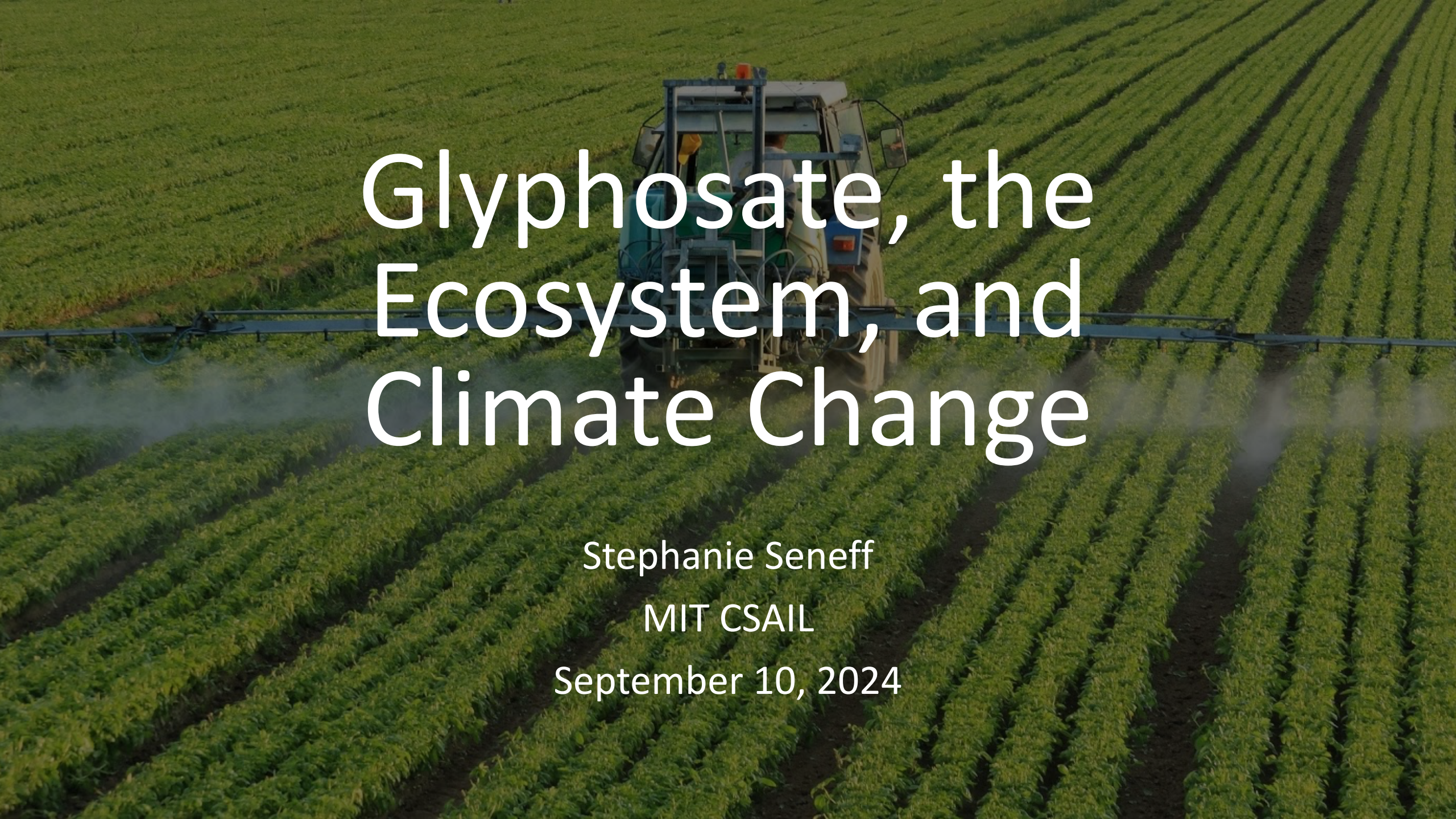

Glyphosate, the Ecosystem, and Climate Change

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MIT CSAIL

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"If you think the economy is more important than the environment, try holding your breath while counting your money.”

-- Guy McPherson

Outline

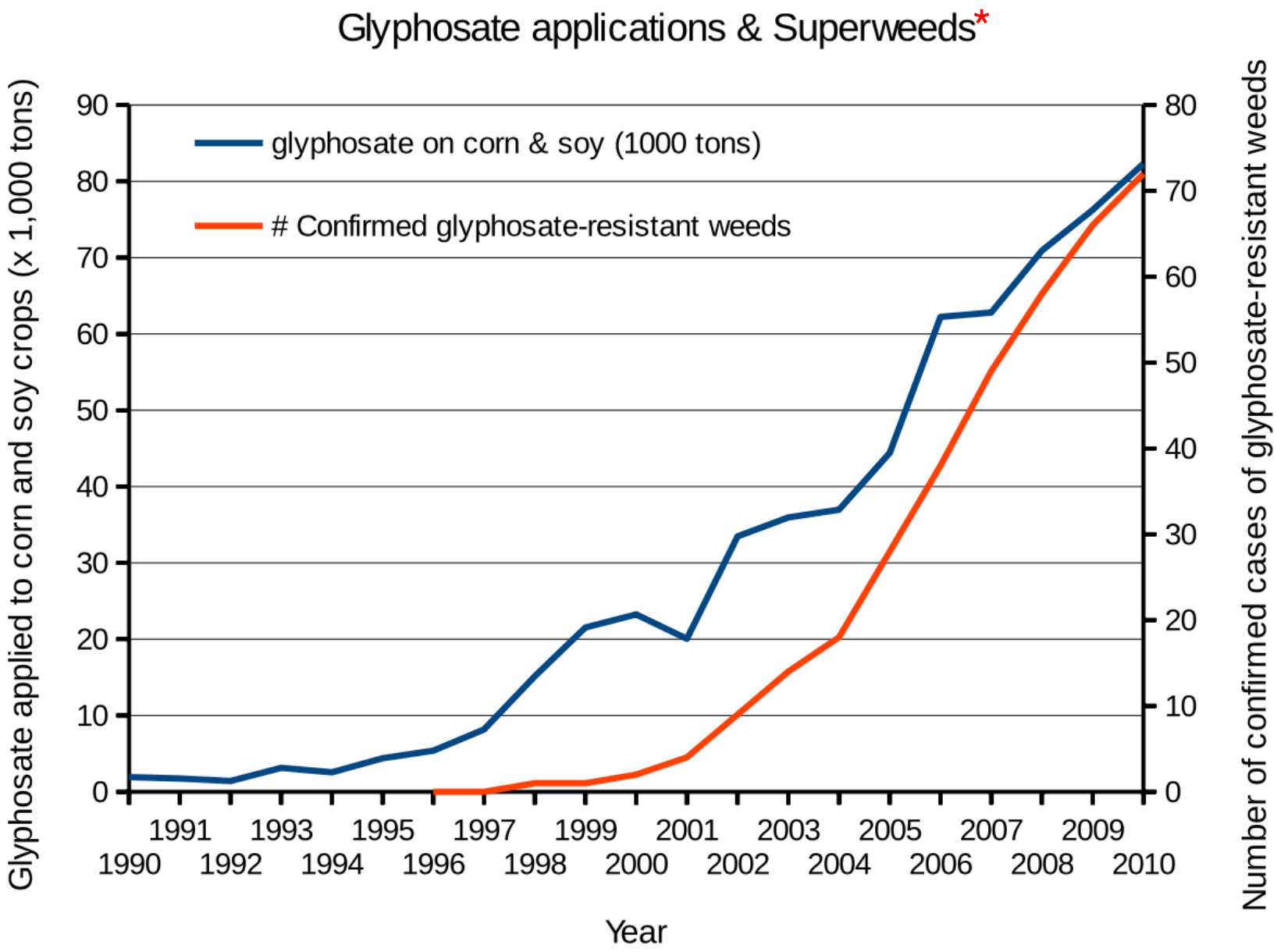
- Introduction
- Glyphosate Disrupts the Ecosystem
- Red Tide and Algae Blooms
- Glyphosate Weakens Plant Resistance to Stressors
- Photosynthesis and Carbon Fixation
- Cloud Seeding & Marine Phytoplankton
- Summary

Introduction

A Brief History of Glyphosate

- Glyphosate is now the #1 herbicide in use in the U.S. and is increasingly used around the world
  - Patented by Monsanto as an herbicide in 1969
  - Introduced into the US food chain in 1974

  - Came out from under patent in 2000
  - Inhibits an enzyme in the *shikimate pathway* involved in the synthesis of tyrosine, tryptophan and phenylalanine (the three *aromatic amino acids*)
- Huge expansion of GMO corn, soy, cotton and canola crops has led to sharp increases in the last two decades



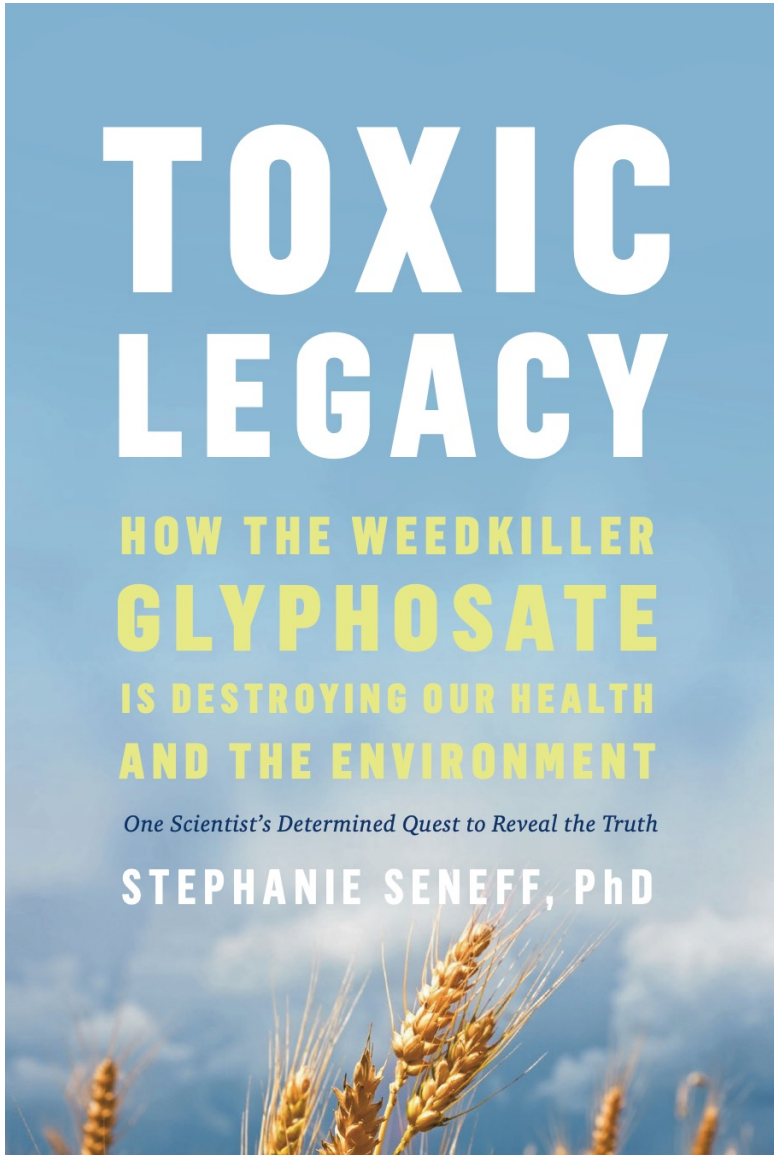
Glyphosate usage increased dramatically over time, likely because of the emergence of glyphosate-resistant weeds

*Figure 1. Judy Hoy et al., Poultry, Fisheries & Wildlife Sciences 2015; 3(1): 1000132.

My Book on Glyphosate

- Released by Chelsea Green in July 2021
- Presents extensive data on glyphosate toxicity to animals and humans
- Shows how glyphosate interferes with sulfate homeostasis
- Argues that glyphosate is insidiously, cumulatively toxic through its diabolical insertion into proteins by mistake in place of the coding amino acid glycine
  - This unique feature explains why it is causal in so many diseases

This book was selected by Kirkus Reviews as one of the top 100 non-fiction books of 2021



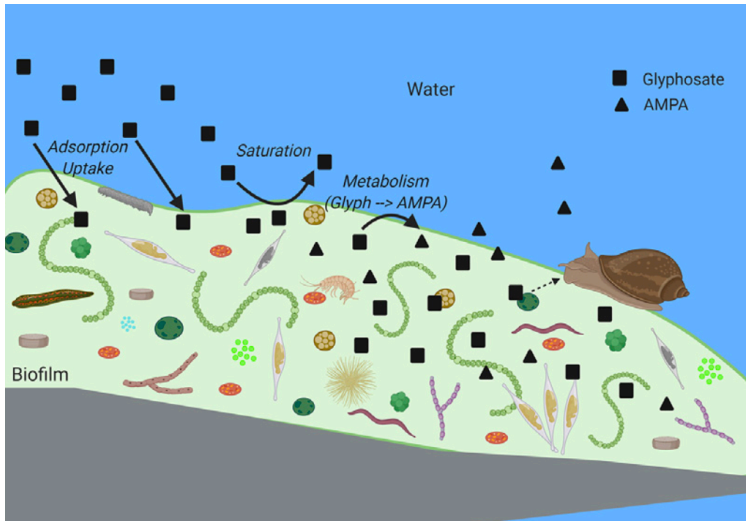
The Big Picture

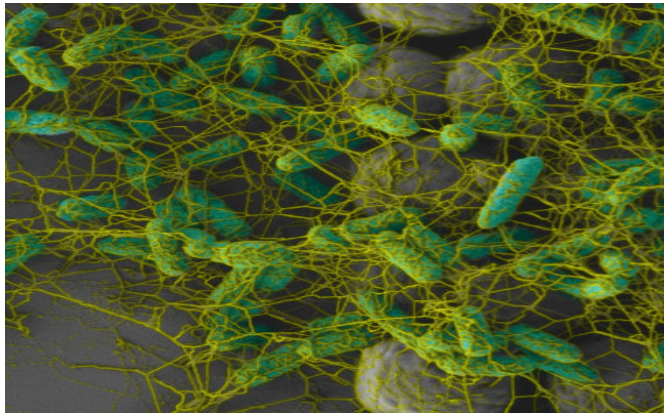
- Glyphosate disrupts many aspects of metabolism in plants, animals, microbes and fungi
- Increased use of fertilizers compensates for inefficient utilization of nitrogen and phosphorus → nitrate and phosphate run-off
  - Nitrous oxide is a potent greenhouse gas and is induced by glyphosate
- Plants are stressed indirectly by glyphosate's adverse effects on fungi and insect predators
- Glyphosate interferes with the capture of carbon in the soil
- Certain marine phytoplankton can seed cloud formation over oceans, but glyphosate suppresses their growth

Glyphosate Disrupts the Ecosystem

Glyphosate Accumulates in Biofilms*

- Glyphosate polluting waterways is rapidly adsorbed into biofilms
- Concentrations of glyphosate in biofilms were *two to four orders of magnitude higher* than those in the surrounding water
- Glyphosate appears to rapidly disappear from waterways, but this is an illusion
- Juvenile fish and amphibians dwell in the biofilms



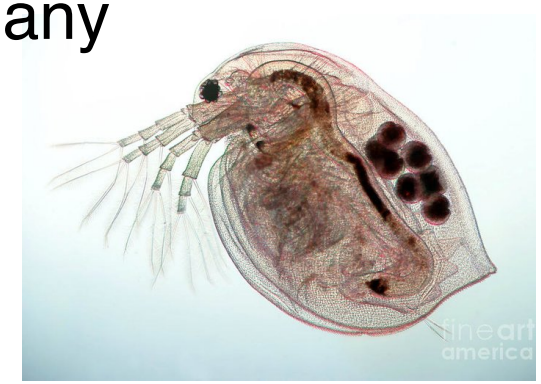


"We may be underrecognizing the potential ecological risk of contaminants, like glyphosate, that are bioconcentrating in biofilms and subsequently being consumed."

*Laura Beecraft et al.Science of the Total Environment 756 (2021) 143993.

Effect of Glyphosate on Water Flea Embryos*

- Water fleas are near the bottom of the aquatic food chain
- Tadpoles, salamanders, newts, aquatic insects and many types of small fish feed on water fleas
- When water fleas were exposed to concentrations of Roundup and glyphosate well below the approved regulatory threshold, they suffered from:
  - Embryonic developmental failure
  - Systemic inflammation
  - Collagen degradation
  - Impaired wound healing
  - Disrupted gut microbes
- The animals that eat the water fleas pick up glyphosate from their food
- Effects on water fleas propagate up the food chain



*Suppa et al. Microbiome 2020; 8:170

"Microbiological characterization of land set-aside before and after Roundup desiccation"*

- An experimental field in Prague, Czech Republic where grasses and legumes were grown was repeatedly desiccated with Roundup and then analyzed
- "The characterization included microbial biomass, available organic carbon, basal respiration, metabolic quotient, biomass-specific available organic carbon, arylsulfatase activity, soil organic matter carbon and total nitrogen"
- qCO_2 is a formula for the "metabolic quotient" reflecting degree of uptake of carbon into the soil
- "In our study, qCO_2 strongly (with high significance) *declined following Roundup desiccation* from 2.4 to 1.6 mg C/g MBC/h"
- "The metabolic quotient obviously signaled unfavorable soil maintenance with *higher efflux of CO_2 to the atmosphere*."
- "*Organic practices* rapidly improve soil microbial characteristics and slowly increase soil organic C (Carbon)."

MBC = microbial biomass carbon

*M. Růžková et al., Plant Soil Environ 2011; 57(2): 88-94

Red Tide and Algae Blooms

"Is Agriculture's Use of Glyphosate Feeding Lake O's Explosive Algae Blooms?"*

- Sugar cane agriculture is extensive all around Lake Okeechobee in S. Florida, and glyphosate is used both to control weeds and as a desiccant
- Cyanobacteria can break down the C-P bond in glyphosate and use its phosphorus atom as a fuel source**

*Prof. Geoffrey Norris.https://jacquithurlowlippisch.com/tag/is-sugarcane-field-glyphosate-feeding-lake-os-blue-green-algae-blloms

**D Drzyzga et al. Environ Microbiol 2017 Mar;19(3):1065-1076

"Chronic exposure to glyphosate in Florida manatee"*

- Glyphosate is ubiquitous in Florida waterways
- Concentrations were higher during the sugar cane harvest
- Florida manatees exposed to glyphosate have increasing body burdens since 2009
- Manatees are sick and they are starving due to loss of seagrass

*Maite De Maria et al. Environment International 2021; 152: 106493

Cyanobacteria Feed Red Tide Algae

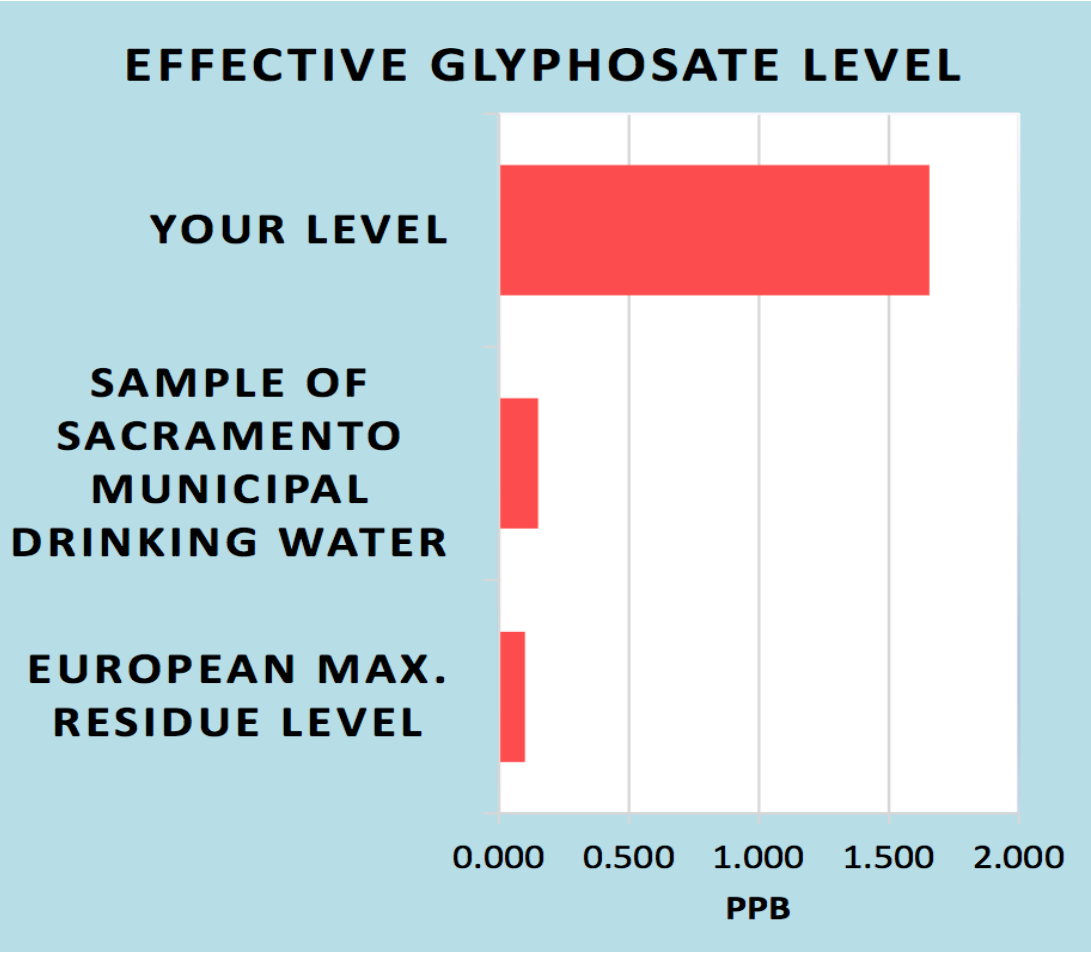
“Both the coastal red tide and the inland blue-green algae have beset South Florida through the summer, killing vast numbers of fish and other wildlife, including dozens of dolphins, manatees, sea turtles, sharks and eels.”*

- Cyanobacteria feed off of glyphosate (phosphorus source) and produce nitrates from nitrogen
- Red Tide algae flourish, supplied with nitrates produced by cyanobacteria **

*https://www.nbcnews.com/news/us-news/toxic-red-tide-florida-researchers-investigate-what-s-making-it-n900771

**https://www.sailorsforthesea.org/programs/ocean-watch/nutrients-feed-red-tide

Test of Glyphosate Levels in Florida Waterways*



Water sample taken from the coast of Cape Coral, at the mouth of the Caloosahatchee River, where cyanobacteria were present

*https://www.momsacrossamerica.com/orange_juice_postive_for_glyphosate_again

Glyphosate Weakens Plant Resistance to Stressors

"Plants Warn One Another of Pest Attack through Mycorrhizal Fungal Network"*

- Mycorrhizal fungi form symbiotic relationships with plants
  - Increase mineral uptake
  - Redistribute water during drought stress
  - Increase tolerance to root and shoot pathogens
- When one plant is infected by aphids, chemical signals are transmitted through fungus network in ground to neighboring plants
  - Neighbors release chemicals to repel aphids and attract predatory wasps
- *Glyphosate disrupted growth of five species of ectomycorrhizal fungi tested in vitro***

*ISIS Report 28/10/13, http://www.i-sis.org.uk/mycorrhizae_and_plant_communication.php

** P. Chakravarty and S.S. Sidhu, European Journal of Forest Pathology 17(4-5), 204-210, 1987

“Predators Help Plants Put Away Carbon”*

- Yale University study
- Plants with three conditions in enclosed environment:
  - No predators
  - Grasshoppers only
  - Grasshoppers and spiders

- Surprisingly, the condition with spiders resulted in 20% more carbon storage in the plants compared to the isolated plants and 40% more than the grasshoppers-only case

Glyphosate exposure reduces spiders’ ability to kill grasshoppers, ants and caterpillars that damage plants

*A Duhaime-Ross, Scientific American, September 2013, p. 16

Concerns about Glyphosate and Citrus*

- Increased crop sensitivity to diseases
- Reduced availability of micronutrients to crops through chelation by glyphosate
- Inhibition of root growth
- Citrus fruit drop

"As citrus weed management programs have continued to rely more heavily on glyphosate, the occurrence of citrus fruit drop resulting from glyphosate application has become an increasing grower concern over the years."

*http://citrusindustry.net/2018/09/05/how-to-handle-glyphosate-related-fruit-drop/

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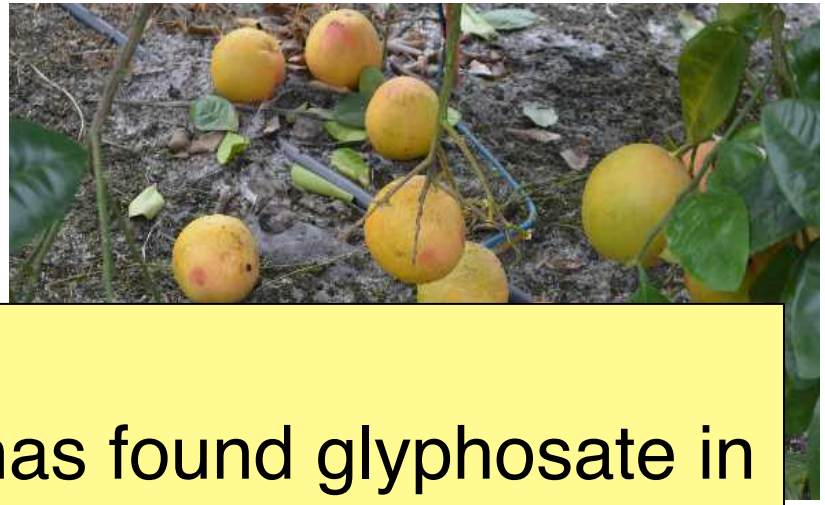

Moms Across America founder Zen Honeycutt has found glyphosate in multiple samples of orange juice produced from Florida orange groves

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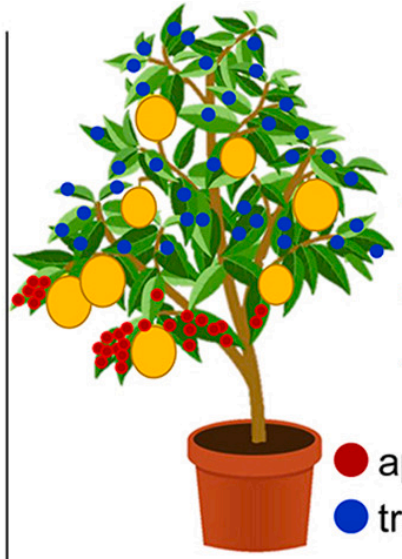
*http://citrusindustry.net/2018/09/05/how-to-handle-glyphosate-related-fruit-drop/

“Glyphosate excessive use chronically disrupts the shikimate pathway and can affect photosynthesis and yield in citrus trees”*

Adult citrus plants with high glyphosate use, even with no phytotoxicity symptoms, show inhibited growth and fruit yield:

Hidden phytotoxicity?



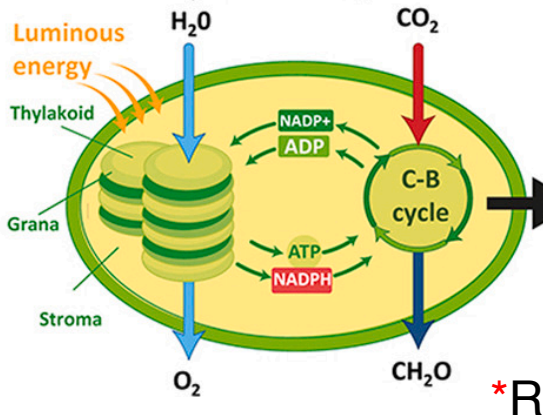
On sink leaves of 4-yr old plants:

GLY doses (mainly at >360 g ea ha^{-1}):

- ↑shikimate accumulation
- ↓net CO_2 assimilation
- ↓fruit yield

● applied GLY (source leaves)
● translocated GLY (sink leaves)

Luminous reaction and Calvin Benson cycle on chloroplasts



- ↑photooxidative damages
- ↓carboxylation
- ↑photorespiration: ↑C drain

*Rodrigo Martinelli et al. Chemosphere 2022; 308: 136468

How Glyphosate Can Disrupt Nitrogen Fixation in Plants

- Mung beans exposed to glyphosate have impaired nitrogen uptake*
- Glyphosate exposure at sublethal levels severely impairs nitrogenase activity**
  - Nitrogenase converts nitrogen gas to ammonia
- Glyphosate inhibits phosphoenolpyruvate carboxylase (PEPC)**
  - PEPC is important for incorporation of both carbon and nitrogen into plants***

Mung beans

*A Zaidi et al., Springer Verlag 2005;25 (4):497-504.

** N de Maria et al., J Agric Food Chem. 2006;54(7):2621-8.

*** R Chollet et al., Annu Rev Plant Physiol Plant Mol Biol 1996;47:273-298.

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- Glypho
  - PEP s***

"The impact of 1 pound of nitrous oxide on warming the atmosphere is 265 times that of 1 pound of carbon dioxide"

https://www.epa.gov/ghgemissions/overview-greenhouse-gases#N2O-references

Mung beans

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Photosynthesis and Carbon Fixation

Study on the effects of glyphosate on glyphosate-sensitive and glyphosate-resistant soybean plants*

- Glyphosate-sensitive plants
  - Leaf photosynthesis was rapidly inhibited by glyphosate
  - Marked increase in glutathione synthesis (antioxidant defenses)
  - Levels of glutamine, asparagine and arginine increased while phenylalanine was sharply decreased.

    "Glyphosate produced a rapid, marked, and sustained inhibition of photosynthetic CO_2 assimilation in the glyphosate-sensitive line."
- Glyphosate resistant plants
  - Chlorophyll content significantly reduced in leaves compared to controls
  - Very high levels of glyphosate were detected in the leaves
  - Increased pools of oxidized glutathione and ascorbate (antioxidant defenses)
  - *Rubisco expression was reduced by a factor of 25.*

*Pedro D Vivancos et al. Plant Physiology 2011; 157: 256-26

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Rubisco is the most common enzyme on the planet, and it plays an essential role in photosynthesis.

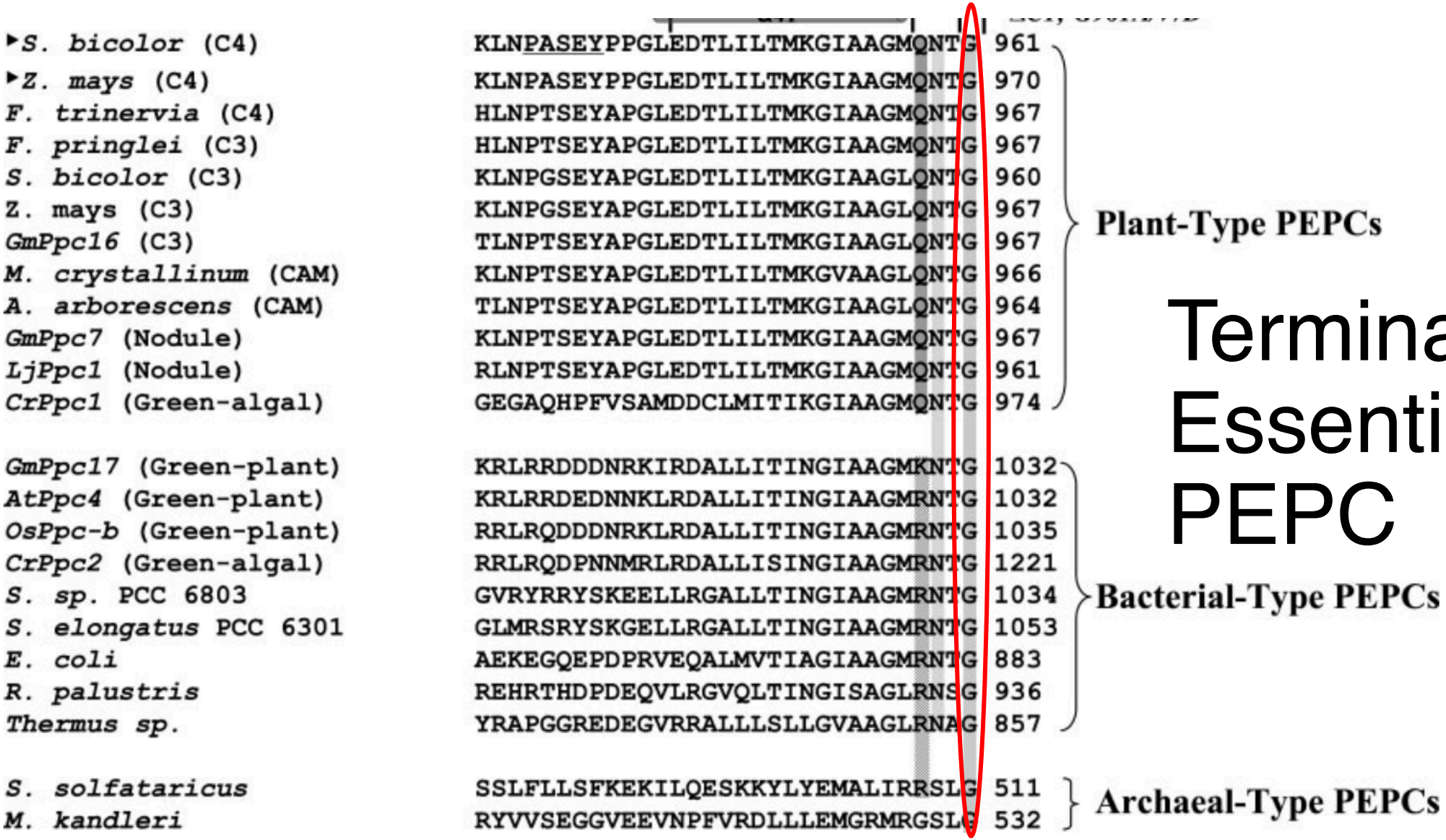
*Pedro D Vivancos et al. Plant Physiology 2011; 157: 256-26

Phosphoenolpyruvate Carboxylase (PEPC)

- PEPC is a ubiquitous enzyme in plants, also often present in archaea, cyanobacteria and green algae
- It is an integral enzyme in photosynthesis to *assimilate CO_2 in green plants*
- The terminal sequence QNTG is highly conserved across multiple phyla
- Glyphosate was shown experimentally to suppress activity of PEPC*
- Replacement of the terminal glycine with the negatively charged amino acid aspartate causes *up to a thousand-fold decrease* in catalytic efficiency**

➔ *Substitution of glyphosate for the terminal glycine would have similar devastating consequences*

*N de Maria et al., J Agric Food Chem. 2006;54(7):2621-8.
**W Xu et al. JBC 2006; 281(25): 17238-17245.



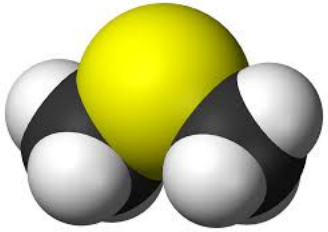
Terminal Glycine Essential in PEPC

*Figure 1. W Xu et al. JBC 2006; 281(25): 17238-17245.

Cloud Seeding & Marine Phytoplankton

“DMS: The Climate Gas You’ve Never Heard Of”*

- Dimethylsulfide (DMS) is a small sulfur-containing gas that plays a significant role in climate change
- DMS decreases the amount of solar radiation that reaches the Earth's surface by inducing cloud formation
- DMS is synthesized from dimethylsulfoniopropionate (DMSP) by marine phytoplankton in shallow ocean water
- Emiliania huxleyi (E huxleyi) is an important marine phytoplankton species that synthesizes DMSP**



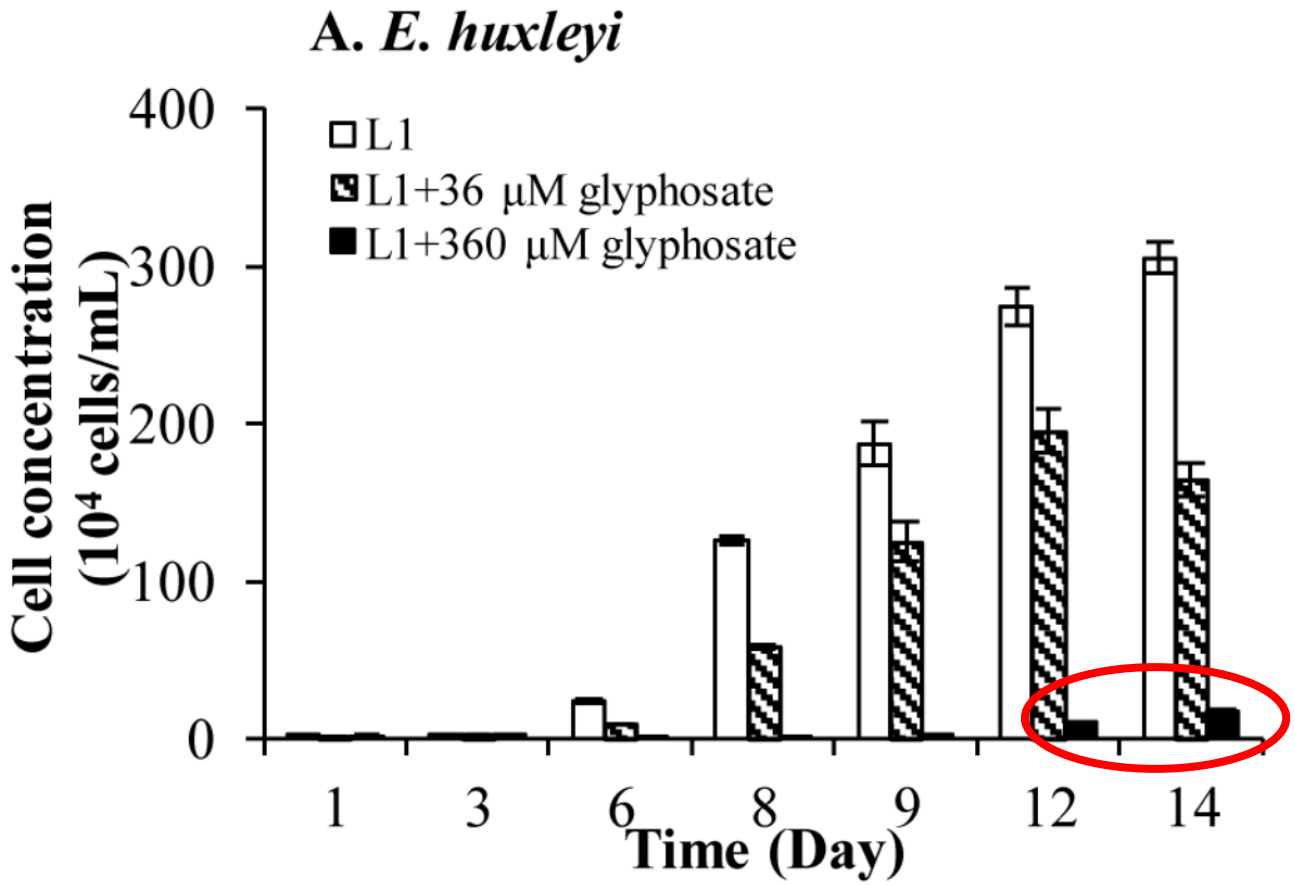
*Scott Dodd. Woods Hole Oceanographic Institute, July 17, 2008. https://www.whoi.edu/oceanus/feature/dms-the-climate-gas-youve-never-heard-of/

**M Kamlow. MSc Thesis. Norwegian University of Science and Technology. 2013. http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A699830&dswid=-6180

Differential Growth Responses of Marine Phytoplankton to Herbicide Glyphosate*

- E huxleyi produces DMSP
- E. huxleyi exhibited severe growth inhibition when exposed to glyphosate at both 36 micromolar and 360 micromolar concentrations

Suppression of the release of DMS from phytoplankton in the shallow seas may have a significant impact on climate change through insufficient cloud formation over the oceans



*C. Wang et al. PLoS ONE 2016; 11(3): e0151633.

Summary

- Glyphosate is pervasive in our environment, and it is a significant contributor to human health issues and harm to the ecosystem
- Glyphosate accumulates in biomass and harms water fleas, at the bottom of the food chain
- Glyphosate disturbs the nutrients in the soil, chelating minerals and interfering with nitrogen uptake and photosynthesis, potentially impacting climate change
- Chemical-based agriculture in Florida is leading to toxic algae blooms, citrus greening, and harm to the Florida manatees
- Marine phytoplankton can seed clouds, but glyphosate interferes with the process
- We urgently need to drastically reduce the use of glyphosate on crops