Technology and Trade-Offs in Managed Ecosystems: The Case of Glyphosate-Tolerant Soybeans

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Farmers use technologies to regulate multiple ecosystem services in support of their crops (Zhang et al. 2007). When they choose among alternative technologies, they implicitly choose alternative bundles of services, which have both on-site and off-site impacts. Such choices often require trade-offs between ecosystem services. New technologies can strengthen or weaken these trade-offs. **In this study, we examine how glyphosate-tolerant (GT) soybean (*Glycine max*) seed has affected the trade-off between weed control and soil health farmers face when choosing a tillage regime.**

Soybeans among a field of glyphosate-resistant Palmer Amaranth (*Amaranthus palmeri*)

Historically, farmers use tillage as a broad-spectrum weed control method throughout the growing season, supplemented with herbicides. With GT seed, farmers can use only glyphosate without intensive tillage or other herbicides. This system provides equivalent weed control while improving soil health, weakening the trade-off between these two services (Perry et al. 2016).

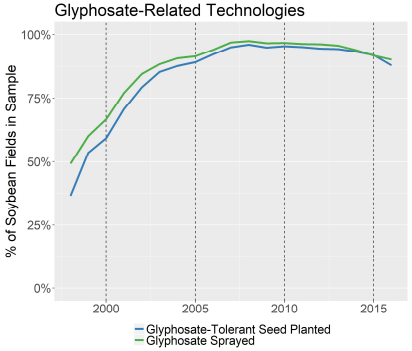
Many weed species have now evolved to resist glyphosate, forcing farmers to respond in order to maintain similar levels of weed control. Farmers can respond by supplementing glyphosate with tillage and other herbicides, which strengthens the trade-off between weed control and soil health. **We exploit spatial and temporal variation in glyphosate-resistant weed populations throughout the United States to measure the impact of glyphosate-resistant weeds on tillage practices throughout the country.**

Data Sources

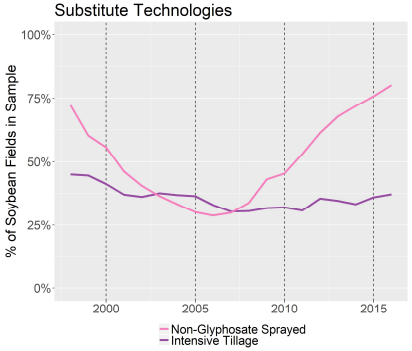
1. **GfK AgroTrak:** field-level herbicide application, seed use, and tillage choice data for thousands of soybean growers throughout the country from 1998 to 2016, recorded in panel format by the market research firm Kynetec
2. **International Survey of Herbicide Resistant Weeds:** state-level records of the year glyphosate resistance is first identified in weed populations, collected by weed scientists across the country
3. **Various federal agencies:** non-herbicide price indices, drought indices, and soil quality indices are collected from USDA-NASS, NOAA, and USDA-NRCS respectively.

Trends in Soybean Weed Control and Tillage Practices

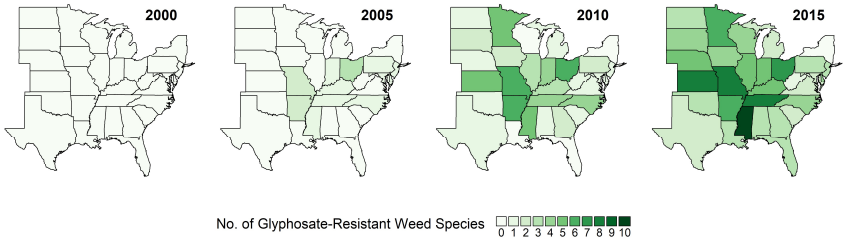
GT seed was rapidly adopted and glyphosate became the dominant weed control technology.



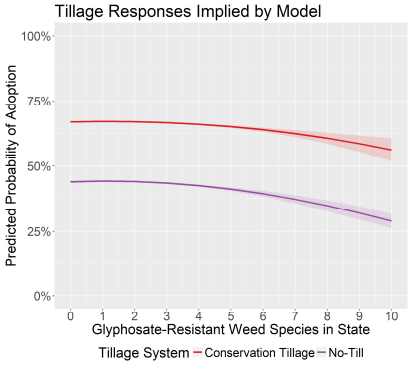
Substitute weed control technology use first decreased, but has since become more frequent.



The return of substitute weed control technologies coincides with the spread of glyphosate-resistant weeds.



Modeling Tillage Responses to Glyphosate-Resistant Weeds



We estimate the statistical effect of glyphosate-resistant weeds on the use of conservation tillage systems with a *nonlinear, multilevel, parametric model*. Our model...

- includes random intercepts at the farm level to control for unobserved heterogeneity;
- accounts for previous tillage decisions at the farm level;
- controls for the use of other substitute herbicides, prices, and regional biophysical conditions; and
- allows for a nonlinear response to the presence of additional glyphosate-resistant weed species.

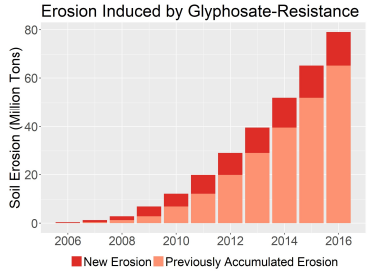
We find that the first few species have little impact. But more species lead to less frequent use of both no-till and other conservation tillage systems. When eight glyphosate-resistant species are present, **conservation tillage use decreases by 6.2 percentage points**, while **no-till use decreases by 9.2 percentage points**, when compared to adoption levels prior to glyphosate resistance. The tillage response curve implied by our model is presented at the left, with all other covariates held at their means.

Impact on Soil Erosion

We use our parametric model to simulate the impact of glyphosate-resistant weeds on soil erosion through the following process:

1. Field-level tillage decisions are simulated under a counterfactual scenario with no glyphosate-resistance and the observed baseline spread.
2. Fields are weighted to represent national soybean acreage under conventional and conservation tillage systems in each year.
3. Erosion rates for each system are applied to resulting scenarios and the difference is attributed to the spread of glyphosate-resistance (Montgomery 2007).

Responses to glyphosate-resistance have accelerated soil erosion rates.



Tillage responses to glyphosate-resistance are responsible for over **79 million tons of soil erosion** into water ways, including **14 million tons in 2016**. Using price parameters from USDA-NRCS cost-benefit analyses, we estimate the social value of this additional soil erosion is approximately $**422 million**. As more weed species continue to adapt to glyphosate throughout the country, the scale of the soil erosion impacts and the value of social damages will continue to grow.

Policy Implications

This research demonstrates how changes in the efficacy of one technology can have secondary effects on the provision of other ecosystem services. As glyphosate efficacy falls, farmers must again make a choice between improved soil health or sufficient weed control, via their tillage decision. Federal and state governments spend over $1 billion annually on programs that encourage the adoption of reduced tillage systems. The cost of such programs is likely to rise as glyphosate-resistant weeds force weed control considerations to affect more and more farmers' tillage decisions.

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References

Montgomery, David R. "Soil erosion and agricultural sustainability." *Proceedings of the National Academy of Sciences* 104.33 (2007): 13268-13272.

Perry, Edward D., GianCarlo Moschini, and David A. Hennessy. "Testing for complementarity: Glyphosate tolerant soybeans and conservation tillage." *American Journal of Agricultural Economics* 98.3 (2016): 765-784.

Zhang, Wei, et al. "Ecosystem services and dis-services to agriculture." *Ecological economics* 64.2 (2007): 253-260.