Aimpoint RESEARCH®

A FUTURE WITHOUT GLYPHOSATE

ASSESSING THE IMPACTS AND COSTS TO AGRICULTURE AND THE ENVIRONMENT

June 2023

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INTRODUCTION

Glyphosate is the most widely used herbicide in the United States, first registered as a pesticide with the U.S. Environmental Protection Agency (EPA) in 1974. Since that time, it has proven to be an effective, cost-efficient weed control tool and enabled farmers to add conservation practices to millions of additional acres year after year by moving from full tillage to conservation tillage, no-till, and/or cover crops. These practices create healthier soils, cleaner water, and climate resiliency through carbon reduction.

In early 2020, an interim decision registration review decision (ID) by the EPA stated there are "no risks of concern to human health when glyphosate is used in accordance with its current label" and "the benefits of glyphosate outweigh the potential ecological risks when glyphosate is used in accordance with labels."

However, a recent series of challenges in the U.S. Court of Appeals and ongoing public debate has led many to question what a future without glyphosate would look like. The following "A Future Without Glyphosate" report[1] leverages multiple research and analytical methods, including open-source research, economic modeling, subject-matter expert interviews, and military wargaming techniques to understand the complexities of glyphosate's impact on agriculture and outline what the future could look like without it.

Ultimately, we conclude that if glyphosate were no longer available markets would adapt through substitution and adjusted practices, but at a substantial cost to farmers and the environment. U.S. farmers would bear the burden of increased input and operating costs with small farmers disproportionately affected. Further analysis reveals a cascading chain of likely higher order effects and unintended consequences, the most impactful being the rapid release of additional greenhouse gases and the reversal of decades of conservation and sustainability gains. The loss of glyphosate would not be trivial.[2]

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[1] Environmental Protection Agency, Glyphosate, updated September 23, 2022, https://www.epa.gov/ingredients-used-pesticide-products/glyphosate, accessed May 2023.

2 This report has been commissioned by Bayer. It was prepared independently by Aimpoint Research, and the conclusions contained in this report are our own.

How Glyphosate is Currently Used

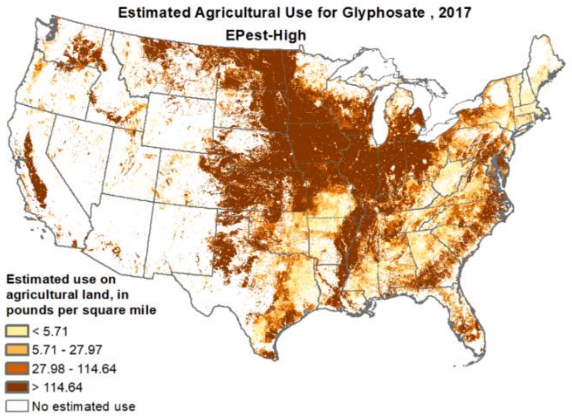

Figure 1 – 2017 Glyphosate use, SOURCE: EPA

Glyphosate is a non-selective herbicide that blocks an enzyme essential for plant growth. It is widely used in U.S. agriculture because it is highly effective at killing most plants. Several commodity seed companies have successfully created varieties which can tolerate glyphosate, allowing farmers to apply the chemical in active fields without killing the cash crop. Some weed varieties have evolved and developed resistance, but glyphosate remains in a high percentage of mixes as one-in-many modes of action. Post-harvest applications of glyphosate are used on winter wheat double crop acres, rather than tillage, to ensure soybeans are planted under weed free conditions.

Farmers also use herbicides to rapidly transition a field from cover crop to cash crop without the need for seed bed tillage. Terminating the cover crop is often done with a combination of herbicides, but the most widely used herbicide in the mix remains glyphosate. It is an integral part of terminating both rye and wheat as well as legume cover crops.

Selecting a Future Without Glyphosate

Our desired outcome is to describe how the agri-food value chain will adapt to, and the plausible consequences associated with, a U.S. farming system without access to glyphosate. Therefore, we explored multiple situations which could reasonably lead to glyphosate no longer being available to U.S. farmers. We are not focused on, nor do we address, how to identify or avert the situations considered.

Glyphosate remains the target of several advocacy groups seeking to restrict or prevent its use through state and federal policy influence. State-by-state action could establish barriers to the use of glyphosate and a complex patchwork of regulations creating a serious practical threat to its manufacture and distribution. Current indicators of potential threat include:

> Various states have considered bans or restrictions on glyphosate, including New York, Massachusetts, and Vermont.[3] The web-based platform Change.org which originates and circulates various policy and other petitions, has targeted a glyphosate ban petition at every state in the U.S.[4]
>
> California, with strict regulatory standards for warning labels and an enormous population, is effectively establishing a parallel labeling standard in contrast to federal standards. The threat of a default “California standard” is very real and is playing out in other policy arenas as well, such as auto emissions under the Clean Air Act, and state animal welfare regulations recently upheld by the U.S. Supreme Court.

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[3] It is noteworthy, as illustrated in the NRCS maps presented later, that these states considering bans on glyphosate are in regions with the least emissions reductions from the adoption of conservation tillage.

[4] The Carlson Law Firm; Texas based law firm pursuing class action suits linking glyphosate to non-Hodgkins Lymphoma.

> Mexico has proposed a ban on glyphosate and genetically modified corn, including imports from the U.S. Mexico is a traditional top market for U.S. corn exports. Bifurcating the market for a fungible supply of U.S. corn, and effectively realigning the international market, resulting from the U.S. government failing to defend sound science under various international trade forums, also catalyze the reduction of glyphosate use.
>
> The U.S. Environmental Protection Agency (EPA) is reassessing glyphosate under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA); the review is expected to be finished in 2026.

The specific mode of restriction is less interesting for this study than the timing and impact to the agri-food value chain. The timeline under which the potential loss of glyphosate plays out is likely to be a function of the specific adverse action taken.

> An immediate loss of federal registration through regulatory action or statutory ban would trigger the most near-term impact.
>
> Loss of federal preemption would progress over a slightly longer period, and certainly one fraught with more uncertainty. However, a loss of preemption could be expected to catalyze a rapid succession of state level actions. While the details of how multiple jurisdictions would move forward are difficult to predict, the degree of political risk would likely reach a point where the market for glyphosate would incorporate these risks and effectively create very short-term impact.

This final future statement served as the stimulus for eliciting subject matter expert feedback, assumptions, and theoretical actions.

> ***“You are one of several actors within the U.S. agri-food value chain just learning that glyphosate is no longer allowed to be used in the United States. Describe how your operations, business, or practices would react.”***

BUILDING THE FUTURE SCENARIO[5]

Aimpoint's analysis is rooted in military strategy, strategic intelligence, and scenario engagements. For the following assessment and analysis, Aimpoint's internal team of analysts, economists, and geopolitical experts leveraged the insights of outside topical expert advisors and conducted an internal wargame process to drive the future state scenario analysis.
The following is a scenario derived from the reactions of subject matter experts when confronted with the future statement, mapping of anticipated decisions, and integration of mathematical modeling where applicable.

How the Agri-food Value Chain Adapts

Farmers react and endure higher costs starting in year one

In year one, farmers are forced to switch to other herbicide products. As shown in Figure 1, shifts are expected primarily in the North Central and Midwest, Northern Plains, South Central, and Southern and Central Plains regions. Crops primarily impacted include soybeans, corn, cotton, and wheat – altogether accounting for over half of the harvested acres in the United States. Functional alternatives to glyphosate are available at double the cost as compared to the cost experienced the year earlier with glyphosate.

Many farmers are constrained by increased costs of seed, technology, and machinery resulting in reluctance to change tillage practices in the first year. However, they start to reconsider their tillage practices moving forward in the near term.

Farmers also face a constrained supply of *all* herbicides due to increased demand for alternatives, ill-positioned stocks, and disruptions in the supply chain. Scarcity increases the cost for less economically efficient alternatives.

New and additional costs would mount over time due to required investments in equipment, implements, and technology as farmers adopt more intensive tillage practices. Notably, 2023 saw machinery values – both new and used – at record high levels from which they are not expected to recover with the renewed demand for equipment. On-farm fuel costs increase as farmers convert to intensive field operation practices requiring more field passes and greater horsepower.

Labor costs increase. This includes direct hired labor and the opportunity costs of farmer operators' unpaid labor and overhead as off-farm income opportunities are abandoned due to the additional time spent on active farm management.

Costs remain high in year two as weed pressure and herbicide resistance increase

Higher costs of production necessitate more borrowing, reducing cash flows and farm debt-to-equity ratios. Agricultural lenders are forced to assume more risk in their loan portfolios and producers accept less favorable terms for operating loans.

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[5] A *scenario* is a narrative description created today that takes place in the future. It provides relational, personal, cultural, and structural dimensions that reasonably exist within the future conditions.

A small percentage of farmers begin noticing increased weed pressure and previously existing herbicide resistance that glyphosate addressed, now requiring additional passes either with different chemistries or more intensive tillage.

Small farmers feel a disproportionate impact from higher costs. Some recognize the loss of off-farm income and the reduced profitability and decide to liquidate while land values are still high. Larger growers able to manage increased marginal costs seize the opportunity to purchase and consolidate other operations.

Equilibrium, but at a cost

Crop production practices shift to a new equilibrium after four years at the expense of conservation gains and environmental impact. Farm profitability over the medium term continues to suffer from the loss of glyphosate; at the five-year mark farm profitability equilibrates but returns only to pre-2008 averages based on higher input costs.

Smaller producers operating at higher costs and lower scale experience a lack of sustainable profitability and are more likely to exit crop production. Chapter 12 bankruptcy filings increase. Costly *ad hoc* relief payments from Congress increase.

The combined effect of financial and economic shifts creates new political pressures for the next iteration of the farm bill, leading to proposals for fundamental restructuring of programs under Title I *Commodity Programs* and Title II *Conservation*. The farm policy debate becomes more contentious, circa the late 1980s.

Ultimately, farming practices adopted to survive a post-glyphosate era pit profitability against environmental benefits. Consolidation of farming operations in the U.S. accelerates to address production costs and maintain per acre margins.

Research and investment in the agrichemical sector are set back decades while U.S. agriculture is no longer positioned as a leading industry in mitigating climate change.

Unintended Environmental Impacts

Alternative products, while functional for weed control, have less favorable environmental profiles, and health risks.

Soil tillage increases over time, resulting in less soil capture of carbon, and increased fuel use from more field operations, resulting in more carbon emissions.

Reduced cover cropping and other conservation practices leads to potential increases in sediment, erosion, water quality, carbon capture and other environmental benefits.

Soil health deteriorates with farmers experiencing increased erosion and incremental declines in long-term farm productivity.

Industries and government reactions

Leverage in merger and acquisition deals shifts toward suppliers of alternative technology providers and away from larger, existing traditional input suppliers. Biological, mechanical, and other innovations ramp up research, production, regulatory approval requests, and marketing to farmers.

Herbicide manufacturers accelerate production of alternative products to mitigate revenue losses. The regulatory approval pipeline is overwhelmed, slowing approvals and registrations. EPA requests additional appropriations from Congress and a 5-10-year[6] period to clear the backlog.

Advocacy groups, having achieved a long-sought objective, lose glyphosate as a fundraising tool and operational model, spawning a new strategy to target other herbicide products.

The combination of higher risks of being targeted by advocacy groups and a longer, slower regulatory approval process by EPA and state agencies adversely impact return-on-investment projections and dampens interest in new agrichemical investment. This encumbers the traditional crop protection industry's ability to finance research and patent alternatives.

A few primary suppliers initiate costly legal action and regulatory advocacy targeted at EPA and states with only a slight chance of reversing the decision. Smaller suppliers protect their thin margins and remain vocal but unwilling to throw their money into the fray.

After years of legal battles, major manufacturers choose *not* to defend their glyphosate positions and focus instead on future technologies. Farmers react by purchasing chemistry and seed from other providers. These companies attempt to recover trust and reputation through discounts and significant information campaigns but lose a generation of farmers who feel abandoned and prejudice the next generation against switching back.

MODELING AND IMPACT ANALYSIS

Following is Aimpoint's analysis from modeling and performance benchmarking in five key areas: Economic Impact on Agriculture, Environmental, Geopolitical, Food Prices, and Innovation.

Economic Impact on Agriculture

Without glyphosate, there would be one of two changes in production practices – or a combination thereof – for soybean, corn, wheat, and cotton farmers:

- → First, farmers will seek alternative products, including existing chemistries and alternative weed control technologies.
- → Second, some farmers will adopt increased tillage practices.

The following models provide an estimate of the range of costs.

Alternative Chemistries Some of the key alternative chemistries to glyphosate are shown below. The cost data is taken from Farmers' Business Network (FBN) and the use rate data below is based on the label.

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[6] Regulatory approval processes can extend 12-17 years from the date of submission to the Agency at a cost per new compound of more than $100 million.

Alternative Chemistries to Glyphosate				
	Avg Cost Per Gal	*Rate (oz /ac)*	*$ /acre / application*	*Labels from*
Glyphosate - RoundUp Powermax 3	$55.95	20	$8.74	Bayer / Monsanto
Clethodim	$91.64	12	$8.59	Valent
w/Dicamba - XtendiMax	$56.19	22	$9.66	Bayer
w/2,4-D (Enlist One)	$49.90	32	$12.48	Corteva
Glufosinate - Liberty 280 SL	$78.22	32	$19.56	BASF
Outlook	$107.82	12	$10.11	BASF

Source: FBN, product labels compiled by Aimpoint Research

Based on a two-pass herbicide system (crop burndown/termination plus an over-the-top application) the table below shows the increased costs per acre of these alternatives compared to glyphosate which ranges from two, to two-and-a-half times more expensive per acre than glyphosate.

Glyphosate Comparison: Cost per Acre per Year		
Annual Cost of Weed Control using:	*$USD per Acre*	*Cost/Acre vs Glyphosate*
Glyphosate Only	$17.48	NA
Clethodim + Dicamba	$36.50	2.09 X
Clethodim + 2,4-D	$42.13	2.41 X
Glufosinate	$39.11	2.24 X
Outlook + 2,4-D	$45.17	2.58 X
Outlook + Dicamba	$39.53	2.26 X

Source: FBN, product labels compiled by Aimpoint Research

Below is data from 2019 compiled by the Environmental Protection Agency (EPA) for the percent of acres by crop on which glyphosate is applied, and the rate of application by active ingredient (AI) and number of applications.

Glyphosate Usage			
Commodity	*Acres with Glyphosate Applied*	*Application Rate lbs active ingredient*	*# Apps*
Corn	80%	0.95	1.3
Soybeans	92%	0.97	1.6
Cotton	89%	1	2.2
Wheat	41%	0.75	1.2

Source: EPA, Watts and Associates, Aimpoint Research

Taking the cost per acre of $17.48 adjusted for AI at 5.4 pounds, for a cost of $3.24, and cost of diesel at $4.14 per gallon, with the application rate and number of applications, yields the following production costs per commodity.

Glyphosate Production Expense			
Commodity	*Cost of Glyphosate*	*Cost of Application*	*Total Cost*
Corn	$307,505,160	$465,953,238	$773,458,398
Soybeans	$369,155,880	$547,837,287	$916,993,167
Cotton	$65,172,600	$93,816,360	$158,988,960
Wheat	$39,288,240	$75,407,552	$114,695,792
Total	$781,121,880	$1,183,014,436	$1,964,136,316

Source: EPA, Watts and Associates, Aimpoint Research

Increased Tillage As shown above, alternative chemistries are two to two-and-a-half times the cost of glyphosate. The other option for weed control is increased tillage. Based on the same cost of diesel and the increased cost of field cultivation, production costs would also nearly double – increasing by more than $1.935 billion.

Change in Costs Replacing Practice with Tillage			
Commodity	*Glyphosate Practice Cost*	*Substitute Tillage Cost*	*Added Costs*
Corn	$773,458,398	$1,428,022,296	$654,563,898
Soybeans	$916,993,167	$1,766,016,986	$849,023,819
Cotton	$158,988,960	$181,418,406	$22,429,446
Wheat	$114,695,792	$524,554,229	$409,858,437
TOTAL	$1,964,136,316	$3,900,011,917	$1,935,875,600

Source: EPA, Watts and Associates, Aimpoint Research

Environmental

Alternatives The loss of glyphosate would leave a gap in weed control options, not only in farm operating costs, but also in functionality and potential environmental impact. First, unlike glyphosate, many alternative products are not 1) applicable to all parts of the U.S. and variety of crops at scale, 2) not for "over-the-top" application, and 3) are not registered for both broadleaf and grasses.

Second, wider spread application of likely alternatives, such as glufosinate and 2,4-D, pose potentially higher risks of environmental impact. Many alternatives have lower soil adsorption factor ratings; higher Environmental Impact Quotient (EIQ) ratings, and higher bioaccumulation factors.

These metrics raise environmental concerns from the expanded use of alternatives in lieu of glyphosate for water quality, wildlife and aquatic species, and overall health and safety.

Environmental Profile of Glyphosate versus Alternatives

	Soil Adsorption Coefficient (L/kg)	Bioaccumulation Factor	Environmental Impact Quotient	Ecology Value	Biodegradable Half-Life (days)
Glyphosate	**1,030**	**2.04**	**15.33**	35	4.46
Glufosinate	425	NA	20.2	42.6	3.55
2,4-D	52.2	68.8	16.67	34	3.55

Key:
Biodegradable Half Life: predicted averaged from EPA CompTox dashboard.
Soil Adsorption Coefficient: EPA CompTox dashboard; the higher the number, the tighter the chemical binds to the soil and the less mobility it has
Bioaccumulation Factor: EPA ComptTox dashboard; a factor > 1 means the concentration of the chemical in the animal is higher than the concentration in the medium (soil, water, air, etc.), i.e., higher numbers are more concerning.
Environmental Impact Quotient (EIQ): value calculated by Cornell University to provide data comparing the environmental and health impacts of pesticides; EIQ Value is average from 3 areas -ecology, farm worker, and consumer, lower EIQ = less impact
Ecology Value (component of EIQ) including impacts on fish, birds, bees, terrestrial animals, beneficial insects, and ground water leaching, lower = less impact

Source: Environmental Protection Agency, CompTox Chemicals Dashboard (epa.gov) , Cornell College of Agriculture and Life Sciences, EIQ Pesticide Values | CALS (cornell.edu), Aimpoint Research

Based on soil adsorption[7], the use of all alternatives would be expected to result in greater leaching into ground water. Glufosinate poses an increased threat of ecological impact on fish, bird, and wildlife while 2,4-D provides negligible marginal benefit at the cost of more leaching and runoff.

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[7] The process of how a liquid adheres to the surface of a solid such as soil.

Glyphosate's low bioaccumulation and ecology impact rating is a key metric given EPA's on-going re-evaluation of glyphosate per a challenge in U.S. Court of Appeals for the Ninth Circuit to the Agency's interim review decision. That challenge was based in part on the assertion that EPA's review under FIFRA triggered Endangered Species Act (ESA) obligations. Hence EPA is now addressing ESA requirements in its ecological review but declared in its interim decision *"the benefits of glyphosate outweigh the potential ecological risks when glyphosate is used in accordance with labels*." [8]

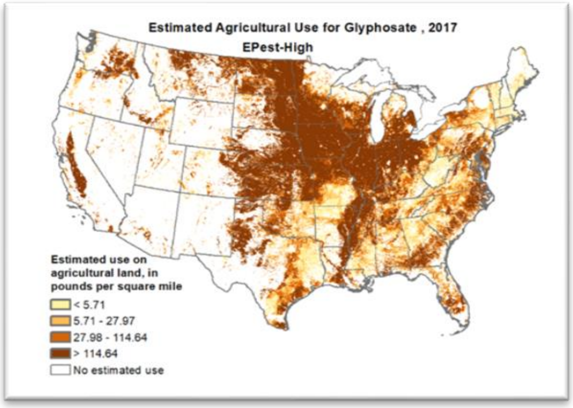
Increasing weed resistance to glyphosate is acknowledged by farmers as an ongoing concern. Producers report greater use of tank mixes with multiple modes of action. However, most mixes continue to include glyphosate, even when not relying solely on it. Thus, glyphosate remains a key tool for weed control and conservation agriculture but not at historical levels.

Tillage Although viable alternatives are available for reduced tillage practices, a loss or restriction of glyphosate could result in marginal increases in tillage for weed control as well as reductions in cover cropping practices. Minimizing soil disturbance consistently over time, maintaining crop residue on the soil surface, and use of cover crops aids in reducing erosion, conserving soil moisture and improving soil health.

The adoption of these soil health practices can improve rainfall infiltration rates and soil water-holding capacity, reducing environmental damage due to sediment, nutrient, and pesticide runoff while increasing drought resilience by reducing the impact of drought on crop yields and reducing irrigation. These practices dramatically reduce fuel use and related emissions. According to NRCS,

> *As expected, most soils gaining* (sequestering) *carbon are under continuous no-till or reduced tillage, …. Nearly 60 percent of all acres losing* (emitting) *carbon are conventionally tilled and could benefit from additional conservation*.[9]

Based on crop practice data from USDA's 2017 Census of Agriculture, and EPA data on glyphosate application from the same year, reduced tillage and no till practices correspond regionally with glyphosate use. Conservation tillage is particularly beneficial in these regions where crop rotations and cropping intervals lead into fallow periods on farmland.



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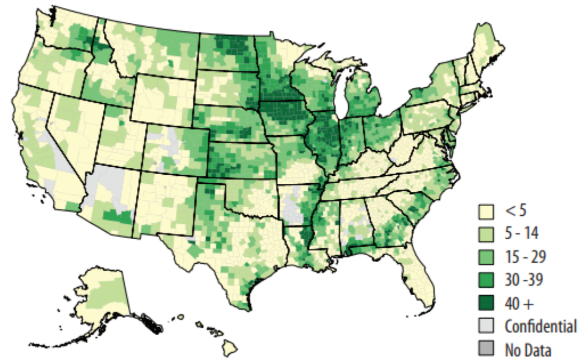
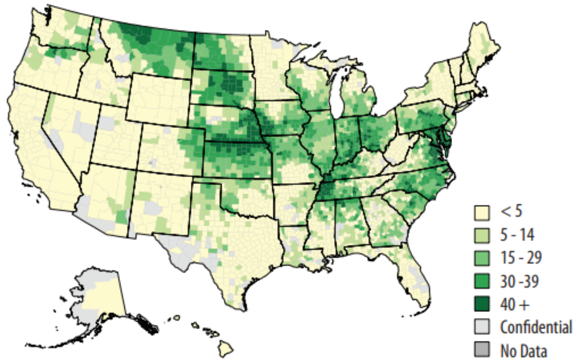
[8] Environmental Protection Agency, *Glyphosate Proposed Interim Registration Review Decision Case Number 0178*, 35, posted May 6, 2019, https://www.regulations.gov/document/EPA-HQ-OPP-2009-0361-2344 accesses June 20, 2023.

[9] Natural Resource Conservation Service, USDA, *Conservation Practices on Cultivated Cropland: A Comparison of CEAP I and CEAP II Survey Data and Modeling*, 68, March 2022, https://www.nrcs.usda.gov/sites/default/files/2022-09/CEAP-Croplands-ConservationPracticesonCultivatedCroplands-Report-March2022.pdf accessed June 20, 2023.



Reduced Tillage Acres as Percent of Total Cropland Acres, by County, 2017



No Till Acres as Percent of Total Cropland Acres, by County, 2017

Glyphosate-enabled conservation agriculture has proven to be a foundational technology for achieving negative carbon emissions from farmland cultivation.

The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS), as part of its Conservation Effects Assessment Project (CEAP), has quantified and reported on the environmental gains from reduced tillage.[10] The CEAP data show the results, measured over a decade, from a 2003-2006 benchmark assessment and then again in a 2013-2016 follow up assessment. During that time, NRCS notes that conservation tillage systems grew to where they were ultimately used for at least one crop in the rotation on 87 percent of cultivated acres.

Overview of Resource Benefits from CEAP I to CEAP II			
Resource Concern	***Per Acre % Change***	***Total Volume Change***	***Unit***
Sediment	-21%	-73,695,526	tons
Irrigation Water	-19%	-6,977,438	acre/feet
Water Erosion	-12%	-69,966,098	tons
Wind Erosion	-15%	-93,753,394	tons
Fuel Use (diesel equiv)	-10%	-110,000,000	gallons
CO2 equivalent emissions		-1,221,000	CO2e
Soil Carbon	39%	+8,862,346	tons
CO2 equivalent sequestration		+32,495,269	CO2e

Source: USDA Natural Resource Conservation Service CEAP II Cropland Assessment 2013-2016, EPA, Aimpoint Research

In addition to benefits for erosion and soil carbon capture, fewer tractor field passes and lower necessary horsepower for pulling heavy tillage equipment yield lower fuel consumption and related greenhouse gas emissions, as shown in the table above.

According to NRCS, continuous no till, at 33 percent of all cultivated acres, represents nearly half (48 percent) of reduced on farm fuel use and reduced emissions - in addition to the increased carbon sequestration from undisturbed soils.

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[10] Natural Resource Conservation Service, USDA, *Conservation Practices on Cultivated Cropland: A Comparison of CEAP I and CEAP II Survey Data and Modeling*, March 2022, https://www.nrcs.usda.gov/sites/default/files/2022-09/CEAP-Croplands-ConservationPracticesonCultivatedCroplands-Report-March2022.pdf accessed June 20, 2023.

Combining the soil carbon capture and reduced on farm fuel emissions from the CEAP data at 33.72 million tons of CO2 equivalent, represents the emissions from 6.8 million gasoline powered passenger cars driven for a year, or the electricity use of 5.95 million homes. Moreover, that CO2 equivalent is equal to the carbon sequestered by 36.475 million acres of forests, yet while still producing food, fiber, and feedstock for renewable fuel.[11]

NRCS further calculated in its CEAP analysis the aggregate reduction in fuel use from conservation tillage, compared to a baseline of complete conventional tillage would save an additional 753 million gallons of diesel fuel, ***roughly equal to the emissions from 1.7 million passenger cars.***[12]

NRCS CEAP Estimated Reductions in Annual Fuel Use and Related Emissions from Conservation Tillage

Tillage Type	***Average Fuel Use/Acre* (gallons)***	***Fuel Use Reduction (million-gallon diesel equivalents)***	***Emission Reductions, in CO2 equivalents (US tons)***	***Acres***	***% of Acres***
Continuous Conventional	5.4	N/A	N/A	42,052,416	13
Seasonal Conventional	3.6	113	1,265,600	62,718,841	20
Continuous Mulch	3.1	139	1,556,800	60,212,092	19
Seasonal No-Till	2.4	144	1,597,128	47,211,285	15
Continuous No-Till	1.8	368	4,132,800	103,108,466	33
Total		763	8,552,328	315,303,100	100

Source: USDA Natural Resource Conservation Service, CEAP-Croplands-2022-ConservationInsight-FuelSavingswithConservationTillage.pdf (usda.gov)

Approximately 80 percent of reduced fuel use was in three primary regions: North Central and Midwest, Northern Plains, and Southern and Central Plains, corresponding with the primary use of glyphosate and reduced tillage practices.

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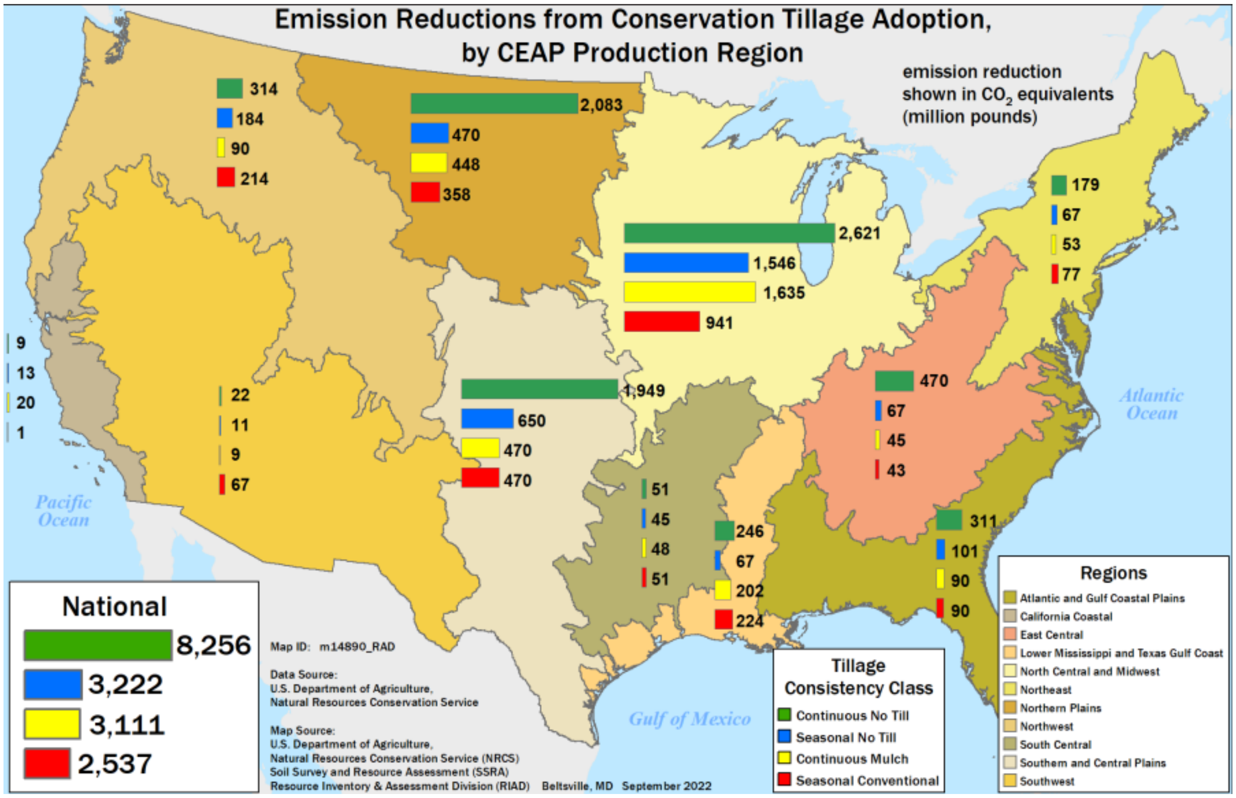
[11] Environmental Protection Agency, Greenhouse Gas Equivalencies Calculator, updated April, 2023, Greenhouse Gas Equivalencies Calculator | US EPA Greenhouse Gas Equivalencies Calculator | US EPA, accessed May 2023.

[12] Natural Resource Conservation Service, USDA, *Conservation Practices on Cultivated Cropland: A Comparison of CEAP I and CEAP II Survey Data and Modeling*, March 2022, https://www.nrcs.usda.gov/sites/default/files/2022-09/CEAP-Croplands-ConservationPracticesonCultivatedCroplands-Report-March2022.pdf accessed June 20, 2023.



Emission Reductions from Conservation Tillage Adoption, by CEAP Production Region

emission reduction shown in CO_2 equivalents (million pounds)

Map ID: m14890_RAD

Data Source:
U.S. Department of Agriculture,
Natural Resources Conservation Service

Map Source:
U.S. Department of Agriculture,
Natural Resources Conservation Service (NRCS)
Soil Survey and Resource Assessment (SSRA)
Resource Inventory & Assessment Division (RIAD) Beltsville, MD September 2022

Per NRCS, one consequence of reduced tillage has been a decrease of applied nitrogen that is incorporated into the soil. This yields a marginal offset of emission reductions, however, on a net basis, soil capture of carbon and reduced fuel use far outweigh any effects of lower soil integration of applied nitrogen.

Of the regions identified above, the reduced soil integration of applied nitrogen from the CEAP I to CEAP II periods were as follows:

- → North Central and Midwest, 75% nitrogen integration dropped to 70%
- → Northern Plains, 80% nitrogen integration dropped to 68%
- → Southern and Central Plains, 72 % nitrogen integration dropped to 58%

Double/Cover Cropping Double cropping and cover cropping play important roles for maintaining the long-term viability of no-till farming. These practices help suppress weeds, slow the evolution of herbicide resistance in weeds, protect soil from erosion and runoff, and enhancing fertility. Double cropping generates additional crop revenue from a fixed number of acres of land, increasing on-farm per acre productivity.

Without glyphosate, less double cropping would occur, especially for winter wheat followed by soybeans. Cotton is also double cropped behind winter wheat in the South. Post harvest applications of glyphosate are used on winter wheat double crop acres – rather than tillage - to ensure soybeans are planted under weed free conditions. Without glyphosate, weed control options would be limited for this crop program, as well as others.

Farmers also use glyphosate as a tool to transition a field from cover crop to cash crop without the need for seed bed tillage. Terminating the cover crop is often done with a combination of herbicides, but the most widely used herbicide in the mix remains glyphosate. It is an integral part of terminating both rye and wheat as well as legume cover crops, a broad-spectrum effectiveness that is lacking in other alternatives.

Over the CEAP I to CEAP II period cover cropping grew from 3.8 million acres to 20.3 million acres. Per NRCS, where cover crops were part of the rotation, gains in soil carbon capture were nearly 30 percent higher than where cover cropping was not used. Likewise, sediment and nitrogen losses were reduced by 17 percent, and total phosphorus loss by 9 percent.

It should be noted that a rapidly growing trend in cover cropping is “green planting,” or planting cash crops into living cover crops rather than desiccated cover crops terminated by herbicide applications. Producer surveys in 30 states under the Cover Crop Benchmark Study determined in 2021 that 70 percent of farmers using cover crops planted green; that is up from 50 percent among the same respondents in 2019. Of those who planted green, 49 percent did so with soybeans and 35 percent with corn.

Cover cropping practices are closely aligned with cost of production and returns per acre. As reported by the Iowa Farm Bureau Federation, researchers lead by the Agroecosystems Sustainability Center of the Institute for Sustainability, Energy, and Environment at the University of Illinois have “… found the increase in cover crop adoption is highly correlated to the funding from federal and state conservation programs. These and similar incentive programs could play an important role in promoting the expanded adoption of cover crops.”[13] Programs include the Environmental Quality Incentives Program (EQIP) and the Conservation Stewardship Program (CSP). As the Iowa Farm Bureau notes, state incentive programs have also played a role, such as the Iowa Department of Agricultural Land Stewardship which provides cost-share payments and, through the USDA Risk Management Agency (RMA) a premium discount on crop insurance.

Renewable Fuels Increased production costs for corn and soybeans and any trend toward increased tillage would create headwinds for ethanol and bio-mass based diesel production, and benefits from use. This is especially the case with changes in tillage practices.

Ethanol is measured on a carbon intensity (CI) score against a baseline of emissions from conventional 2005 gasoline. The CI score is measured for all phases, from farming practices, to ethanol milling, co-product use credits, transportation of feedstock and ethanol, and tail pipe emissions from ethanol using vehicles. Farming practices rank with the second highest CI, behind actual ethanol milling.

According to Scully et al (2021),[14] *Estimates for the carbon intensity (CI) of corn ethanol over the past three decades range from approximately 105 grams of carbon dioxide equivalent emission per megajoule of energy* ($gCO_2e\ MJ^{-1}$) *in 2009 to approximately 52* $gCO_2e\ MJ^{-1}$ *in more recent years (2010 EPA, 2018 American Coalition for Ethanol, 2020 Argonne National Laboratory.*

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[13] Zhou, Q., Guan, K., Wang, S., Jiang, C., Huang, Y., Peng, B., et al. (2022). Recent rapid increase of cover crop adoption across the U.S. Midwest detected by fusing multi-source satellite data. Geophysical Research Letters, 49, e2022GL100249. https://doi.org/10.1029/2022GL100249

[14] Scully, Melissa j, *et al* 2021, Carbon intensity of corn ethanol in the United States: state of the science *Environ. Res. Lett.* **16** 043001

There are various models, but the most recent CI scores since 2015 have been published by the California Air Resources Board (CARB), Argonne National Laboratory (ANL), and USDA as shown in the table below.

CI Analyses measured in gCO2e MJ-1							
	CARB 2015	***ANL 2016***	***USDA 2018***	***CARB 2019***	***ANL 2019***	***ANL 2020***	***USDA 2018 projection for 2022***
Farming CI	34.4	27.7	22.8	28	26	25.6	21.3

Source: Carbon intensity of corn ethanol in the United States: state of the science, Aimpoint Research

The 2018 analysis published by USDA, A Lifecycle Analysis of the Greenhouse Gas Emissions of Corn Based Ethanol, which included a projection for 2022 based on improved practices across the ethanol production change against a business-as-usual baseline. For farming practices specifically, USDA assumed reduced tillage, cover cropping and nutrient management on all corn production., which lowered the CI score from 22.8 to 21.3 grams of carbon dioxide equivalent emission per megajoule of energy (gCO2e MJ−1), a nearly 7 percent drop from 2018. That projection has not been met based on current farming practices, but with an increase in tillage, the farming practices contribution to ethanol's overall CI score could be expected to increase, rather than decrease.

Geopolitical

Any regulatorily-induced reduction in glyphosate use in the U.S. is not likely to change the acceptance or usage of glyphosate or that of glyphosate tolerant varieties amongst the world's major producers of corn, soybeans, and cotton. According to USDA in the 2020/21 crop year, the adoption rates for herbicide tolerant biotech crops in Brazil was 98 percent for soybeans, 88 percent for corn and 80 percent for cotton. The adoption rate for soybeans in Argentina is 99.8 percent, and in 2020, Argentina became the first country to approve the cultivation of a glyphosate tolerant wheat variety. Roughly one-third of Argentine wheat production is exported to Brazil.

In April of 2023, China approved and/or renewed 113 genetically engineered (GE) products for domestic cultivation and production, including the first ever approval of a gene-edited trait in China. The combination of Brazilian and Argentine exports to China - now the world's largest importer of corn, wheat, and soybeans and soon to be cotton – with China's recent acceptance of domestically produced glyphosate tolerant crops, cements the notion that this technology will continue to be a dominant feature of global agricultural production and trade. In fact, a recent study suggests that the size of the glyphosate market in China could reach $2.2 billion by 2030 compared to current U.S. sales of $2.4 billion and current global sales of $8 billion. The use of herbicide tolerant crops has driven substantial increases in production efficiency and conservation benefits in numerous countries. It is likely that China will pursue domestic commercialization of biotech crops to capitalize on these benefits.

We will not attempt to simplify the complexity of the debate over glyphosate inside the European Union (EU), nor will we speculate as to whether the EU will decide to extend its one-year approval that is set to expire on December 15, 2023. We also note that global regulatory authorities and experts do not agree with the International Agency for Research on Cancer's (IARC) 2015 monograph regarding the safety of glyphosate for animals or humans. The influence of NGOs in the EU's agricultural regulatory policies goes back decades and goes well beyond the acceptance or rejection of glyphosate tolerant biotech traits. The EU's lack of adoption of agricultural innovations has had a negative impact on global agriculture production trends and trade, with lower yields in Europe driving the EU to import feed grains and oilseeds to meet its demand for animal feed.

If fully implemented, the EU's Farm to Fork initiative will continue to have a chilling impact on crop and livestock production inside the EU and potentially impose unscientific regulatory approaches on third countries. Regardless of the regulatory outcome for glyphosate, the EU should strongly reconsider its future direction for agricultural policy, which threatens to further erode the European agricultural sector and hold back the use of innovative technologies in other countries that are striving to increase agricultural productivity, efficiency, and sustainability.

However, the tide appears to be turning against this resistance to genetic engineering and technological innovation across much of the rest of the world. One possible exception, at least in the short-term, may be Mexico. In February 2023, Mexico issued a formal decree banning genetically engineered (GE) white corn for masa/tortilla production and a ban on all other food/feed uses of GE corn will occur when there is sufficient supply of non-GE corn. Mexico's efforts to prohibit white corn imports is predominantly a protectionist measure to placate President Lopez Obrador's domestic political base rather than hostility towards this technology. Mexico's action against glyphosate is not likely to remain after Lopez Obrador leaves office in 2024. While U.S. government regulation that negatively positions glyphosate could impact the regulatory environment for this technology in several nations, it is not like to result in major regulatory changes amongst the world's other large producers of corn, soybeans, and cotton.

Food Prices

Commodity Cost Pass Through The determinant factors for food inflation are many and complex. While the array of factors includes commodity price appreciation for crops such as corn, soybeans and wheat, other – and often larger – drivers are outside of the commodity value chain. Such factors include labor, energy, capital, packaging, and transportation on the supply side, as well as demand side dynamics such as consumer preferences, income, and even monetary policy and the general rate of inflation.

The pass-through of commodity costs depends on the portion of a finished food product's price that is dependent on the farm value of commodity inputs. For example, while wheat, in the processed form of flour, is certainly a critical input to bread, other input costs are larger factors. However, for animal proteins (meat, poultry, dairy products, and eggs), the cost of corn and soybean as feed and feed products is a much larger cost component. Likewise for vegetable oil from oilseeds commodities such as soybeans. The cost of meat, poultry, cheese, and edible oils is impactful particularly on food service sector costs given their widespread use.

As commodity markets are inherently volatile, processors and manufacturers generally resist passing through increased commodity costs, when those costs are in the general range of expected price volatility, or when those costs are expected to be shorter term. This principle, known as "price maintenance," happens at the wholesale and retail level. Larger cost increases, however, are more likely to be passed through the value chain.

The above dynamic can be observed empirically through inflation trends. From 2010 to 2019, annual average CPI food inflation averaged 1.9 percent. Starting with the disruptions from COVID and their aftermath, the food CPI started to accelerate rapidly, ending the 2022 calendar year at 9.9 percent – the highest rate of food inflation since 1979. That increase in the CPI is significant as, according to the Bureau of Labor Statistics (BLS), food makes up 13.474 percent of consumer inflation.

While commodity prices in 2022 were driven by impacts from drought, the effects on global commodity markets from the War in the Ukraine, ***another significant factor in food inflation was the on-farm cost of production***. As detailed previously in this paper, the loss of glyphosate would adversely impact farmers' costs of production moving forward over at least a medium term (four to five year), duration.

Based on USDA data, driven by higher input costs – including fuel, fertilizer, and pesticides – the cost of production in 2022, on average, in dollars per acre grew significantly from both 2020 and 2021. The 2022 USDA estimated cost of production, and the two-year growth, was: Corn $911/per acre at 34 percent; Cotton $876 per acre at 28 percent, Soybeans $621 per acre at 26 precent; Wheat $431 at 34 percent.

Given this analog to 2022 of production cost increases and commodity price appreciation, a medium to longer-term outlook on the effects of the loss of glyphosate can be considered to add marginal inflationary pressure, though it is difficult quantify. The likely impact would be that food inflation will not quickly return to its historical trend; over the 30 years from 1992 to 2021 food inflation averaged 2.4 percent with a high of 5.4 percent in 2008 and a low 0.3 percent in 2016. Production cost increases are likely to slow the rate of food inflation returning to normal annual trends moving forward. Food products most affected would include animal proteins, which use corn, soybean, and cottonseed as feedstuffs.

Consumer Perceptions on Food Prices Food inflation is a major concern among consumers. According to the April consumer survey from Circana,[15] 94 percent of primary shoppers expressed some level of concern about rising food prices. The survey shows 75 percent of consumers are actively cutting spending due to higher prices. Total retail food volume sales in April 2023 dropped by 2 percent while spending increased by 6 percent. Similarly, the Food Industry Association Q1 2023 grocery shopper trends poll found that 48 percent of consumers are extremely concerned about high grocery prices; that's up from 40 percent in October 2022.

Meat and poultry retail sales reflect the impact of food inflation; at the end of April 2023 based on 52-week averages, volume sales are down 2 percent and 6.9 percent from one and two years prior, while dollar sales are up 3 and 7.2 percent respectively. Consumers are buying less meat to afford other food and grocery items.

SNAP and Nutrition Policy Implications About 12 percent of U.S. households participate in the Supplemental Nutrition Assistance Program (SNAP) for food purchases. Based on USDA research from 2016,[16] protein foods – such as meat, dairy, and eggs – are the top expenditure category for SNAP households accounting for 23 percent of food expenditures. This exceeds the 21 percent of total spending on those same items by non-SNAP households. As a result of the added production costs to key feedstuff commodities from a loss of glyphosate, it can be expected there will be marginal, though small, inflationary pressure put on consumer spending on proteins, and on the costs of federal nutrition programs, such as SNAP, the National School Lunch and School Breakfast Programs and the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC).

Innovation

Glyphosate has been a catalyst to other innovations within agriculture; for example, glyphosate tolerance was the first major breakthrough for the development of herbicide tolerant (HT) seeds. For soybeans, corn, and cotton, 90 percent or more of all acres are now planted with HT seeds. Additionally, scientists developed insect tolerant traits and advanced the ability to "stack" these traits, which, when combined has led to overall decreases in insecticide use while protecting yields.

It is important to note the next generation of weed control technology beyond synthetic herbicides remains in the development phase, facing unresolved hurdles to achieving scale and adoption. Any sudden loss of glyphosate, the most widely used herbicide, would present various challenges in the short term.

The future of weed control can be expected to unfold in four phases. The first will come from leveraging artificial intelligence (AI) and computer vision for precision spraying. This technology is intended to reduce synthetic herbicide use through precision application. The second phase

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[15] The leading provider on retail consumer data formed in 2023 by the merger of IRI and The NDP group.

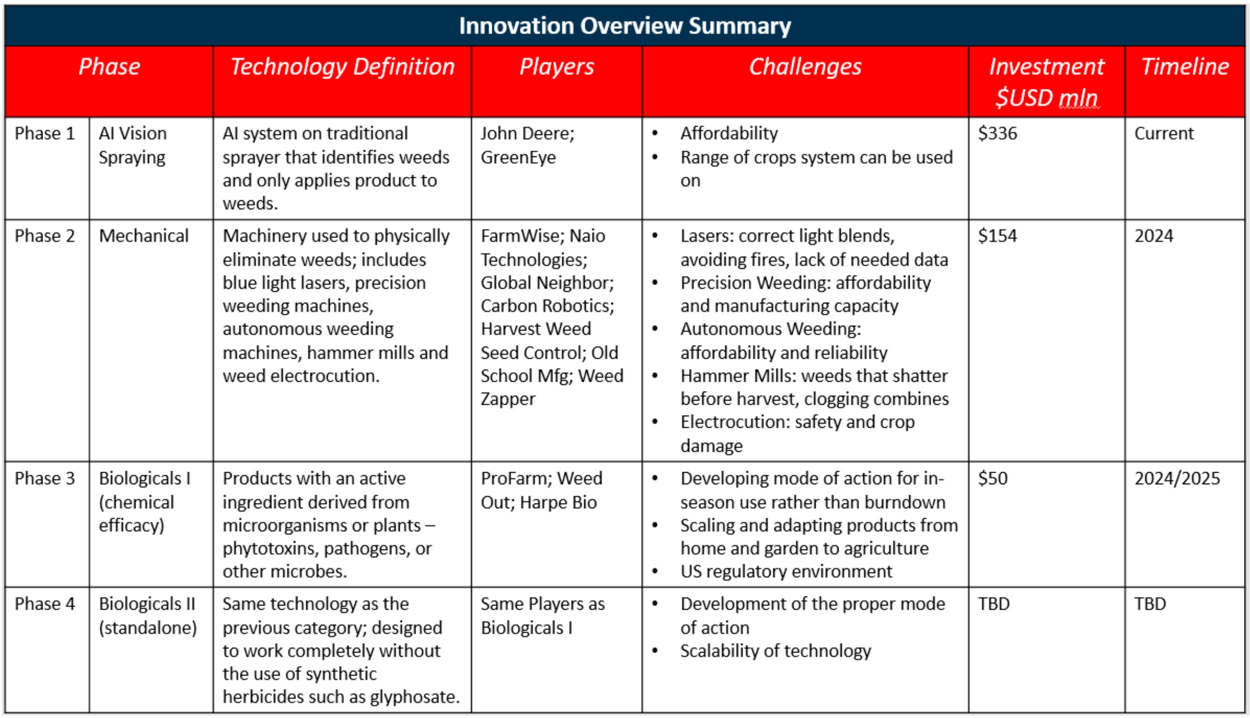
[16] Steven Wallander, David Smith, Maria Bowman, and Roger Claassen, *Cover Crop Trends, Programs, and Practices in the United States, EIB 222*, U.S. Department of Agriculture, Economic Research Service, 2021

will come from advancements in mechanical weeding via fully autonomous machinery and precision weeding implements. Third will be the launch of biological herbicides used in combination with synthetic herbicides, used at a catalyst for efficacy. Biologicals will ultimately develop to the fourth phase where bio-herbicides can stand on their own.

Overall, significant investment is still needed across all these spaces to bring new commercially viable and scalable solutions to market. Widespread adoption of the above new technologies likely will not occur until the end of the decade.

As opposed to traditional research in chemistry, future solutions will require more research and development in artificial intelligence (AI), machine learning, and computer vision. In lieu of new chemistries, these alternatives are being developed to address herbicide tolerance in weeds, either as an alternative weed control method, or through reduced application by precision application or catalyzing the mode of action.

A loss of glyphosate, however, not only leaves a gap in weed control solutions for the shorter term but can be expected to have an adverse impact on the development of many of these new technologies, particularly biological products. Without glyphosate, the research and development investments needed for this first phase of bioherbicides would stall as the return on investment would be limited.



Innovation Overview Summary

Phase		*Technology Definition*	*Players*	*Challenges*	*Investment $USD mln*	*Timeline*
Phase 1	AI Vision Spraying	AI system on traditional sprayer that identifies weeds and only applies product to weeds.	John Deere; GreenEye	• Affordability • Range of crops system can be used on	$336	Current
Phase 2	Mechanical	Machinery used to physically eliminate weeds; includes blue light lasers, precision weeding machines, autonomous weeding machines, hammer mills and weed electrocution.	FarmWise; Naio Technologies; Global Neighbor; Carbon Robotics; Harvest Weed Seed Control; Old School Mfg; Weed Zapper	• Lasers: correct light blends, avoiding fires, lack of needed data • Precision Weeding: affordability and manufacturing capacity • Autonomous Weeding: affordability and reliability • Hammer Mills: weeds that shatter before harvest, clogging combines • Electrocution: safety and crop damage	$154	2024
Phase 3	Biologicals I (chemical efficacy)	Products with an active ingredient derived from microorganisms or plants – phytotoxins, pathogens, or other microbes.	ProFarm; Weed Out; Harpe Bio	• Developing mode of action for in-season use rather than burndown • Scaling and adapting products from home and garden to agriculture • US regulatory environment	$50	2024/2025
Phase 4	Biologicals II (standalone)	Same technology as the previous category; designed to work completely without the use of synthetic herbicides such as glyphosate.	Same Players as Biologicals I	• Development of the proper mode of action • Scalability of technology	TBD	TBD

CONCLUSION

Glyphosate is the most widely used herbicide in the United States, as it is effective in controlling weeds, cost efficient compared to alternatives, and has enabled farmers to widely adopt conservation practices such as reduced tillage and expanded cover cropping. Its loss as an agricultural production tool would not be trivial. Ultimately, markets would be forced to reluctantly adapt through substitution and adjusted practices, but at substantial cost to farmers and the environment.

For example, alternative products exist, but at a much higher per acre cost; likely replacements for glyphosate would increase the cost of herbicide inputs by two to two-and-a-half times. Further, without glyphosate there would be an increase in soil tillage for weed control, which would significantly increase farmers' cost of production, both for labor and machinery, but would also result in less soil carbon capture and increased emissions from additional fuel use, two major environmental advancements it has helped foster.

While various technologies are in development to reduce and/or replace synthetic herbicide use in crop production, none of these new innovations are yet at commercial scale to overcome the near-term economic shock of an immediate loss of glyphosate. Glyphosate has been a catalyst to agricultural innovation and its loss would inhibit the progress of some next generation innovations. This, and the heightened political risk of regulatory action would result in a chilling effect on further research, development, and investment in the advancement of new technologies.

Impacts of the loss of glyphosate have the potential to ripple through the commodity value chain, from renewable fuels to food and feed costs. Though the most severe effects would be borne at the farm level, marginal changes in the increased carbon intensity, due to a reduction in no-till and other conservation farming practices, could reduce market demand for corn and soybeans used as renewable fuel feedstock and commodity production costs would rise for food and feed use. These are two unintended consequences worth careful consideration with the aggregate higher cost being passed through to end users of renewable fuels and meat, poultry, dairy and eggs.

Finally, any regulation-induced reduction in glyphosate use in the U.S. is not likely to change the acceptance or usage of glyphosate or that of glyphosate tolerant crop varieties among the world's major producers of corn, soybeans, and cotton. This would place U.S. agriculture at a competitive disadvantage globally.

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