the way farmers managed their weed populations. 46 Prior to the introduction of this technology, weed management required much more knowledge and semi-skilled labor in order to avoid harming crops and beneficial biota while managing weeds. 47 In addition to nonchemical control practices, management involved using a range of carefully timed applications of multiple herbicides. 48 The advent of GM glyphosate-resistant crops has allowed farmers to easily apply glyphosate as the only weed management tool in soybean, corn, cotton, canola, sugar beet, and alfalfa. 49 In 2008, GM crops were grown on nearly 96 million hectares (ha) of global cropland, and in the U.S. glyphosate-resistant GM crops comprise 63% of corn, 68% of cotton, and 92% of soybean plantings. 50

The technology is effective and easy to use, which is why many farmers exclusively plant glyphosate-resistant crops and apply glyphosate to the fields year after year. 51 This reliance has led to the rise in number and extent of herbicide-resistant weeds and a decline of glyphosate’s effectiveness as a weed management tool. 52 In 2015, researchers confirmed thirty-two weed species resistant to glyphosate, a rise from twenty-one in 2011. 53 Notably, herbicide resistant weeds are mobile, and a survey of Australian farmers showed that 62% believed their herbicide-resistant weed infestation was due to the movement of weed seed or pollen. 54 A sampling of the resistant weeds includes Palmer amaranth (the impact of Palmer is discussed in the introduc-


46. Mortensen et al., supra note 45.

47. Id.

48. Id.


50. Id. at 346–47; Mortensen et al., supra note 45, at 76.

51. Mortensen et al., supra note 45, at 76.

52. Id.


tion), horseweed, and johnsongrass. In addition to food production challenges, other negative environmental externalities of herbicide resistance include “increased soil erosion, carbon emissions and water quality degradation.” If the consensus amongst the agricultural industry is to fight herbicide resistance only with additional herbicides, evolution undoubtedly will win and leave society’s decision-makers with many more wicked problems in its place.

III. THEORETICAL APPROACHES FOR DEALING WITH WICKED PROBLEMS

Wicked problems are resistant to permanent solutions; as a result, today’s problems are a byproduct of collective failures in trying to understand and solve yesterday’s problems without accepting the existence of a new paradigm requiring new methods. Within the regulatory community, the cascading effect of wicked problems causes serious challenges for governments bound by traditionalist thinking and inflexible administrative pathways. What is needed is support for alternative decision-making tools and governance systems.

If there is no one clear problem, it makes sense that there is also no single answer or approach for coming to grips with a solution. For example, if there was not enough scientific knowledge to solve the problem, then the traditional answer would be that more scientific research is needed to fill the gaps, which in turn reduces uncertainty and provides the grounds for a science-based and agreeable solution. However, in the arena of herbicide resistance and agricultural weed management, there is not a lack of scientific uncertainty; instead, the fundamental problem is a divergence of viewpoints amongst different stakeholders, requiring a solution that establishes participation, debate, and mediation amongst the different parties involved in order to reach a consensus.

Importantly, a workable solution to herbicide resistance cannot be developed without addressing the human dimension of the issue, including social, economic, political, and cultural aspects. Herbicide

55. Heap, supra note 53.
56. Ervin & Jussaume, supra note 19, at 403.
57. Mortensen et al., supra note 45, at 77.
59. Termeer et al., supra note 58, at 682.
60. Head, supra note 58, at 106.
61. Id.
63. Head, supra note 58, at 106.
64. Ervin & Jussaume, supra note 19, at 405.
resistance can be explained from a scientific basis, but one must also acknowledge and accept that human factors contributed to a socio-ecological context that allowed herbicide resistance to emerge. In other words, it is important to understand what human motivators caused glyphosate to be the dominant weed management tool across wide swaths of our country’s agricultural landscape. One reason for the rise in glyphosate use was that it simplified weed management, but it also reduced the use of work intensive tillage for weed control, which minimized soil erosion and maximized soil health while providing economic gains by reducing labor costs. Surveys of farmers revealed that the simplicity and flexibility of glyphosate-resistant crop technology were the most important reasons for adoption. The simplicity of glyphosate trumped the scientifically preferred method of integrated rotation of crops, herbicides, non-herbicide weed control, and cultural factors.

A. Economic Justifications

Economics, as previously mentioned, played a large role in the adoption of glyphosate-resistant crops and the increased use of glyphosate as the only weed management tool. Economic factors connected to the rise of resistance have been studied for years. The economic benefits specifically attributed to the use of glyphosate include increased yields and lower costs. Aside from the direct economic benefits, there are also not insignificant indirect economic and social benefits including increased flexibility that allows for off-farm jobs and enhanced personal safety. However, these economic gains are short-term, and one hurdle for the adoption of a solution to herbicide resistance is effectively changing farmers and policymakers’ focus to

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65. See supra Part II (on development of herbicide resistance).
66. Ervin & Jussaume, supra note 19, at 405.
67. Id. at 406.
68. Id.; Norsworthy et al., supra note 62, at 45.
69. Duke & Powles, supra note 45, at 348–49.
72. Ervin & Jussaume, supra note 19, at 408.
long-term economic success. A recent survey conducted by USDA’s Economic Research Service found that glyphosate resistance increased costs and reduced yields and returns—the exact opposite of the initial on-farm savings gained by adoption of glyphosate-resistant crops and use of glyphosate as the only weed-management tool. The study surveyed the average impact of glyphosate-resistant weeds on yields, production costs, and returns and found that farmers who reported the presence of glyphosate-resistant weeds realized lower returns than similar farmers who did not. Additionally, farmers who used glyphosate by itself had lower yields and returns than similar farmers who used at least one other herbicide in combination with glyphosate. Notably, even though using more than one herbicide has higher production costs, the study found that the additional costs were more than offset by the higher yields. These new findings demonstrate that even steps taken toward managing glyphosate resistance are more cost effective than simply ignoring the resistance.

But it is not just the farmers who benefit from an integrated weed management approach; the viability of the long-term success of an herbicide is also in the economic interest of the herbicide manufacturers. Even with patent-based monopoly rights, herbicide manufacturers should have a strong incentive to protect the durability of their compound, rather than acquiescing to the eventual phase out and consequential outlays for research and development of new herbicides to manage the resistance problem. But perhaps the incentives of shareholder stock values and the need for new product development to support share price outweigh these environmental concerns. Nonetheless, in theory, manufacturers could raise the price of the herbicide to generate equivalent revenue while lowering the rate and extent of use, which would help to conserve the effectiveness of the herbicide.

B. Other Policy Paradigms

Economics alone cannot explain the reluctance to adopt new practices; instead, we must also look at the social and cultural context of

74. Ervin & Jussaume, supra note 19, at 408.
75. Fernandez-Cornejo & Olsteen, supra note 2.
76. Id.
77. Id.
78. Id.
79. Id.
80. Ervin & Jussaume, supra note 19, at 408.
81. Id.
decision making. There are two administrative theories for dealing with developing policies that face limitations from wicked problems.\footnote{84. Durant & Legge, supra note 33, at 313.} 

Neo-managerialism, popular since the early 1990s,\footnote{85. Id.} focuses on what market forces allow or dictate and does not provide feedback or a role in policy-making from the public sector or public service unless the market dictates a feedback response.\footnote{86. Id.} Under this regime, elected officials efficiently declare policy, while administrators determine ways to realize the policy, often with the help of private actors through grants, contracts, and partnerships.\footnote{87. Id.} Within this process, the decision making is based on the market and objective rationality as the means of persuasion.\footnote{88. Id.} Researchers generally agree that neo-managerialism may not be the best approach for managing wicked problem policy, and instead point to an alternative approach known as the deliberative theory of administration.\footnote{89. Id.} Rather than viewing the role of managers as deciding the best way to design public policy, the deliberative model identifies that there is usually no value consensus on a problem, and rather the solution must be a reflection of the diversity of stakeholders involved.\footnote{90. Id.} Proponents of the deliberative theory argue that the only way to address a wicked problem is through building a sense amongst all stakeholders that the solutions and policies put forth are legitimate.\footnote{91. Id. at 314.} Legitimacy can only exist when those affected by the policy develop trust in the managers, public agencies, and decision processes involved.\footnote{92. Id.} Therefore, this approach emphasizes understanding amongst the stakeholders in order to make legitimate and successful policies.\footnote{93. Id.}

If we use the deliberative theory to develop a policy solution to the wicked problem of herbicide resistance, it is essential to understand the community of stakeholders impacted by the policy decisions. In addition, it is important to understand how individuals make their decisions to adopt new practices. The theory of planned behavior posits that information about the benefits of a new agreement cannot be the sole reason for individuals to engage and adopt the agreement.\footnote{94. Roslynn G. Brain et al., Why Do Cattle Ranchers Participate in Conservation Easement Agreements? Key Motivators in Decision Making, 38 AGROECOLOGY & SUSTAINABLE FOOD SYS. 299, 300 (2014).} Instead, individual behavioral intent is a function of attitudes, subjective beliefs, and perceived control regarding one’s ability to adopt the pol-
Therefore, in order to determine if a policy is tailored to both solve a wicked problem and be adopted by the community that decision-makers are attempting to reach, it is imperative to look at the societal values and characteristics important to that community.

This has enhanced significance in the agricultural context because, unlike many venues, agriculture is not merely an occupation; it is a lifestyle. Farmers as a whole tend to understand their work in individual terms, meaning that self-reliance, skill, hard work, thrift, and other similar characteristics are necessary for a successful harvest. Although individualism is a core value, the historically close-knit interdependence of rural life dictated that individual ambitions must be tempered by the need to consider the community's needs and desires. Notably, as farms have gotten larger and further away from the romantic, agrarian ideal, individualism is a more defining characteristic with a move away from the shared importance of community.

Additionally, researchers have tried to uncover why farmers continue to use controversial agricultural practices when faced with extreme criticism. While farm size and land ownership continue to change, the farmers' agricultural practices have remained the same. In addition, when surveyed, farmers reveal that despite outsider information advocating for change, they intend to continue the practices they have been doing. Many farmers are unwilling to change their behavior because these practices are linked directly to farmer identities. These farmers have deeply held identities rooted in economic and cultural beliefs, which have remained static over time. Farmers view themselves as proud and traditional rural individualists that are alone in a society full of “others,” labeled as villains (including government and environmentalists). From this perspective, people are...

95. Id.
98. Id.
101. Wilson et al., supra note 100, at 21.
102. Id. at 22; see generally GREGORY MCISAAC & WILLIAM R. EDWARDS, SUSTAINABLE AGRICULTURE IN THE AMERICAN MIDWEST (1994).
103. Wilson et al., supra note 100, at 22.
104. Id. at 25.
105. Id. at 26.
either allies or adversaries, and critiques of agricultural practices become critiques of the agricultural lifestyle farmers work so hard to protect, including their values, beliefs, norms, and traditions. When asked about excessive use of agricultural chemicals, 95% of farmer-respondents expressed that applying chemicals is essential for controlling yields. When provided with information about recommendations for weed management, 81% of the same farmer-respondents saw the recommendations, no matter what organization the information came from, as one pushed by the distrusting hand of the government. The results of this study suggest that any attempt to change farmer behavior must come from an insider with the same values in order for the information to be accepted.

This profile of the modern farmer suggests that any successful agreement or policy developed for this landscape will allow farmers to continue to use their independent judgment to achieve their well-being and will avoid the appearance of either government handouts or control.

IV. INTEGRATED WEED MANAGEMENT AND COOPERATIVE AGREEMENTS

Worldwide, the majority of plant species that are developing herbicide resistance are weeds in agricultural environments; fifteen pasture species have developed resistance, and eight of those are primarily agricultural weeds. The reason weeds develop herbicide resistance in agricultural systems has to do with a mixture of characteristics of specific weeds, herbicides, and weed management practices. Most of the weeds have high seed production, which makes it more likely that a genetic variation will occur that will exhibit a resistance. Additionally, most agricultural weeds are annuals, which are the most problematic weeds because of their high seed production, large seed-banks, and several reproductive generations per season. Herbicide use and management also affect the likelihood that herbicide-resistant weeds will develop. In agriculture, it is common to repeat herbicide applications within a single year and over consecutive years. Usually, land managers will rely completely on one herbicide for weed

106. Id. at 27.
107. Id. at 30.
108. Id.
109. Id. at 31–32.
111. Id.
112. Id.
113. Id.
114. Id.
115. Id.
control without embracing any other weed control options, such as mechanical or cultural control practices, which also contributes to the adaptation of herbicide resistance. In response, integrated chemical and biotechnology companies are promoting second-generation GM crops resistant to additional herbicides as the next solution to the productivity problem—a short-term fix likely to create new resistant weed challenges. What is clear from the ecology perspective is that weed management practices are the most important factor contributing to herbicide resistance, and biotechnology as a tool to feed the world’s population is only sustainable when used as part of a broader integrated and ecologically based weed management system. The success and sustainability of agricultural weed management practices shapes the success and sustainability of agriculture as a whole. This Part will discuss the benefits of integrated weed management by focusing on the beneficial use of cooperative weed management agreements or CWMAs.

Integrated weed management is an approach to managing weeds that relies on multiple modes to stress weed populations and increase the crop’s ability to compete successfully. In other words, integrated weed management uses knowledge of organisms and a variety of tools to provide selection pressure, which allows a competitive balance in favor of the crop at the detriment of the invasive weeds. The principal strategies in integrated weed management include preventive, agronomic and cultural, and chemical tools for weed management. A robust integrated weed management system uses

116. Id.
117. Mortensen et al., supra note 45.
118. DiTomaso, supra note 110; Mortensen et al., supra note 45, at 76, 81.
119. Mortensen et al., supra note 45.
120. The term “cooperative weed management agreements” refers to contracts that coordinate multiple parties, stakeholders, and landowners in the implementation of an integrated weed management strategy on a large temporal and/or spatial scale. Invasive Plant Centers, http://www.invasiveplantcenters.org/cwmass.htm [https://perma.cc/E25Q-QLU7]; Mary E. Hershderfer et al., Key Attributes Influence the Performance of Local Weed Management Programs in the Southwest United States, 60 Rangeland Ecology Mgmt. 225, 226 (2007).
122. A. G. Thomas et al., Weed Community Response to Contrasting Integrated Weed Management Systems for Cool Dryland Annual Crops, 51 WEED RES. 41, 42 (2010); Young, supra note 121, at 108.
123. Bhagat Singh et al., Integrated Weed Management—A Strategy for Sustainable Wheat Production—A Review, 34 Agric. Rev. 243, 244 (2013). Preventative tools are the least costly of the management tools, but are also the least frequently used. Id. Preventive techniques include using certified clean and weed free seeds, using clean farm equipment and machines, pulling out weeds before the seed setting, controlling the weeds in animal feed and manure, and mechanical and manual weeding. Id. Agronomic and cultural strategies use knowledge and growing strategies to favor the crop’s competition over invasive weed species. Examples of agronomic and cultural strate-
techniques from all of the strategies and does not rely solely on herbicides. Researchers have demonstrated that cropping systems that adopt an integrated weed management system can produce competitive yields and comparable profit margins relative to those systems that solely rely on herbicides.\(^\text{124}\)

Cooperative weed management moves integrated strategies a step further. Cooperative weed management refers to efforts that coordinate multiple parties, stakeholders, and landowners in the implementation of an integrated weed management strategy on a large temporal and/or spatial scale.\(^\text{125}\) Even if weed scientists have identified and empirically tested a set of technically effective integrated best management practices, and even if most growers adopt the technical farm level recommendations, the failure to coordinate practices among neighboring landowners will influence the evolution of herbicide-resistant weeds across the ecosystem.\(^\text{126}\) This is because even the most diligent land manager using a wide range of management techniques will not be successful in the long run if invasive weeds can find refuge on a neighboring property.\(^\text{127}\) Historically, CWMAs have been used on public lands under the leadership of state and federal government agencies working with adjacent or enclosed private natural resource managers to reduce invasive plants.\(^\text{128}\)

Most CWMAs share six basic characteristics\(^\text{129}\): (1) defined geographic area; (2) broad collection of landowners and natural resource managers; (3) governing committee; (4) long-term commitment to cooperation; (5) overarching plan for managing invasive species; and (6) means to facilitate cooperation across jurisdictional boundaries.\(^\text{130}\)


\(^{125}\) See *Invasive Plant Centers*, supra note 120; Hershdorfer et al., *supra* note 120, at 226.


\(^{127}\) *CWMA Cookbook: A Recipe for Success* (Midwest Invasive Plant Network, 2d ed. 2011) [hereinafter *CWMA Cookbook*].

\(^{128}\) For example, Michigan’s Upper Peninsula has five cooperative weed management areas formed as public-private partnerships with a focus on unmanaged lands with significant, but not exclusive, public ownership. *See Cooperative Weed Management Areas of the Upper Peninsula*, Upper Peninsula Resource Conservation & Dev. Council, http://www.upred.org/partners.asp [https://perma.cc/3ENX-HR3D].

\(^{129}\) *CWMA Cookbook*, *supra* note 127, at 3.

\(^{130}\) *Id.*
While most cooperative weed management areas are a mix of public and private interests managing invasive species, there is potential for a group of neighbors to form their own cooperative weed management area and function in a similar way. To that end, a formal, legally binding agreement among the group would assist in ensuring the long-term functionality of the effort, but how this could fit into existing legal structures warrants careful consideration, especially within the context of individualism and resistance to government mandates found within the agricultural community. Nonetheless, such agreements can help manage herbicide resistance by giving teeth to arrangements made between neighbors and solidify efforts to move beyond simple herbicide use in efforts to manage their invasive weeds. Accordingly, the following Part outlines existing strategies for invasive weed regulation and legal approaches to sustaining common pool resources.

V. THE REGULATORY REGIME AND MANAGING COMMON POOL RESOURCES

Nature does not observe property boundaries and weeds spread. The effectiveness of certain herbicides to combat weed infestation is a common-pool resource. But because of this movement, weeds that are resistant to a particular herbicide or herbicides can migrate onto a neighboring property—even if the neighboring property has adopted integrated weed management practices. Without effective rules that limit access and provide incentives for users to invest in the resource, instead of exploiting it, common-pool resources (including herbicide resistance) are vulnerable to abuse. Models produced by the USDA’s Economic Research Service have demonstrated that grower returns from those who manage resistance are higher when neighbors also manage resistance. The simulation showed that when both neighbors are managing resistance, their returns average $378 per acre, but when both neighbors ignore the resistance problem, their returns average only $312 per acre. The simulation also found that returns are lower, whether the farmer manages or ignores resistance, when the neighbor ignores resistance. This can be explained better with an example: a grower who manages resistance (and whose neighbor also manages resistance) will have a return of $378, but if he ignores resistance (while the neighbor is still managing resistance) the return is $319. This is a gain of $59 per acre if the farmer manages

131. Ervin & Jussaume, supra note 19, at 409.
132. Id.
134. Livingston et al., supra note 133, at 16, 18.
135. Id. at 16.
136. Id.
137. Id.
resistance.\textsuperscript{138} However, if the farmer’s neighbor ignores resistance, when the farmer manages resistance he receives a return of $336 as compared to $312 if he ignores resistance, resulting in a gain of only $24 per acre.\textsuperscript{139} This increase in potential gain is an incentive for both neighbors to manage their resistant weeds.\textsuperscript{140} Although this new research has identified an economic incentive to manage resistance, the legal system has a long history of ignoring the impact of invasive plant species.

A. Existing Regulatory System

Existing state-level laws that attempt to solve invasive weed issues generally fail to regulate problematic plants. These weak rules cover, on average, only 20% of the species considered invasive by scientific authorities.\textsuperscript{141} State legislatures began to regulate invasive plant species in the late nineteenth and early twentieth centuries because of concerns over plant species that negatively affected crop yields.\textsuperscript{142} In more recent times, the laws regulating noxious weeds have expanded to protect the environment and ecosystem functions.\textsuperscript{143} However, these laws vary widely in scope, interpretation and application, and government at all levels has struggled with how to implement effective strategies to prevent new introductions of invasive species.\textsuperscript{144} Additionally, state-by-state implementation of broad-scale protective measures is ineffective at controlling the introduction of invasive species.\textsuperscript{145} In 2010, Congress enacted the Plant Protection Act (PPA) in order to consolidate federal authority over plant pests into a single statute. The statute creates a Federal Noxious Weed List ("the List"), and once a species is included on the List, the government prohibits distribution and transportation within the U.S.\textsuperscript{146} The PPA has several significant limitations, including the lack of statutory authority, to require removal or remediation of already established noxious weeds on private land. Also, the PPA can only restrict noxious weeds moving interstate, meaning the PPA has no power to stop the movement of noxious weeds entirely within a state; regulation of intra-state noxious

\textsuperscript{138} Id.
\textsuperscript{139} Id.
\textsuperscript{140} Id. at 17.
\textsuperscript{141} Quinn et al., supra note 20, at 125.
\textsuperscript{142} A. Bryan Endres, Bioenergy and Novel Plants: The Regulatory Structure, in BIOENERGY AND BIOLOGICAL INVASIONS: ECOLOGICAL, AGRONOMIC, AND POLICY PERSPECTIVES ON MINIMIZING RISK 85, 85 (Lauren D. Quinn, David P. Matlaga & Jacob N. Barney, eds., 2015).
\textsuperscript{143} Id.
\textsuperscript{144} Id. at 85–86; P.E. Hulme, et al., Will Threat of Biological Invasions Unite the European?, 324 SCI. 40, 40–41 (2009); Quinn et al., supra note 20, at 124.
\textsuperscript{145} Endres, supra note 142, at 85–86; Quinn et al., supra note 20, at 133.
weeds is left up to the individual states to determine how to manage.\textsuperscript{147} Finally, the preventative aspect of the List is dampened by the USDA’s tendency to include invasive plants with established negative impacts in the U.S., so the sale or movement of known invaders is not regulated until there is already substantial harm.\textsuperscript{148} In addition to the PPA, a 1999 Presidential Executive Order established the National Invasive Species Council (NISC), which serves as a coordinator and information-sharing role among various government agencies, but does not have the power to prevent the introduction or spread of invasive plant species.\textsuperscript{149} 

Legal approaches to noxious weed regulation at the state level usually delegate the power to designate noxious weeds to the state department of agriculture.\textsuperscript{150} Most states possess the authority to add species to their respective state noxious weed lists; however, state weed control laws on private lands are rarely enforced, and state laws generally do not impose civil liability on the landowner for the damage caused by the spread of weeds onto adjacent properties.\textsuperscript{151} 

While invasive species spread regardless of set boundaries, state laws only regulate within the state, creating a piecemeal regulatory system that is ineffective and inefficient at regulating invasive plant species.\textsuperscript{152} When existing state-level laws that attempt to solve the issue fail, there is a need for substantial investment in governance systems at multiple levels, including contiguous landowners and farmers who can work collectively to help stave off plant species invasions.\textsuperscript{153}

B. Legal Approaches to Common Pool Resources

1. Tragedy of the Commons

Before the term wicked problem was coined, there was its precursor, the tragedy of the commons.\textsuperscript{154} Introduced in 1968 by Garrett Hardin, the tragedy of the commons arises when there is a common pool resource that is being depleted with no technical solution to the dilemma.\textsuperscript{155} A technical solution is one that requires only changing the techniques of the scientific approach, without any change in
human values or ideas of morality. To demonstrate this problem, Hardin introduces us to the tragedy of the commons, featuring a pasture that is open to all. Each herdsman will attempt to keep as many cattle as possible on the pasture in order to maximize his gain. This results in a net gain to the herdsman because the positive utility awarded solely to him for the proceeds of the sale of the extra cattle outweighs the negative utility of overgrazing the pasture, which is shared by all, so the herdsman only bears a fraction of the negative consequence. The tragedy arises when each herdsman comes to the same rational conclusion of adding livestock to the pasture, until the point where the common pasture is ruined. As Hardin speculates, “[e]ach man is locked into a system that compels him to increase his herd without limit—in a world that is limited.” Hardin’s conclusion is that unregulated use of a common resource brings ruin to all. The laws and concepts of private property deter the owner from thinking of the problem on a larger scale and instead aid the focus on easy short-term solutions by claiming it is his natural right as a landowner to do whatever he wants with his land. This theory is disappointing to some because the dangerous solution is not created by malice or a bad actor; instead, it is the result of collective appropriate and innocent acts done by individuals on their own. The answer, according to Hardin, lies in the combination of private property laws coupled with government regulation to manage the problem.

It is relatively straightforward to translate herbicide resistance into a tragedy of the commons scenario—each landowner has the right to manage weeds on his or her property in the way he or she chooses. If the landowner decides that the cheapest and most efficient route to weed extermination is using glyphosate-resistant crops in combination with spraying only glyphosate, then there is an initial net benefit in crop yield and weed management costs. However, when all rational neighboring farmers chose the same management strategy, the commons is destroyed as herbicide resistance becomes a problem that lowers yield and raises management costs. This can be explained better with an example used previously in this Article; a grower who manages resistance (and who’s neighbor also manages resistance) will

156. Id.
157. Id. at 1244.
158. Id.
159. Id.
160. Id.
161. Id.
162. Id.
163. Id. at 1245.
165. Corker, supra note 154, at 106.
have a return of $378, but if he ignores resistance (while the neighbor is still managing resisting) the return is $319.\textsuperscript{166} This is a gain of $59 per acre if the farmer manages resistance.\textsuperscript{167} However, if the farmer’s neighbor ignores resistance while the farmer manages resistance, he receives a return of $336 as compared to $312 if he ignores resistance, resulting in a gain of only $24 per acre.\textsuperscript{168} When both landowners ignore resistance, the result is lower economic gains overall.\textsuperscript{169}

The tragedy of the commons theory has been incorrectly interpreted to mean that common ownership of the resource leads to excessive use and degradation of the resource; instead, the attribute that leads to excessive use is open and unregulated access, not common ownership.\textsuperscript{170} There has not been a common pool resource management program that has specifically addressed herbicide-resistant weeds, but researchers have developed a framework for what an agreement between landowners for common pool resource management should look like.\textsuperscript{171} A management approach must clearly define the boundaries of the common pool resource, adapt the rules to local conditions, assure broad participation within the boundaries, implement monitoring mechanisms, impose sanctions for violations of the agreement, put in place conflict resolution mechanisms, and have multiple levels of governance.\textsuperscript{172}

2. Water and Drainage

Although commonly thought of as a common pool resource in the context of aquifer supply or in-stream flows, the presence of too much surface water and the need to drain land via subsurface tiling and intermittent ditches across a watershed presents another opportunity for common resource management. Envisage a series of levees surrounding each individual field that prevents the flow of water across properties and into local waterways. This blocking of the natural flows within a watershed usurps the ability of others to use the geological formations that facilitate drainage, thereby reducing the resource value. But even if the right to drainage is not what economists would classify as a

\textsuperscript{166} Fernandez-Cornejo & Osteen, supra note 2; Livingston et al., supra note 133, at 15–16.
\textsuperscript{167} Fernandez-Cornejo & Osteen, supra note 2; Livingston et al., supra note 133, at 15–16.
\textsuperscript{168} Fernandez-Cornejo & Osteen, supra note 2; Livingston et al., supra note 133, at 15–16.
\textsuperscript{169} Fernandez-Cornejo & Osteen, supra note 2; Livingston et al., supra note 133, at 16.
\textsuperscript{170} Ervin & Jussaume, supra note 19, at 409.
\textsuperscript{171} See Ervin & Jussaume, supra note 19, at 409; see generally Elinor Ostrom et al., The Future of the Commons: Beyond Market Failure and Government Regulation (2012).
\textsuperscript{172} Ervin & Jussaume, supra note 19, at 409–11.
pure common pool resource, or even a public good.\textsuperscript{173} the principles and frameworks developed to facilitate farmer’s ability to tame wetlands and convert wide swaths of the country into agricultural production is a model for the more complex—or wicked—problem of herbicide resistance. It bears explicitly mentioning that the authors acknowledge the ecological damage that has been perpetrated as a result of over-aggressive draining of wetlands,\textsuperscript{174} but nonetheless look to this underlying organizing strategy of drainage districts as a potential solution to herbicide resistance due to the widespread acceptance in the agricultural community of the governance process and effectiveness.

Approximately 124 million acres of land across the continental United States is artificially drained through a series of ditches and sub-surface tiles that span property boundaries and traditional political subdivisions.\textsuperscript{175} This is a system based on watersheds and dealing with a common enemy—wet fields—in which the uncoordinated movement of water from one field to another would simply “shift” the problem to others. Recognizing this problem, legislatures across many states in the late 1800s enacted “Drainage Codes” or similar statutes that provided rules for water movement and the structure, based on landowner consent, to establish drainage districts.\textsuperscript{176} Due to the potential problem of hold-outs blocking the means to secure adequate drainage and/or flood protection within a watershed, these laws provided landowners with a government-authorized legal organization—a drainage district—to force uncooperative owners into the proposed


Once formed, districts can levy assessments to pay for drainage improvements and enter land for maintenance purposes. Commissioners may be elected or appointed and carry out the essential functions of the district operations, including hiring engineers and other professionals. And as public corporations charged with specific governmental functions, districts may exercise the power of eminent domain.

Importantly, drainage districts may not conform to the boundaries of any other political subdivision (e.g., township) unless both entities happen to coincide with a particular watershed. This keeps the focus on the purpose—drainage—rather than other potentially divisive political issues that may exist within a community that serves to galvanize the group in a type of collective action against a common problem. Perhaps it is this geographical distinctiveness, coupled with effectiveness in improving land for agriculture, which has enabled most districts to operate without significant opposition from agricultural producers.

VI. RECOMMENDATIONS & CONCLUDING THOUGHTS

Returning to our wicked problem of herbicide resistance, we can pull together theoretical approaches to problem solving and the six core functions or characteristics of successful cooperative weed management agreements in the public land’s environment, along with the legal structure of drainage districts, to develop a strategy to move forward. As discussed above, the benefits of each farming operation adopting integrated weed management strategies results in significant profit per acre increase for all parties. But as planned behavior theory instructs, decisions to change are not solely a function of economic benefits—attitudes, beliefs, and perceived control are also impor-
tant. Thus, the societal values and characteristics of the particular community must be evaluated with respect to tailoring a solution to this wicked problem.

Private agreements among landowners to work collaboratively and adopt integrated weed management strategies are an important first step and certainly fit within the control and beliefs aspects of planned behavior. But over time, neighborly agreements break down, fade away, or conveniently are disregarded in the face of adversity—for example, through the establishment of fence maintenance laws in most states. Models for cooperative weed management agreements (“CWMAs”) are available, but what is needed is the development of a process that would facilitate neighbors coming together and binding themselves to integrated weed management principles.

Successful CWMAs have defined boundaries, a broad collection of stakeholders, robust governance committees, long-term perspective, focus on an overarching plan, and a means to facilitate across jurisdictional boundaries. Drainage districts share the same characteristics: defined boundaries, varied landowners within the area, elected or appointed commissioners, long-term perspective of drainage, and cross-jurisdictional boundaries based on the watershed. The general acceptance within the agricultural community of drainage districts lends support to a similar structure in other contexts. The agricultural community solved the drainage problem more than a century ago with the formation of drainage districts. Accordingly, adopting a statutory scheme for the establishment of CWMA districts, modeled on existing drainage district law could help to unravel this wicked problem of herbicide resistance.

New policies are needed to promote integrated approaches in order to manage herbicide resistance from destroying the environment and crop yields. Steps must be taken to ensure that new herbicide-resistant crops and their corresponding herbicides are not used in the same way as glyphosate, but rather are one component of a larger integrated weed management system. It is difficult to imagine a single regulation that adequately addresses the problem; instead, the agri-

183. See supra notes 94–95 and accompanying text (describing planned behavior theory).
184. See Schlessinger, West & Endres, supra note 10, at 1–3; Mortensen et al., supra note 45, at 83.
186. See supra notes 129–130 and accompanying text (discussing successful CWMAs).
187. Mortensen et al., supra note 45, at 75.
188. Id. at 82.
189. See Ana Novoa et al., Soft Touch or Heavy Hand? Legislative Approaches for Preventing Invasions: Insights from Cacti in South Africa, 8 INVASIVE PLANT SCI. &
cultural community should embrace a new institutional structure—one that encourages development of CWMAs and is thereby a step toward a more sustainable agricultural landscape.