Farmers' dilemma: Social aspects of weed management decisions

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Farmers make numerous complex decisions to manage risks associated with crop production. One such decision is the use of herbicide-resistant crop technologies in cotton, corn, or soybean. Selecting herbicide-resistant traits to use in soybean production has become especially complex as more options become available. Farmers must weigh many factors when choosing a strategy, including their ability to follow application requirements, weather variability, and the future actions of neighboring farmers. The future actions of neighboring farmers are often not known with certainty. The presence of uncertainty increases the complexity of the decision and creates potentially adversarial situations. Understanding why each farmer makes specific farm management decisions may be helpful for individuals that provide advice or mediation in disagreements that arise due to opposing strategies. We use non-cooperative game theory to explain how seemingly irrational weed management practices are in fact rational farm management strategies by presenting a series of scenarios faced by many types of farmers.

Non-cooperative game theory can be used to understand decision making among interrelated parties, such as neighboring farmers when they must simultaneously make management decisions without knowledge of the other's actions. These "games" map out possible scenarios and outcomes, such that each outcome is associated with payoffs for each decision maker. The value assigned to each choice can be a specific value, such as profit, or can simply represent general differences in benefits realized from each strategy. The greater the assigned value, the more beneficial the strategy is for each player. The intent of these "games" are to identify stable outcomes called Nash equilibria.[1] Although a Nash Equilibrium is the most stable outcome, it is not necessarily the best possible outcome for any of the decision makers.

Defining the players as two types of farmers: Defensive Dan and Sprayer Sue

Our "game" has two decision makers who are neighboring farmers. One farmer, "Defensive Dan", pays careful attention to timely spraying and other details on his farm. He is proactive with respect to herbicide resistance management and is not optimistic that a "silver bullet" weed management technology is on the horizon. Dan does not intend to spray dicamba but is trying to decide whether to plant dicamba-resistant soybean or another herbicide-resistant technology.

[1] John F. Nash, Jr. won the Nobel Prize in Economic Sciences in 1994 for his work on equilibria in non-cooperative games. Nash was also the focus of the 2001 movie "A Beautiful Mind".

We denote Dan's strategy of using dicamba-resistant seeds as "Xtend" and that of using another herbicide-resistant technology as "Other". This decision will affect weed management practices, including the possibility of causing crop injury due to off-target herbicide movement (OTM). Dan believes his proactive weed management practices in an Other system results in greater yield and/or lower weed control costs. The decision may also influence yield and profitability if the crop is injured by OTM from someone else's herbicide application. However, the likelihood of this damage is based on unknown factors such as other farmers' spraying behavior and weather conditions at the time of herbicide applications.

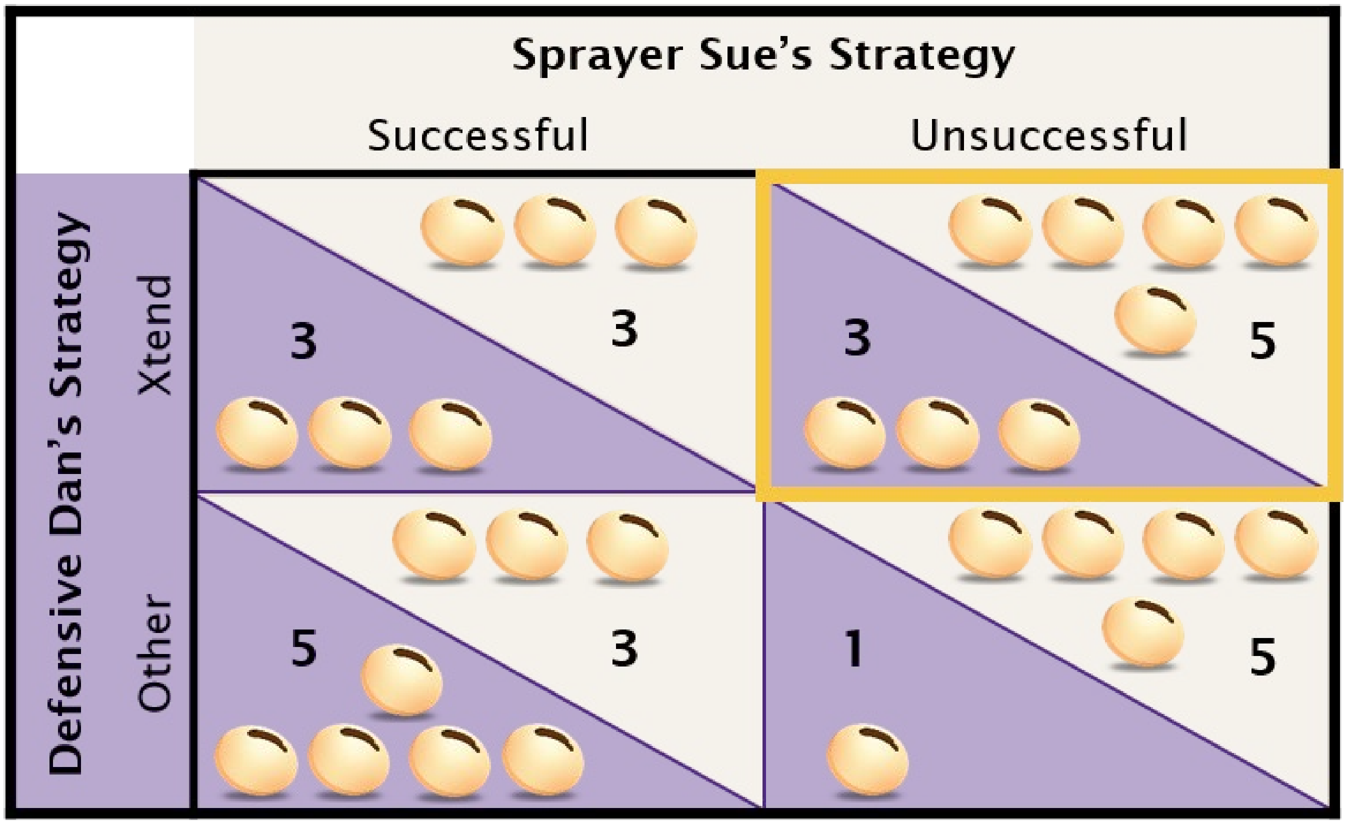
The other farmer, "Sprayer Sue", has limited sprayer capacity and struggles to make timely herbicide applications. She devotes little effort to managing herbicide-resistant weeds and is eagerly looking for the next technology coming from the herbicide industry. She will spray dicamba, but her efforts to follow drift management guidelines may or may not be successful. We denote the two outcomes as "Successful" and "Unsuccessful". When Sue is Successful, little to no injury to nearby sensitive soybean occurs due to OTM. But when Sue is Unsuccessful, OTM does occur such that sensitive soybean in the vicinity are injured with visible symptoms and expected yield loss.

Dan and Sue must choose their strategies simultaneously without full knowledge of the others' action but understanding that the others' action will impact their own payoff. Since we have two players, each with two possible choices, there are four possible outcomes. Each outcome has a payoff for Sue and Dan. The payoffs in each scenario are not specific to any farmer's budget or profit-loss statement, but rather are relative values that reflect differences among strategies with regard to factors such as each player's expected yield, expenses, and intangible transaction costs such as reputation and status in their community. Farmers' expectations may be based on actual or perceived advantages in their operation. The relative values in the scenarios below were chosen in part for clarity of the explanation. In the graphical representation of each farmers' payoff, the payoff for Dan is listed on the left in the purple-shaded triangle and the payoff for Sue is listed on the right. Stable outcomes are indicated by a gold outline.

Scenario 1*: Initial farmers' dilemma of managing OTM*

The values in Payoff 1 are based on a situation that assumes no penalty to Sue if OTM occurs, even though Dan's soybean yield is reduced. The Xtend\Successful cell represents the outcome when Sue's efforts to manage drift are successful and Dan chooses to use Xtend. Remember, Dan believes the Other system results in a larger payoff than Xtend under his management, so if Sue is Successful, Dan is better off to choose Other. However, Dan does not know in advance if Sue will be Successful. If Sue is Unsuccessful, Dan gets a greater payoff with Xtend soybean, as Xtend offers protection against drift damage. The payoff for Sue is the same in both rows, but greater than Dan's payoff when Unsuccessful, due to her belief that advantages associated with simplified herbicide selection in the Xtend system reduce farm management operating costs.

The stable outcome is identified by examining the behavior of each farmer given the other farmer's behavior. A scenario does not have to have a stable outcome and may have more than one stable outcome. If we start with Dan's decision assuming Sue was Successful, his payoff could be either 3 (if Xtend) or 5 (if Other), so Dan would choose Other. If we consider Dan's decision when Sue was Unsuccessful, his payoff could be either 3 (if Xtend) or 1 (if Other), so he would choose Xtend. Now consider Sue's payoffs given Dan's decisions. She could realize a payoff of 3 (if Successful) or 5 (if Unsuccessful) when Dan chooses Xtend, and when Dan chooses Other, Sue's payoffs are still 3 (if Successful) and 5 (if Unsuccessful). Since the only strategy both farmers would select is Xtend\Unsuccessful, it is the stable outcome. In this stable outcome, neither farmer could improve their payoff by choosing differently, given the other farmer's decision.



Payoff 1. Baseline scenario with no penalty to Sue for Unsuccessful spraying. Gold outline indicates stable outcome.

There are a few points that can be taken away from Payoff 1:

1) Dan should use Other soybean if he believes Sue will be Successful, but use Xtend otherwise;

2) Sue is better off to spray without caution (and risk being Unsuccessful), regardless of Dan's decision;

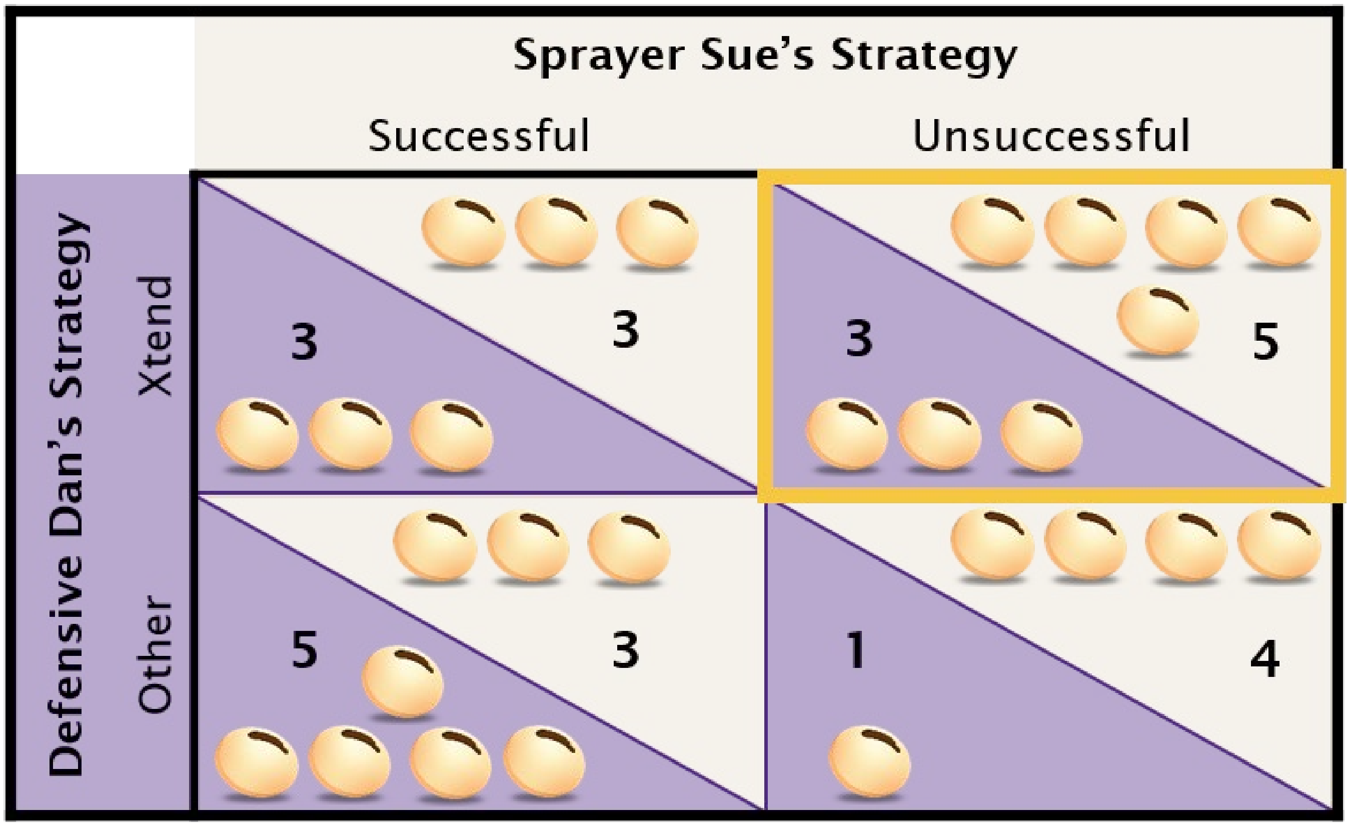
3) The outcomes with greatest combined payoff are Other\Successful, Xtend\Unsuccessful;

4) Xtend\Unsuccessful is the most stable or likely outcome for Scenario 1, because neither farmer can improve their payoff with a different choice assuming the other farmer does not change their strategy. Assuming Sue remains Unsuccessful, if Dan chooses Other instead of Xtend, his payoff decreases from 3 to 1. Assuming Dan remains Xtend, if Sue changes to Successful, her payoff decreases from 5 to 3.

Changes to external factors could alter the stable outcome of this scenario. One possible influence is the imposition of fines by regulatory agencies. This is explored in Scenario 2 and Scenario 3 to determine how the severity of the penalty would alter Sue's behavior. In Scenario 4, players exchange compensation without publicly reporting OTM. The final external influence we examine in Scenario 5 is decreased production costs due to rebates, subsidies, or product pricing.

Scenario 2: *Small regulatory fine for injury caused by OTM*

In Scenario 2, a fine is imposed on Sue when yield damages are incurred by Dan. Modifying Scenario 1, the fine is imposed such that Sue has a payoff of 4 instead of 3 (fine = 1) if she sprays Unsuccessful and Dan plants Other soybean. In this scenario, the stable outcome remains constant at Xtend\Unsuccessful.



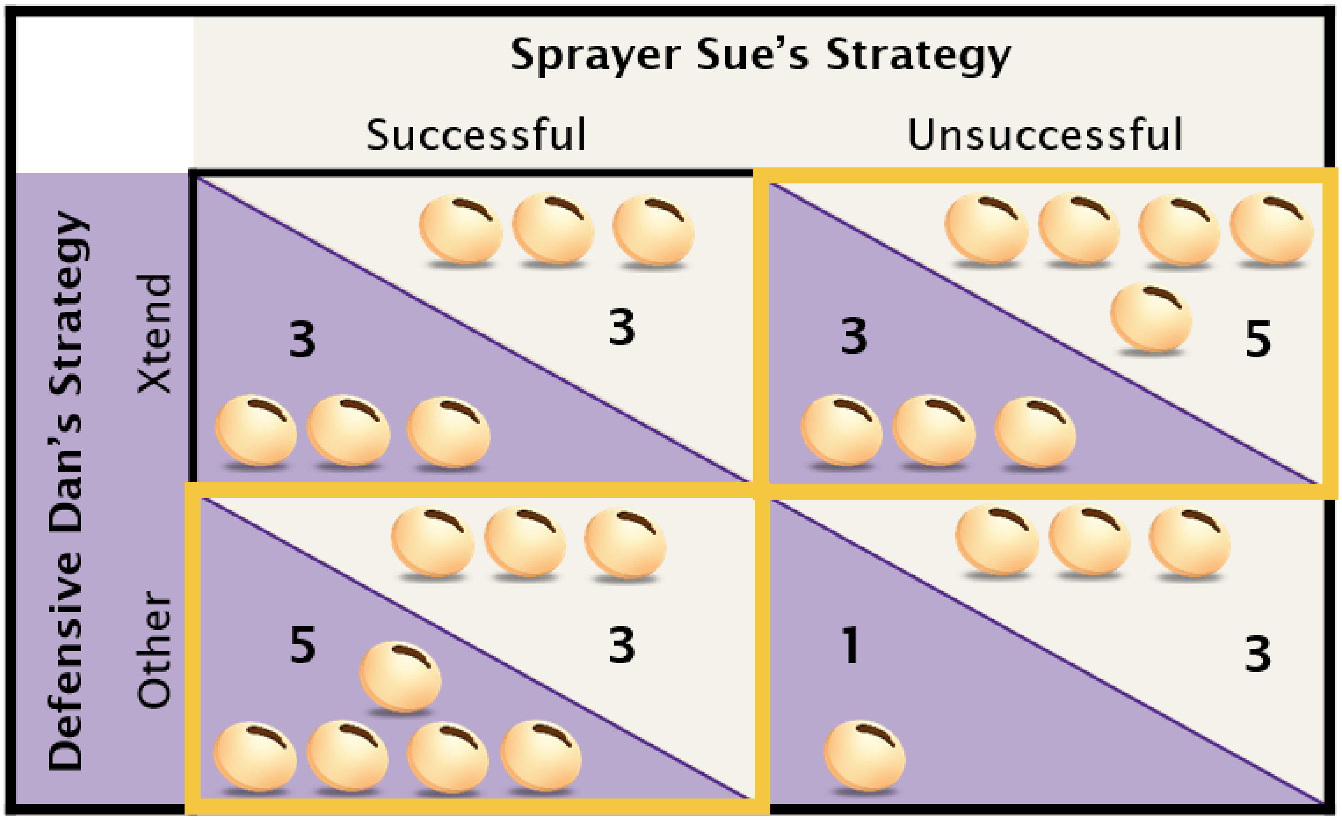
Payoff 2. Small fine imposed on Sue for injury caused by OTM. Gold outline indicates stable outcome.

Payoff 2 can be summarized as:

1) The best seed selection for Dan is still Other if Sue's application is Successful but Xtend if Sue is Unsuccessful;
2) Regardless of Dan's choice between Xtend and Other, an Unsuccessful application is better for Sue;
3) The outcome with the greatest overall payoff for Dan is still Other\Successful;
4) The stable outcome remains Xtend\Unsuccessful, indicating the small fine did not cause a practice change.

***Scenario 3**: Large regulatory fine for injury caused by OTM*

In Scenario 3, a larger fine is assessed when Sue sprays Unsuccessful and Dan realizes a yield loss. If a more severe fine (fine = 2) is assigned to Sue such that the payoff is 3 when Other soybean is injured, then two stable outcomes exist. The large fine results in a smaller payoff for Sue in the Other\Unsuccessful strategy such that Other\Successful *and* Xtend\Unsuccessful become stable outcomes. When sufficiently large fines are imposed on Sue, soybean acreage is split between Xtend and Other and demand for varieties with Other herbicide resistant technology expands as Dan opts for combination of Other and Xtend. For Scenario 3, a change in farm management practices are expected due to the sufficiently large fine assessed for Unsuccessful spray applications.



Payoff 3. Large fine imposed on Sue for injury caused by OTM. Gold outlines indicate stable outcomes.

The summary of Payoff 3 is:

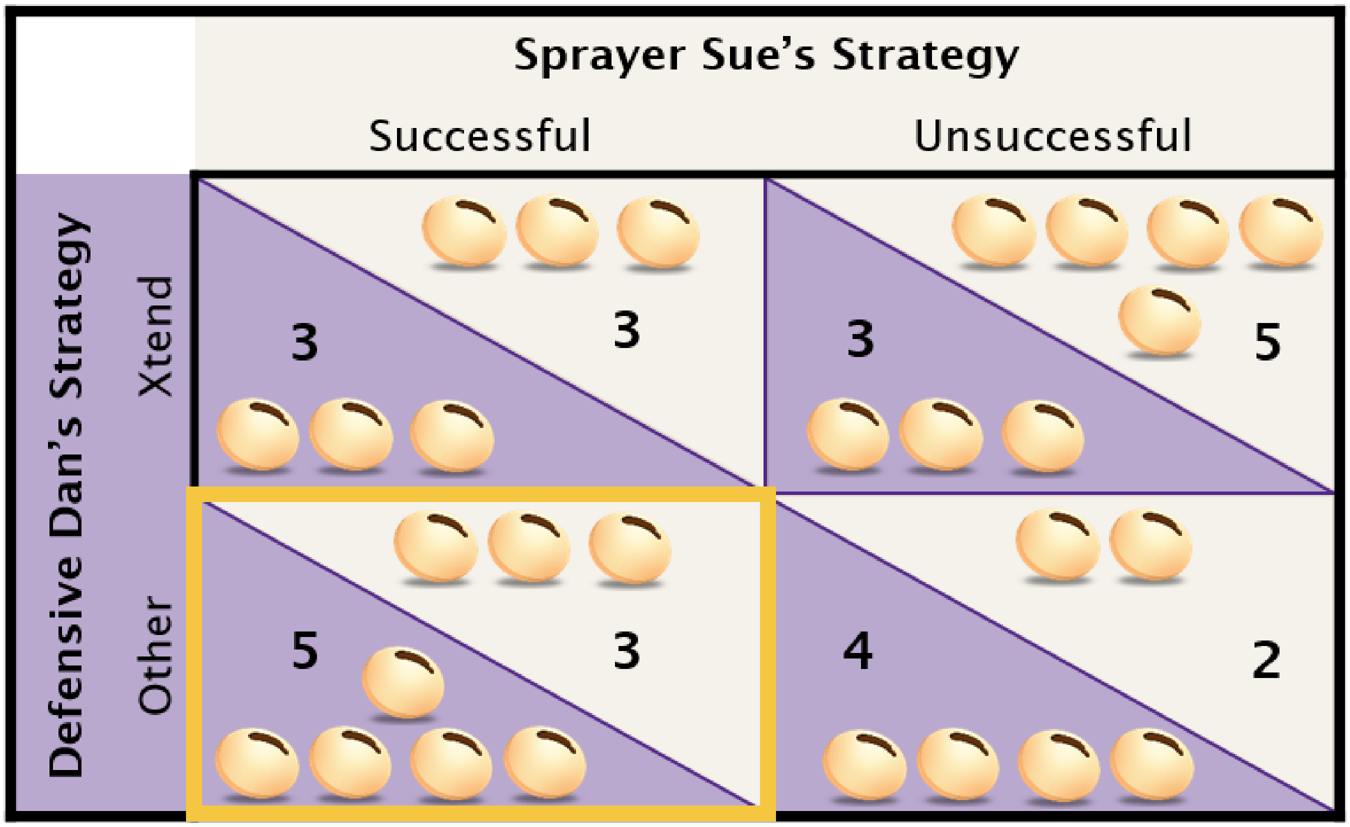
1) Dan should still plant Other soybean if Sue's application is successful and Xtend if the application is Unsuccessful;
2) Sue will still have a greater payoff for spraying Unsuccessful if Dan plants Xtend but her payoff is similar for both types of application if Dan plants Other;
3) The outcome with the greatest payoff for Dan is still Other\Successful;

4) Farm management practices of both farmers have been altered due to the substantial fine on Sue;
5) There are two stable outcomes: Other\Successful and Xtend\Unsuccessful.

Another possible scenario would be for the farmers to reach a bargain; similar to scenarios where Sue pays a fine but in this scenario the "fine" goes to Dan for compensation. For example, Sue could pay Dan if Other soybean have a yield reduction as a result of an Unsuccessful application. Unfortunately, these types of bargains are not always possible.

Scenario 4*: Sue provides compensation to Dan for damages*

Dan may choose not to formally report crop injury to Other soybean and instead seek compensation from Sue. This may reduce the financial and social costs for both parties as compared to filing a publicly-visible formal complaint. If Dan's Other soybean is injured, his payoff increases from 1 to 4 and Sue's payoff decreases from 5 (with no penalty) to 2 relative to Scenario 1. This assumes the compensation to Dan is less than the potential fines imposed by regulatory agencies on Sue or other transaction costs (including intangible costs) incurred by either farmer. Again, the payoffs in Other\Unsuccessful cell are changed. Unlike the previous scenarios, unreported compensation results in Other\Successful as the stable outcome.



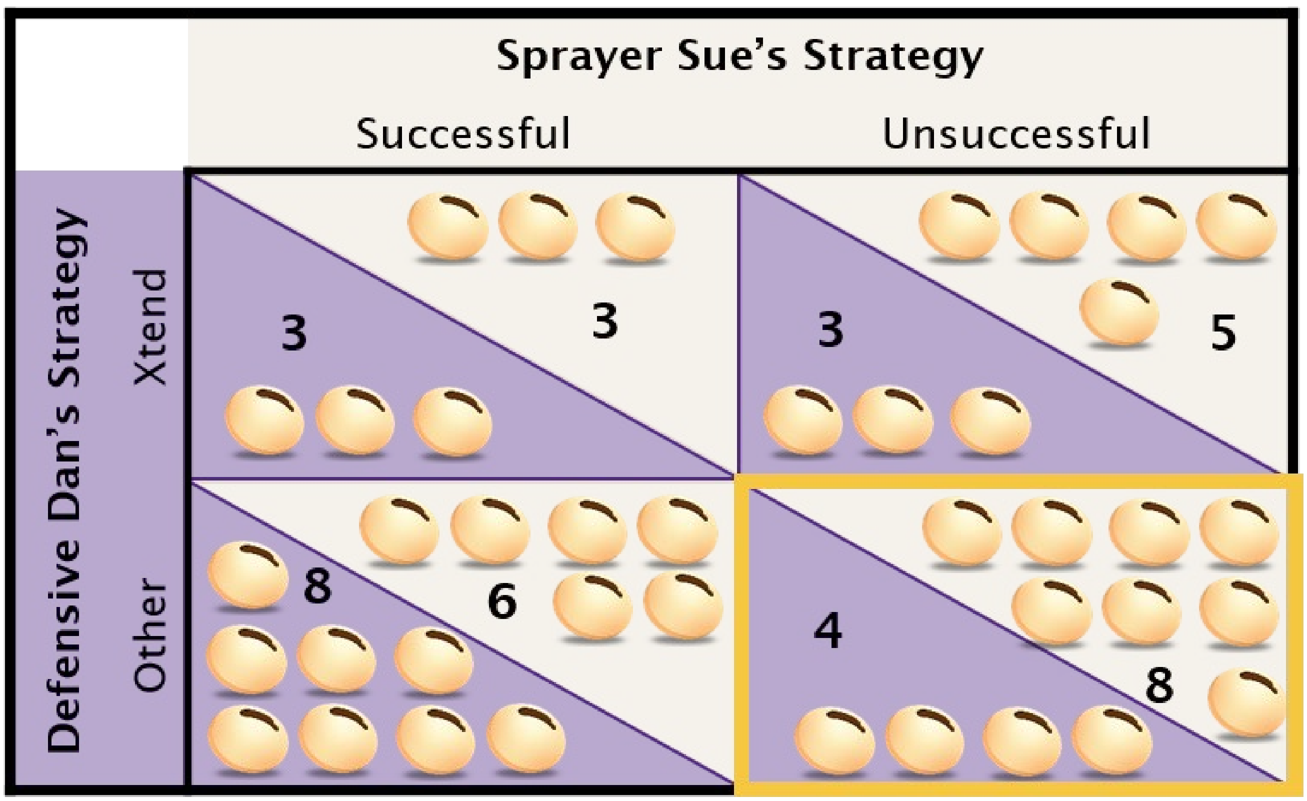
Payoff 4. Sue directly compensates Dan for yield loss from OTM. Gold outline indicates stable outcome.

Payoff 4 is summarized as:

1) Dan should plant Other soybean whether Sue's application is Successful or Unsuccessful;
2) Sue will have a greater payoff for spraying Unsuccessful if Dan plants Xtend and Successful if Dan plants Other;
3) The stable outcome is Other\Successful.

Scenario 5: Pricing strategy lowers cost of producing Other soybean

A manufacturer of crop protection chemicals or seeds may choose to implement product pricing or rebate programs to incentivize a practice change that increases market share. These price changes may be on seed or crop protection chemicals, or they may be subsidies for meeting program criteria. Beginning with Scenario 1, our hypothetical pricing strategy lowers the cost of production in Other soybean such that the payoff increases by 3 when Dan or Sue chooses Other.



Payoff 5. Pricing strategy increases payoff for Other soybean seed. Gold outline indicates stable outcome.

Payoff 5 is summarized as:

1) Dan should plant Other regardless of Sue's actions;
2) Sue's strategy should be Unsuccessful regardless of Dan's planting decision;

3) Practice changes can be prompted when manufacturers strategically adjust prices;
4) The stable outcome is Other\Unsuccessful.

Takeaway message

These scenarios demonstrate how various external factors might influence a farmer's decision regarding which herbicide-resistant crop technology to use. We do not comment on the value of the herbicide-resistant technologies or the consequences of OTM; rather, we seek to recognize that each farmer makes the most rational farm management decision based on beliefs about their own operation and expectations of other farmers' choices. In the first two scenarios, the stable outcome was Xtend\Unsuccessful, indicating that a small fine did not change farmer behavior relative to the initial scenario. When a larger fine was imposed in Scenario 3, two stable outcomes were realized, Xtend\Unsuccessful as in the previous scenarios as well as Other\Successful. When farmers directly compensated one another in Scenario 4, the stable strategy was Other\Successful. In Scenario 5, reduced production costs for Other caused a practice change such that Other\Unsuccessful was the stable strategy. In Scenarios 1, 2, 3, and 5, Dan's decision may not have been the most profitable strategy for his operation, but was the best decision to manage the uncertainty associated with Sue's behavior. Likewise, Sue may appear to make irrational decisions when considering her farm, but her decisions can be explained with game theory when intangible benefits are considered. Thus, these examples illustrate why two farmers operating in a complex environment may choose different herbicide-resistant crop technologies, yet each choice can be explained as rational.

The hypothetical scenarios provided here are of interest to farmers to understand their peers' decision-making process, policy makers considering fines for OTM, manufacturers of seed and crop protection chemicals for pricing and rebate programs, and Extension professionals working with farmers from both groups. While we have chosen to focus the present discussion on soybean trait selection as a strategy to mitigate risk associated with OTM, this theoretical framework can be useful to explain many farm management decisions.

The scenarios presented in this document are intended for educational purposes only and do not imply recommendation of any management practices. Use of specific products is for illustrative purposes only and are not intended as endorsement or disapproval of any product or technology.

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