CHOICES
A publication of the Agricultural & Applied Economics Association
AAEA Agricultural & Applied Economics Association
4th Quarter 2016 • 31(4)

Intervention to Manage Pest Resistance: Community-Based or Government Regulation

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JEL Classifications: *Q10, Q15, Q18, Q30, Q57*
Keywords: *Community-Based Approach, Pesticide Efficacy, Pest Resistance Management, Pest Spillovers*

Pest resistance management is a major concern in modern agriculture. The advent of herbicide tolerant (HT) traits introduced into corn, cotton, and soybean led to rapid adoption of HT seeds initially in cotton and soybean and eventually in corn. Glyphosate quickly became the herbicide of choice and frequently the only herbicide used on these crops. As weeds developed resistance to glyphosate and western corn rootworm (WCR) to bacillus thuringiensis (Bt) traits, producers, the agricultural industry, and EPA have been expressing concern and calling for action (for example, EPA, 2016a; EPA 2016b; WSSA, 2016a; WSSA 2016b).

> It is important to point out that pest resistance is not a new problem. It has been around since humans began using pesticides. But agronomic management practices adopted over the last 20 years have significantly increased the evolutionary rate of pest resistance.

Initially, pesticide efficacy—pest killing power—is a finite stock resource that can be more rapidly depleted if its use is misallocated over time and space. Pest characteristics combined with behavioral and socioeconomic factors can challenge the model of profit-maximizing economic behavior, such as, independent, decision-making farmers. This setting can lead to market failure in cases where mobile, resistant pests spillover onto neighboring fields and impose costs on neighboring farmers. In this scenario, pesticide efficacy is a resource common to all farmers in the community or public good. Resistant individuals in the pest population deplete everyone's pesticide efficacy for controlling that pest. If pests are mobile, independent, farmer-based management decisions may lead to more rapid depletion of the pesticide efficacy. Thus, policies that intervene to slow resistance development, such as a voluntary, community-based or a government regulatory approach to resistance management may maximize benefits to all producers in the community. Under the appropriate circumstances, a community-based approach has the potential to be a more efficient, community welfare improving outcome.

> A major challenge in resistance management is determining how rapidly resistance will develop. Pest resistance development depends on biology of pest species, intensity and frequency of pesticide use, cropping patterns, climate, and the nature and diversity of pest management technologies. There is uncertainty in predicting the rate of resistance development and such predictions become increasingly uncertain with rapid and widespread adoption of genetically engineered crops (Fernandez-Cornejo et al, 2014). Given uncertainty in the rate of resistance development, it is difficult to forecast and manage resistance in an economically efficient manner. Thus, convincing farmers and other stakeholders in the agricultural community to adopt resistance management practices (RMPs) will be more challenging in the absence of sound economic information.

Economics of Resistance Management

Most agricultural input decisions are relatively short term, recurring annually or biannually in the case of crop rotations. The farmer may decide to maximize profits in producing a crop with the optimal combination of inputs or produce a given level of crop output with the least cost combination of inputs, including pest control. Over time, some pests may become resistant to a specific pesticide input, especially with increased intensity and duration of application—for example, repeated use of glyphosate on HT crops over multiple growing seasons or the repeated use of the same Bt trait to manage WCR over multiple growing seasons. Thus, managing pest resistance is a dynamic problem of resource allocation over time, similar to a fixed stock of groundwater.

Initially, each pest control option has a fixed stock of efficacy—killing power, potency against non-resistance individuals in the target pest population, or marginal economic value. That efficacy is gradually lost as individuals develop resistance to a particular pesticide and become predominant in the population. Moreover, reliance on a single mode of action and frequent applications intensifies selection pressure for resistant individuals. In the longer term, the farmer will face increasing pest control costs as efficacy is depleted or resistance evolves throughout the pest population. Control of the pest may then require additional management practices. Such resistance management practices may include crop rotation, supplemental tillage, use of more expensive herbicides, herbicide tank mixes with different modes of action, or use of residual and foliar herbicide applications during a growing season. In extreme situations, the farmer may have to switch to a different crop.

If resistance management practices are adopted as a matter of course, the long run net returns to pest control may be greater. If not, more extreme and expensive pest management practices may be needed as efficacy is depleted. Generally, adopting resistance management practices (RMPs) extends the life of cheaper, effective products and sustains net returns.

If we only consider the case of an individual farmer and an immobile, resistant pest population limited to farm boundaries, what happens on the farm stays on the farm. The economic impact of employing or not employing pest resistance management practices is the individual farmer's management problem. How does the farmer slow or manage the development of resistance to a particular pest control practice? The recommended approach is to adopt a variety of RMPs to slow resistance development.

An important economic question is, does adoption of RMPs improve long term net returns to the farmer. If adoption improves net returns, then the farmer has a motive or incentive for adoption. If not, the farmer may take a wait and see attitude. There are a few studies of the economic impacts of RMP adoption: Edwards et al., (2014) in a benchmark study of glyphosate resistance evaluated 156 growers in six states from 2006-10. They compared control costs, yields, and net returns for the standard practice (SP) glyphosate only with RMPs (alternative herbicides containing multiple modes of action). Although RMP control costs were slightly higher than SP, net returns were not statistically different. An earlier study (Hurley, et al., 2009) of weed management costs when using RMPs or glyphosate, concluded that the use of RMPs on soybean following HT corn was a cost-effective weed management strategy.

Livingston, et al., (2015), studied how managing horseweed affects short and long term profits in continuous soybean (S), continuous corn (CC), and a corn-soybean (CS) rotation. They found that RMPs, were most profitable in continuous soybean but not as important for corn-soybean or for continuous corn. They concluded that this may be due to costs being certain and in the present and benefits being uncertain and in the future.

Factors Affecting Adoption of RMPs

Even though RMPs may maximize long term profits, evidence indicates that farmers are slow to adopt RMPs (Pannell and Zilberman, 2009). A number of other factors or "barriers" may help explain this outcome (Hurley and Frisvold, 2015). Behavioral and socioeconomic factors may challenge rational economic behavior—profit maximizing—on the part of farmers and landowners and these factors may lead to a form of market failure. Although the line between socioeconomic and behavioral factors may be blurred, we use the following definitions to distinguish between the two. Socioeconomic factors are economic and social values tied to the local community and involve shared characteristics, norms, social networks, and institutions.

Some examples of socioeconomic barriers to adoption may include:

- Not all costs are easily monetized in crop production. When it comes to simplicity, convenience, and flexibility in different types of farming systems—for example, opportunity cost of farmer's time related to off-farm employment or farm size—the decision becomes more complex;
- Farmers typically discount future costs and returns. If they use a higher discount rate, more distant and uncertain benefits are penalized more heavily and RMPs are at a greater disadvantage of being adopted. The opposite is true of using a lower discount rate.
- Farmers may be maximizing whole farm net returns as opposed to a crop net returns, especially when having an integrated crop-livestock operation;
- Rental agreements may impact farmer's planning horizon—for example, rented vs. owned land, crop share vs. cash leases, short vs. long term agreements;
- Sources and quality of information services may vary—for example, Extension Services, certified crop advisers, independent crop advisers, input suppliers, company agronomists.

Behavioral economics relates more to individual behavior in risky and uncertain environments and can be thought of as the study of behavioral failures or anomalies relative to rational market behavior (Shogren and Taylor, 2008). Examples in pest resistance management may include:

- Choices under risk and uncertainty—or risk attitudes—may be most important. For example, response to low probability, high consequence risks—"wicked weed" problems;
- Livestock production and securing on-farm feed supply to manage economic risk and biosecurity concerns;
- Complexity and information uncertainty surrounding resistance development and RMP effectiveness;
- Distortions caused by subsidized crop insurance provisions, monitoring costs and low-value commodities, and new pesticide optimism (Dentzman et al., 2016).

A relatively new area of discovery is to do surveys and studies of the role of socioeconomic and behavioral factors in farmer management and agronomic decision-making. Hurley and Frisvold (2015) identified factors that may slow adoption including expectations of future herbicide technology availability, non-monetary costs like time and convenience, and uncertainty of weed mobility.

Diaz-Rivera and Miranowski (2016) considered the role of socioeconomic and behavioral factors in RMP adoption using data from the 2012-2014 Iowa Farm and Rural Life Poll. They found the positive factors associated with weed RMP adoption were percentage of total cropland rented, contrary to common perception, and farm income share greater than 75% of total income. We may infer that near full-time farmers are better managers of resistance development. At the same time, the magnitude of livestock activities negatively affected RMP adoption.

Finally, Stallman and James (2015) raised issues that may be important to adoption of a community-based approach. They evaluated Missouri farmers' willingness to cooperate to control pests. Their finding indicated that farmers were more apt to cooperate if it was a local rather than county effort, if they believed they would benefit from cooperation, if farmers were active in community organizations, if they trusted extension, and if they were more concerned about pesticide impacts on the environment.

The results of these studies indicate that commonly held perceptions of socioeconomic and behavioral factors may not always coincide with empirical results from analysis of survey data. Better understanding of the drivers for local adoption of RMPs in a community or area may yield significant benefits when designing local community-based RM incentives and requirements. Further, the impacts of socioeconomic and behavioral factors may be expected to vary by community, area, state, and region, making a stronger case for community-based intervention.

Does the existence of socioeconomic and behavioral factors in adoption of RMPs, justify some form of government intervention in resistance management policy? Not necessarily. First, it is necessary to determine if the socioeconomic factors and behavioral anomalies are significant distortions of profit maximizing behavior. If they do not cause significant distortions, they do not need to be considered in the context of resistance management policy. If they do, is a workable policy solution available? It may call for adjusting the design of policy incentive mechanisms, such as mechanism design to accommodate these anomalies. Although complicated, attention to mechanism design becomes important in providing efficient policy incentives or bargaining rules and protocols.

Second, unless we can appropriately adjust mechanism design, there are no assurances of achieving the desired response to a voluntary or involuntary intervention policy (Shogren and Taylor, 2008). Adopting a top-down regulatory approach to address socioeconomic factors and behavioral anomalies will likely be fraught with noncompliance—for example, Bt corn refuge policy—or prohibitive monitoring and enforcement costs.

Third, a community-based approach is designed, in part, to change or alter farmer and community behavior with respect to resistance management. This is a local approach to address and modify local behavior. The community works with tenants, landowners, consultants, suppliers, seed and chemical companies, and the banking community to encourage a longer-term approach for adoption of RMPs.

When is Intervention Economically Justified?

As noted before, if the pest is immobile and there are no significant spillovers or externality costs, then it is only a private concern and needs to be managed by the farmer or the landowner. In these cases, do nothing— let the market work.

If the pest is mobile and creates significant spillovers on neighboring farms, then it may create significant social costs external to the farm. The spillover of pest resistance to neighboring farms depreciates the value of neighbors' control options, and creates a common resistance problem.

When does this case call for intervention? The answer depends on the magnitude of the social cost imposed by the spillovers, the spatial nature of the pest problem, and the ability to modify local social characteristics and behaviors. A three-part categorization of responses, following Ervin and Frisvold (2016) and others, is:

- If pest mobility is limited and the neighbors avoid spillover costs by adopting cost-effective RMPs, then there is little need for intervention (Miranowski and Lacy, 2016);
- If pest mobility is moderate, then it will depend on the spatial distribution and magnitude of spillover costs;
- If pest mobility and spillover costs are high, then intervention may be necessary—for example, Palmer amaranth. If spillover costs are isolated to defined and localized areas, then a community-based solution may be more effective. If the spillover is widespread and costly, then it may best be addressed through government intervention to correct a public bad.

If resistant pest populations are mobile and the loss of susceptible populations is a common property problem, is intervention necessarily justified? If so, when can a community-based approach be rationalized? The answer is, it depends.

First, it depends on the added benefits of intervention outweighing the added social costs incurred—including monitoring, voluntary compliance oversight, and other transactions costs. If small externality costs are involved, community-based approaches may not improve social welfare.

Miranowski and Lacy (2016) demonstrated that neither a community-based approach nor government intervention is necessarily justified for WCR at the state level in Iowa. Using a decision-theoretic framework over a 20-year time period, they found that corn-soybean (CS) and corn-corn-soybean (CCS) rotations were effective RMPs and dominate growing continuous corn (CC) in terms of longer run net returns. If the farmer adopted a CS or CCS rotation, the spillovers from neighbors not using crop rotation was minimized, that is, including soybean in the rotation is a very effect practice to reduce resistant populations of WCR. Diaz-Rivera and Miranowski (2016) found similar preliminary results for current weed complexes in Iowa.

The WCR results for Iowa should not be interpreted as applying to all local communities and areas in the state. Some local communities and areas have unique WCR resistance management situations. These communities and areas tend to employ CC rotations and/or the same or similar Bt traits repeatedly over time. For example, more intense livestock production areas may rely more on own-farm production of corn for feed. Under these circumstances, the added resistance management benefits of adopting a community-based approach may outweigh the added costs of addressing the socioeconomic and behavioral factors at the local community level. Similarly, recently established Palmer amaranth infestations have been found in more isolated locations around the state of Iowa. These infestations may also benefit from proactive use of a community-based approach to avoid elevated costs of weed management in the future.

Second, if intervention is justified on the basis of net benefit improvement, how does a community decide if resistance management is amenable to community-based management? If spillovers are moderate and not widely dispersed, community-based solutions may improve social welfare but may require incentives or community-imposed compliance protocols for success.

Third, if large spillover costs are involved and widely dispersed—that is, the mobile resistant pest population is not confined to localized areas but widely dispersed across a state or region—government intervention may be required to correct the problem if the added economic benefits of intervention exceed the added costs.

What are community characteristics necessary to the success of a community-based RM approach (Ervin and Frisvold, 2016; Ervin and Jussame, 2014; Endres and Schessinger, 2016)?

- Does the community have a well-established social network to make a community-based approach viable (Collier, 2015)? Does the community have potential leadership and a commitment to follow through to make resistance management sustainable over the long run? How is the community defined spatially, organizationally, and legally—for example, a town, county, or watershed? If the community is too small, it may encounter diseconomies of size. If too large and diverse, there may not be a well-established community social network.
- What is the nature of the pest pressure, what are the impacts on farm productivity, and how is the pest currently being controlled and to what extent? What are the potential costs imposed on neighboring farmers and the community if not controlled? Can the community demonstrate that their resistance management strategy will improve net benefits and be sustainable in the long run?
- Are there resources and incentives to encourage farmers and members of the agricultural community to participate? Membership and participation needs to be inclusive of farmers, landowners, lenders, coops, local suppliers, and retailers, extension and outreach, crop consultants, and seed and machinery companies. Also, wildlife, conservation, and other environmental groups may be interested in facilitating adoption of RMPs in some areas.
- Is the community willing to establish a monitoring system to evaluate progress toward improved resistance management, changes in community and human behavior, and adoption of resistance management practices? Does the community have a conflict resolution and compliance system for participants?

Underlying these criteria are necessary conditions applying to any system designed to intervene in pest resistance management. In the absence of these conditions being met, efforts to intervene to improve pest RM are not likely to succeed. The programs must have strong scientific information and effective communications, recommendations, and outreach to the community participants. Sound and consistent scientific information on RMPs have to be disseminated to farmers and community stakeholders so they understand the need for and net benefits of practice adoption and the costs of inaction to the community.

This is not a new idea. County weed commissioners and mosquito abatement districts go back to at least the 1930s. There are a number of examples from area-wide pest eradication and management districts/areas. Typically, these had some form of local, state, and/or federal government involvement at least in coordination. These efforts arose in response to a common pest problem, for example, boll weevil, pink bollworm, mosquitoes, screwworm, weeds, invasive pest species, or other resistance management problems. Although most of these efforts were beyond the scope of a community-based effort, the framework used to implement these projects may serve as a model for local community-based projects (Ervin and Frisvold, 2016; Endres and Schlessinger, 2016, and Miranowski and Carlson, 1986).

What are advantages and challenges of a community-based approach to resistance management?

- Typically, government intervention is a top-down, one size-fits-all approach that does not recognize unique features of the local community, production environment, local farming systems, or characteristics of local farmers and agriculture. A voluntary, community-based approach can be tailored to address local conditions, farming systems, people and community. At the same time, the community-based approach can design RMPs that are appropriate to this environment and slow the development of resistance;

- Community intervention is generally more acceptable to farmers than top-down government intervention. It allows flexibility for local farmers to cooperatively meet local RM challenges adapted to local practices and conditions as opposed to potentially restrictive government RM regulations;
- Community-based approach capitalizes on the community's social network, norms, and institutions to achieve local cooperation, change individual and community behavior, and shape the future economic well-being for farmers and the community;
- Success of community-based intervention will depend on strength of local social network, leadership team, stakeholder participation and commitment, and a deliberate process of building community infrastructure. A strong social network will be required to secure participation, monitoring and enforcement of flexible RMPs, and secure resources to incentivize RMP adoption.
- Community-based approaches are generally slow, deliberate processes of building community infrastructure and institutions, stakeholder participation and commitment, and a sustainable leadership team; if a resistance pest population is highly mobile and capable of causing extensive spill over costs, government regulation or more assertive government-community partnerships may be required to meet rapidly spreading pest management challenges.
- Sometimes if may take a local weed crisis to invoke community-based action!

Three Final Observations

First, the losses in net returns from not adopting RMPs are not necessarily significant for many of the pests and periods of analysis considered, especially in "larger area" studies. Obviously, the same may not hold true in all cases, especially Palmer amaranth, a so-called "wicked weed." Also, farmers in some local communities and areas may have more serious problems managing specific-pest resistance—for example, Bt in heavy livestock production areas—than the state as a whole. These local communities may be more amenable to a community-based approach than the state or large area as a whole (Hendricks et al., 2015).

Second, as Miranowski and Lacy (2016) report for the case of WCR, if neighboring farmers adopt the dominant crop rotation strategy (CS or CCS) in a dynamic game, both win. Alternatively, if one farmer does not, the farmer that uses a CS or CCS rotation suffers little or no loss. Similar evidence from Livingston et al., (2015), shows little significant impact of weed resistance spillovers in the CC and CS rotations but significant impacts in the SS case. Again, these studies considered average impacts for a state and a larger region. The same results may not hold true for a specific area or community.

Third, socioeconomic and behavioral factors may be significant and matter in some cases. These issues are more naturally addressed in a community-based approach but will require cooperation and buy-in by all farmers and agricultural interests in the community. Local monitoring and peer pressure should be able to achieve better community participation relative to government intervention. Such socioeconomic and behavioral factors could create significant distortions in a top-down regulatory approach that focuses on monitoring and enforcement of labeling and other regulatory practices.

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The author thanks Steve Bradbury and reviewers for their helpful comments and his colleagues on the Iowa Pest Resistance Management Plan (http://www.ipm.iastate.edu/content/pesticide-resistance-management-workshop-2015), especially Aaron Gassmann, Mike Owen, and J. Arbuckle, for helpful input and discussions on evaluating community-based pilot projects.