History of Herbicides and Herbicide Resistance

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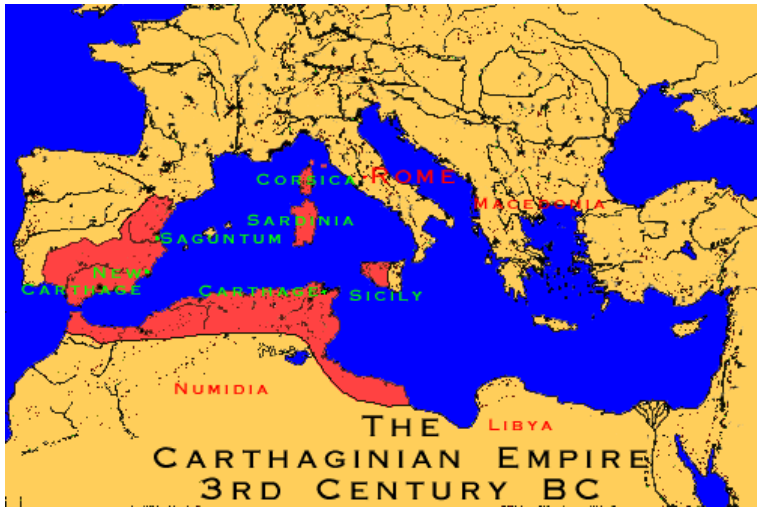
Learn by Doing

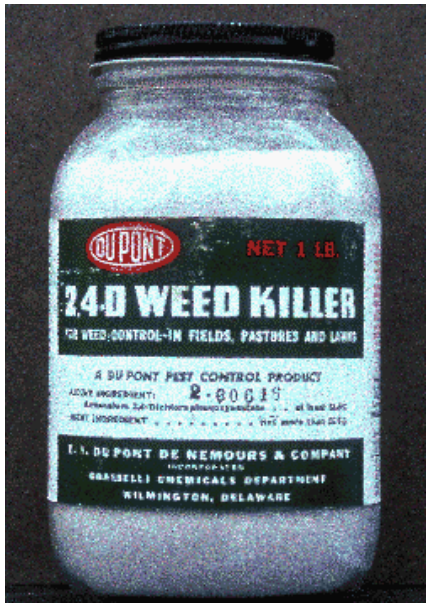
Carthage

- Romans brought down Carthage in 164 BC using salt to destroy their agriculture
- Sulfuric acid, salts of copper and arsenic, carbon bisulfide
- Very high rates
- Non-selective



Advent of modern herbicides: 2,4-D (2,4-dichlorophenoxy) acetic acid

- Discovered during WWII plant physiology research on growth regulators
- Selective/low rates
- Clopyralid (Transline) and triclopyr (Garlon) are also growth regulators

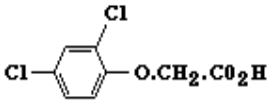


Growth regulator problems

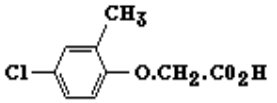
- Dioxin contaminant in making Agent Orange (2,4,5-T)

A guerrilla in the Mekong Delta paddles through a mangrove forest defoliated by Agent Orange (1970). Photograph by Le Minh Truong © National Geographic Society

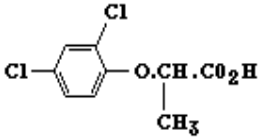
2,4-D
2,4-dichlorophenoxyacetic acid



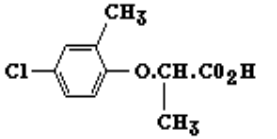
MCPA
4-chloro-2-methylphenoxyacetic acid



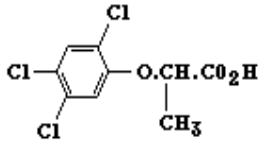
Dichlorprop (2,4,-DP)
2-(2,4-dichlorophenoxy) propionic acid



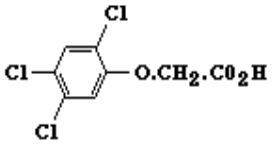
Mecoprop (MCPP)
∝-(4-chloro-2-methylphenoxy) propionic acid



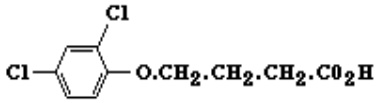
Fenoprop (Silvex, 2,4,5-TP)
2-(2,4,5-trichlorophenoxy) propionic acid



2,4,5-T
2,4,5-trichlorophenoxyacetic acid



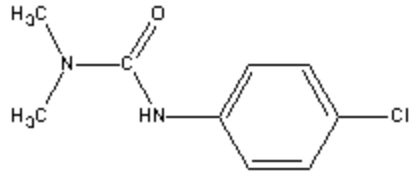
2,4-DB
(2,4-dichlorophenoxy) butyric acid



Structures of 2,4-dichlorophenoxyacetic acid (2,4-D) and chemically-related herbicides.

Phenyl substituted ureas

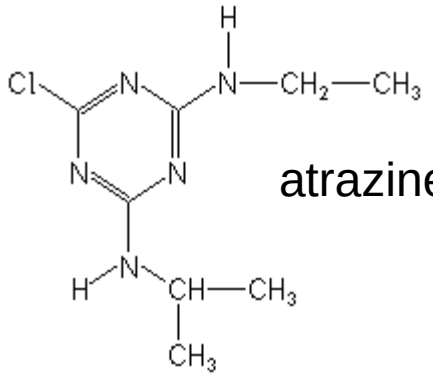
- Discovered in 1951
- Examples are Monuron, diuron
- Photosynthetic inhibitor (the most common mode of action of all herbicides)



Monuron

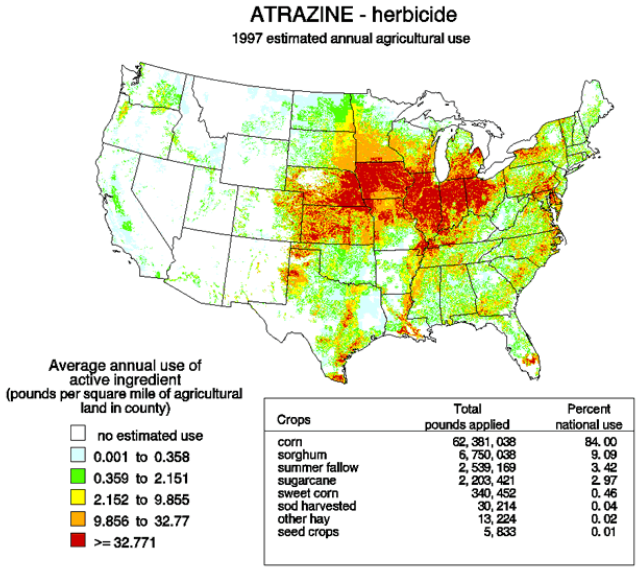
Symptoms of PSII e- transport inhibitors on bean

Triazines

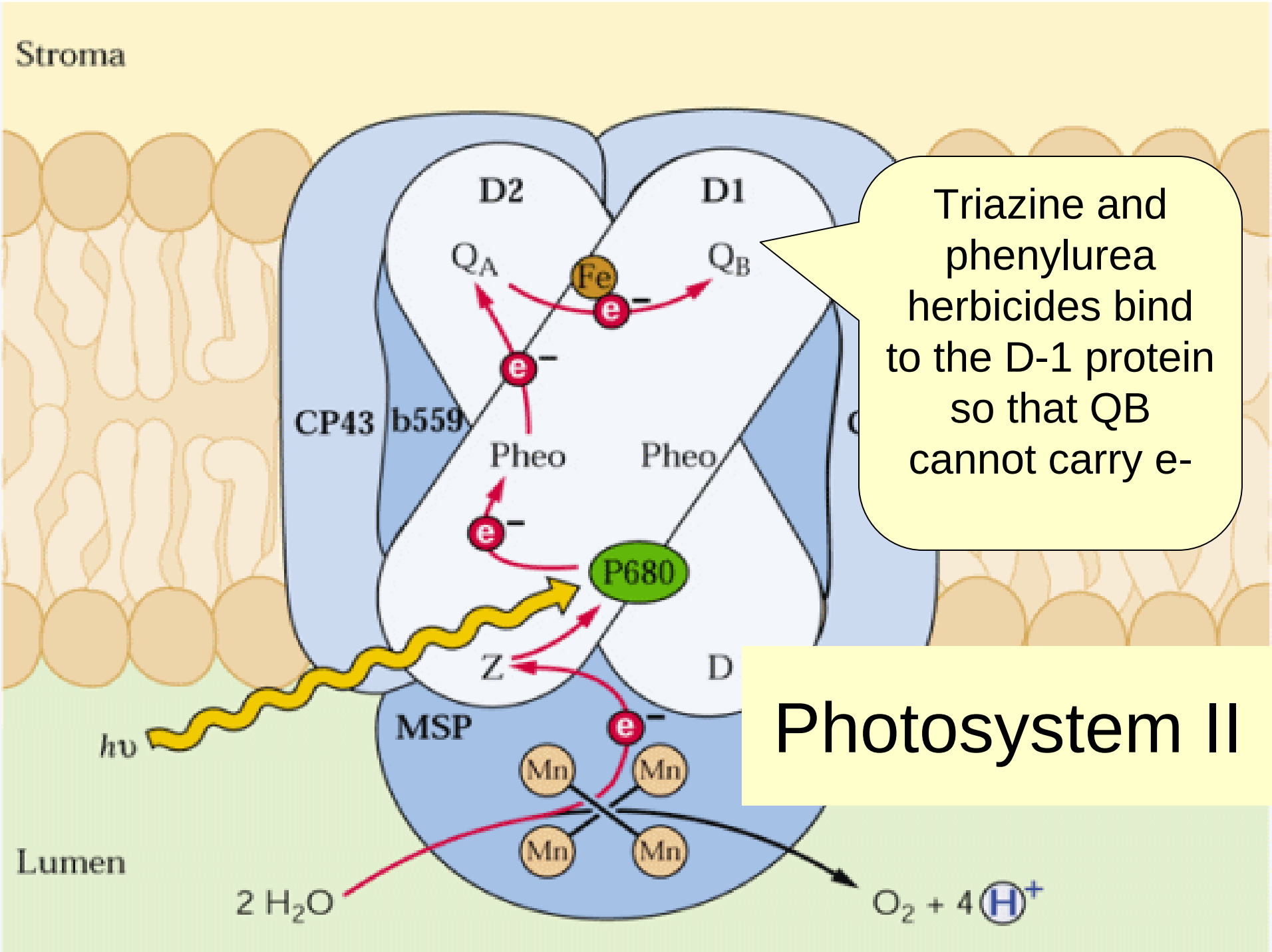


atrazine

- Developed in 1955
- Atrazine, simazine, Velpar
- Photosynthetic inhibitor
- Long residual activity

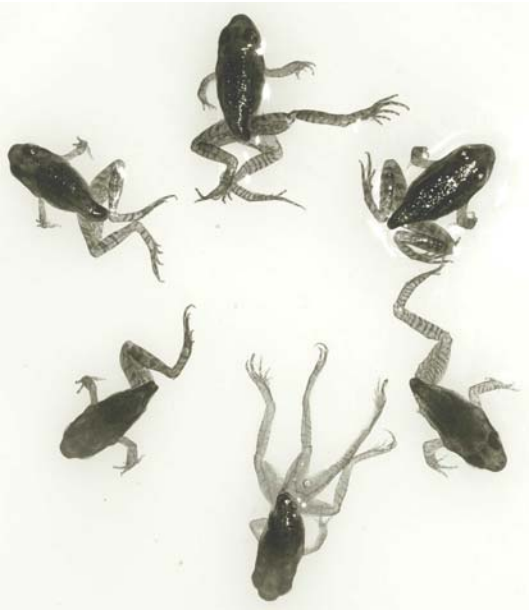


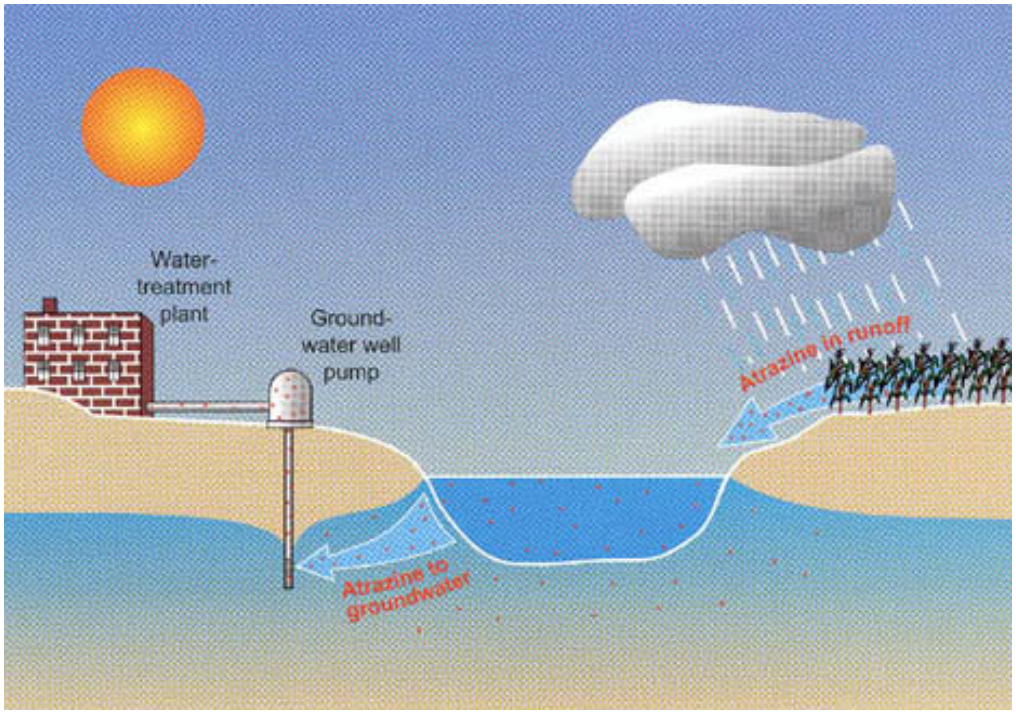
Atrazine use (kg/km^2) is high is corn growing regions of midwestern US (USGS 1991).


Stroma
D2
D1
Q_A
Fe
Q_B
e⁻
e⁻
CP43
b559
Pheo
Pheo
e⁻
P680
Z
D
MSP
e⁻
$h\upsilon$
Mn
Mn
Mn
Mn
Lumen
$2\,H_2O$
$O_2 + 4\,H^+$
Triazine and phenylurea herbicides bind to the D-1 protein so that QB cannot carry e-
Photosystem II

Problems with the triazines

- Aquifer contamination
- Hormone mimics/ endocrine disruptors





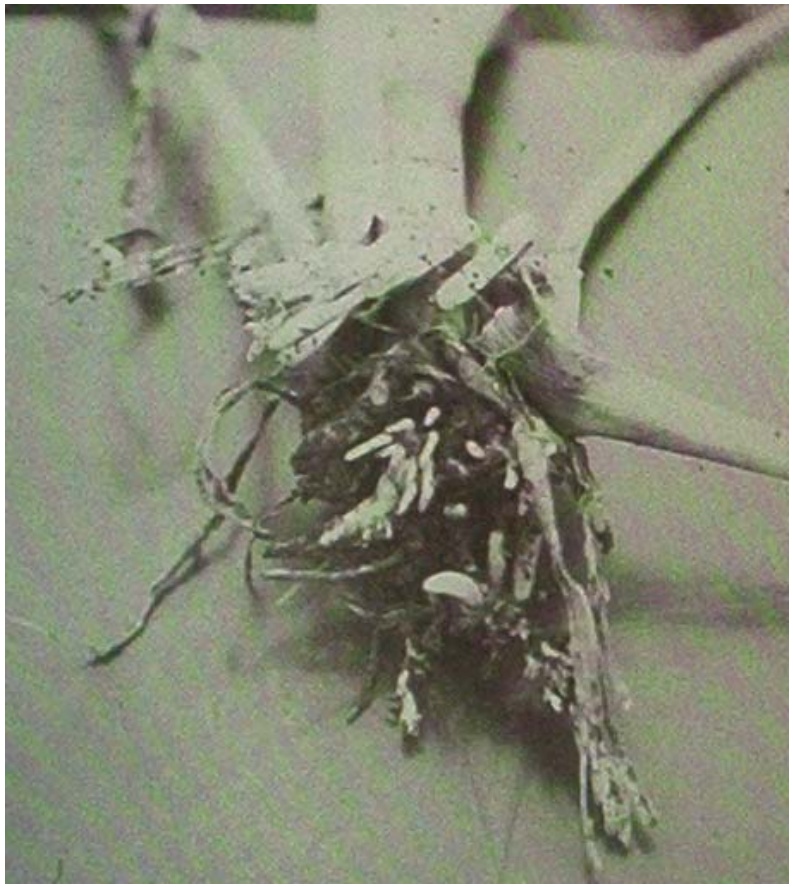
ACCase Inhibitors: the 'dims' and 'fops'

- Grass-specific ACCase inhibitors: sethoxydim= Poast fluazifop= Fuslade
- Inhibits acetyl-CoA to fatty acids

ACCase inhibitor on rice

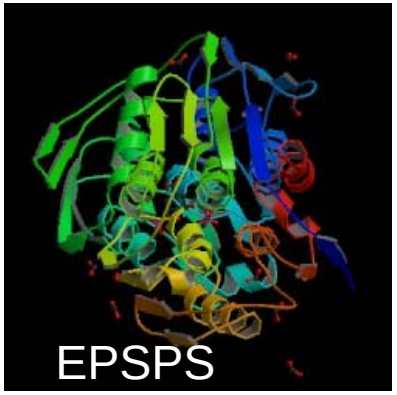
Dinitroanalines

- Introduced in the 1960's
- Dinitroanilines (trifluralin (Treflan®), oryzalin (Surflan®)) are carbamate herbicides
- Binds to tubulin during the formation of microtubules stops cell division.

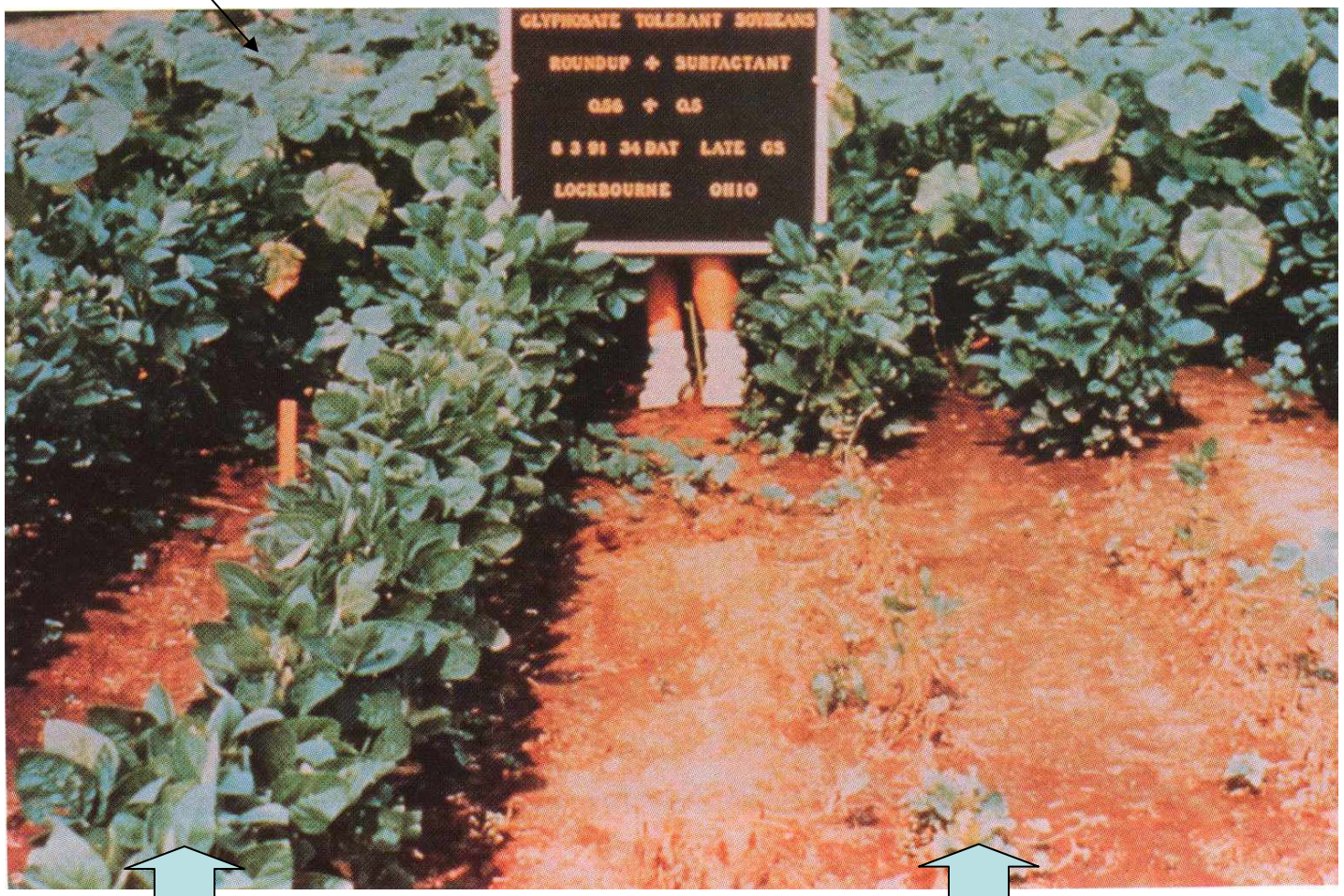


Glyphosate

- Developed in the late 1970's
- Marketed first as Roundup
- Inhibits EPSPS
- Non-selective until…



velvetleaf



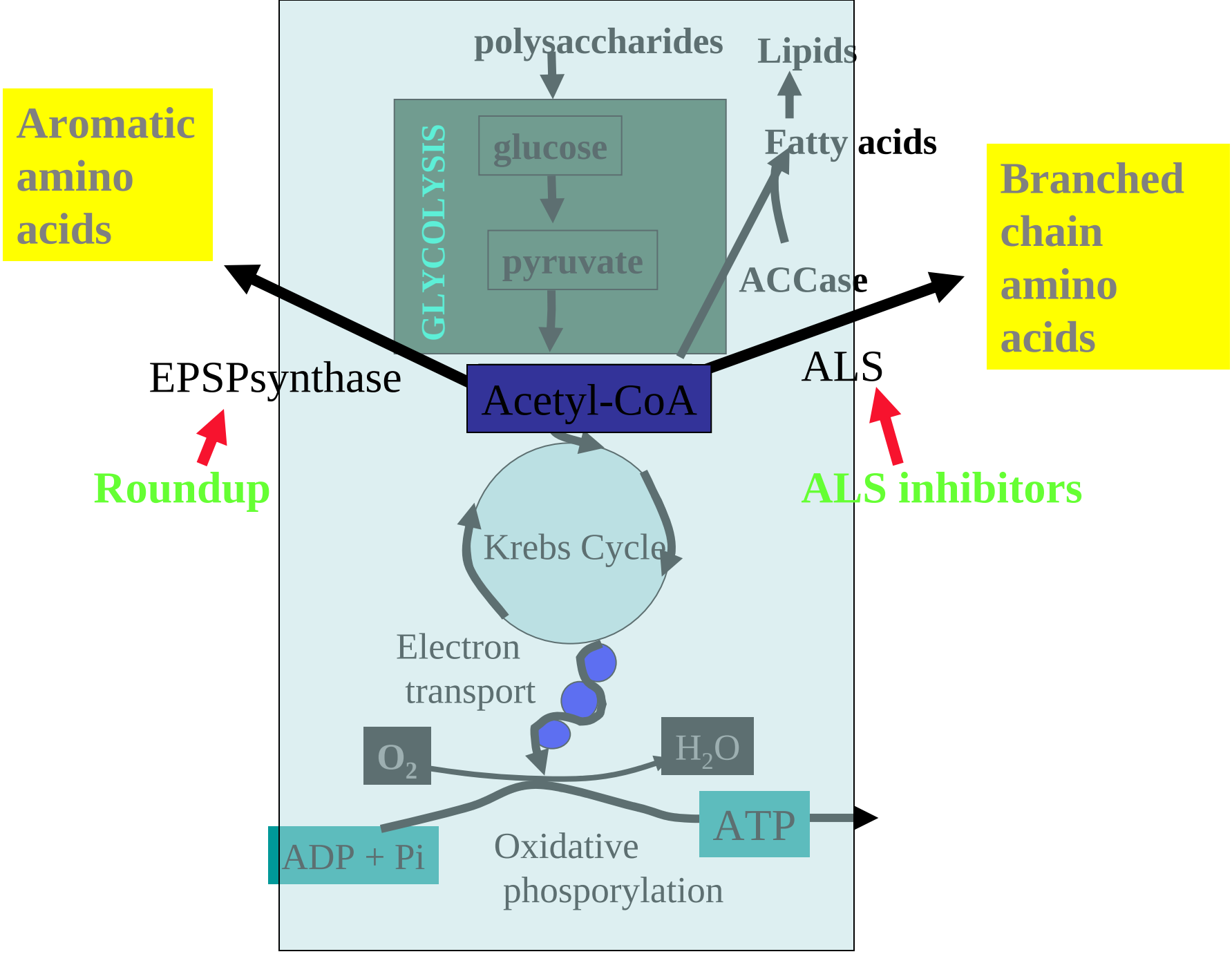
Roundup Ready soybean

conventional soybean

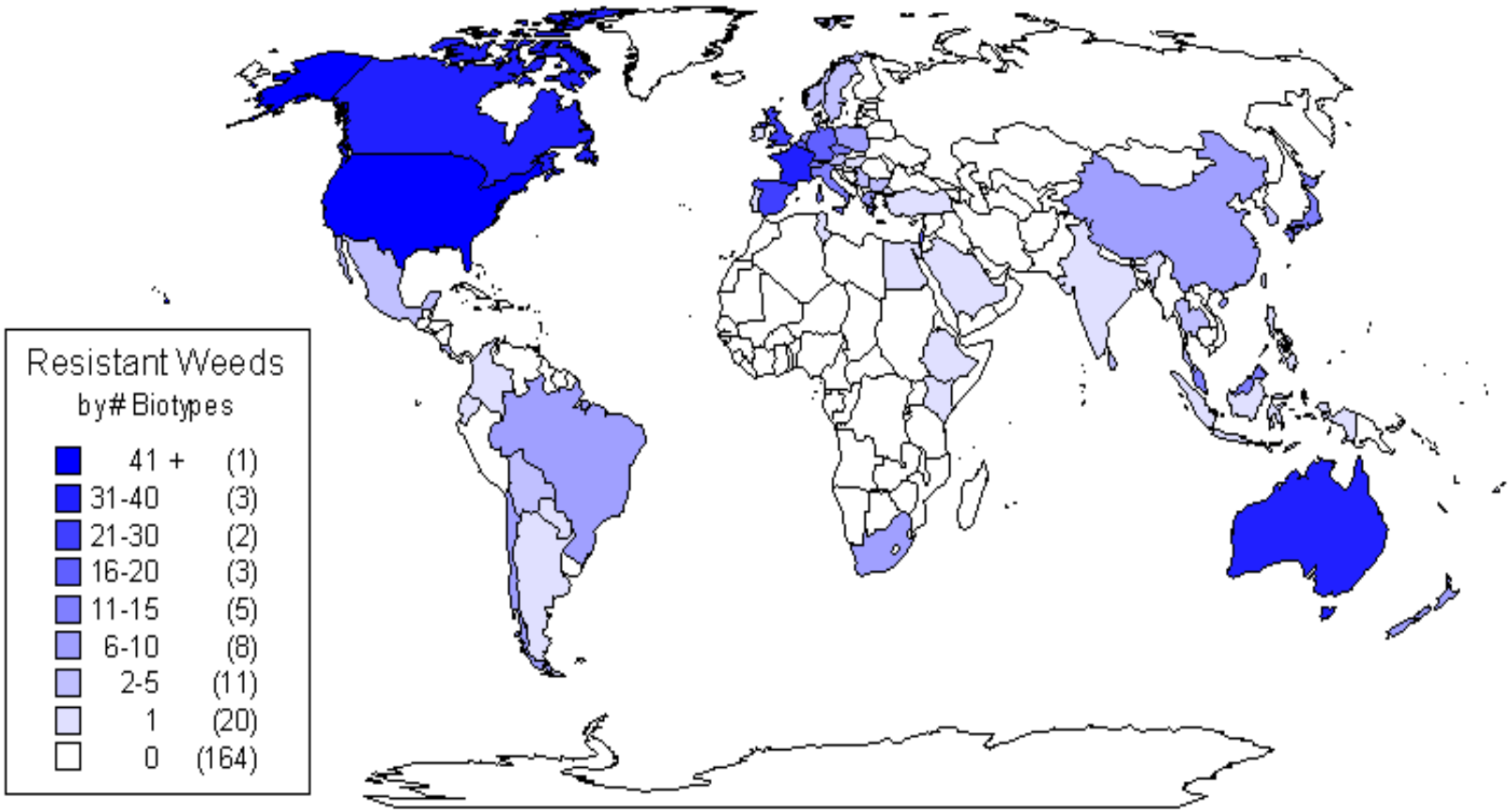
ALS Inhibitors

- Developed in the 1980's
- Imidazolinones: imazethapyr (Pursuit)
- Sulfonylureas: 'urons' bensulfuron(Londax), chlorsulfuron (Glean, Telar)
- pyrimidinyloxybenzoate, triazolopyrimidines
- Very low rates (g/A)

ALS inhibitor symptoms begins at growing points where branched chain amino acids are needed


polysaccharides
Lipids
Aromatic amino acids
GLYCOLYSIS
glucose
Fatty acids
pyruvate
ACCase
Branched chain amino acids
EPSPsynthase
Acetyl-CoA
ALS
Roundup
ALS inhibitors
Krebs Cycle
Electron transport
O_2
H_2O
ATP
ADP + Pi
Oxidative phosporylation

Distribution of Herbicide Resistant Biotypes

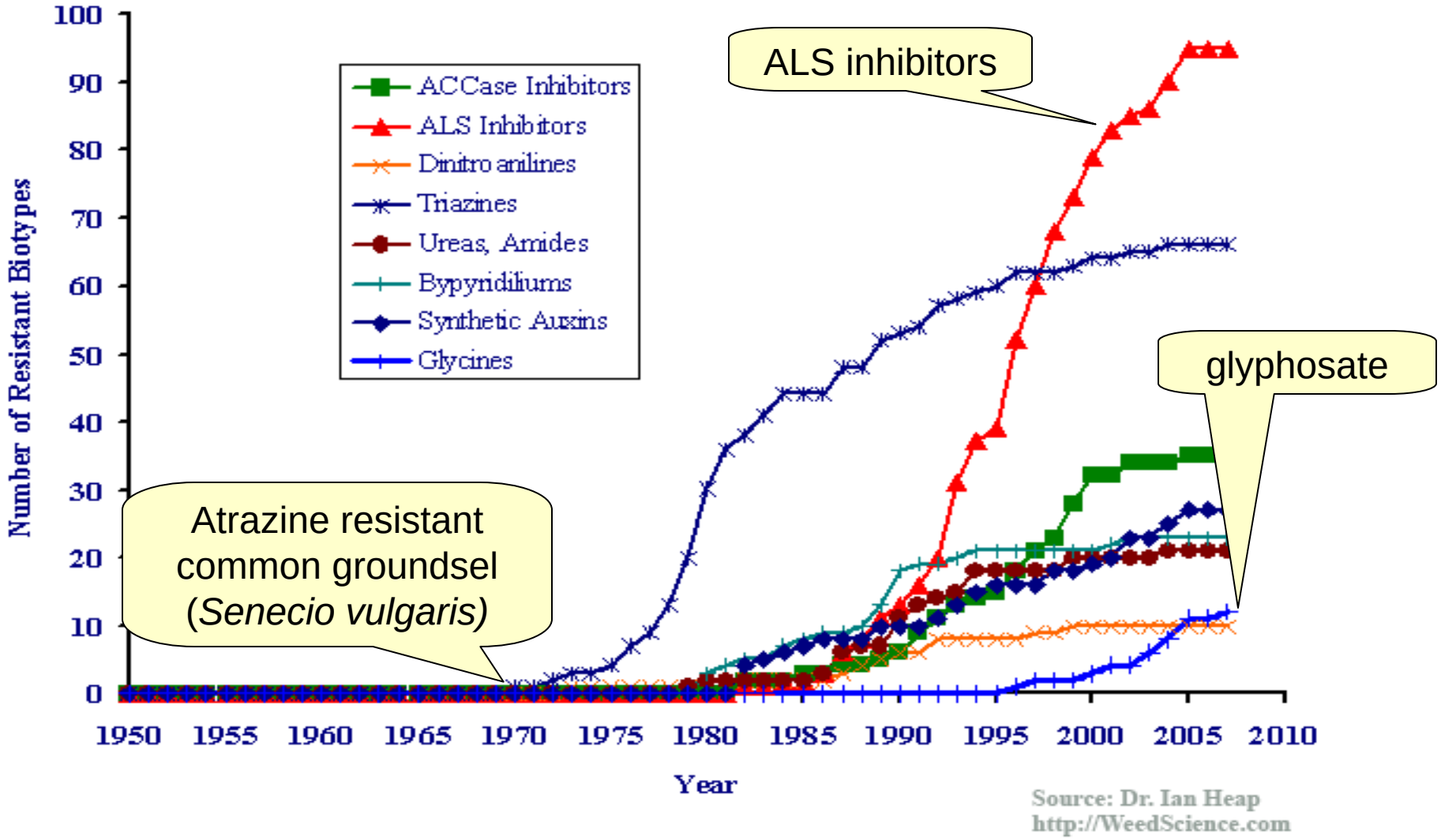


Source: Dr. Ian Heap
www.weedscience.com

Most Important Herbicide-Resistant Species

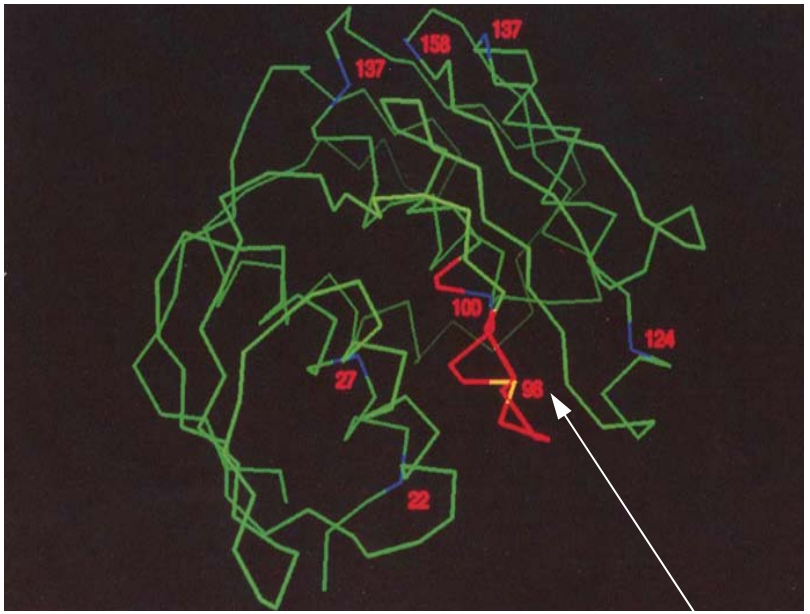
1.	Rigid Ryegrass	*Lolium rigidum*
2.	Wild Oat	*Avena fatua*
3.	Redroot Pigweed	*Amaranthus retroflexus*
4.	Common Lambsquarters	*Chenopodium album*
5.	Green Foxtail	*Setaria viridis*
6.	Barnyardgrass	*Echinochloa crus-galli*
7.	Goosegrass	*Eleusine indica*
8.	Kochia	*Kochia scoparia*
9.	Horseweed	*Conyza canadensis*
10.	Smooth Pigweed	*Amaranthus hybridus*

Development of herbicide resistance



Glyphosate resistance

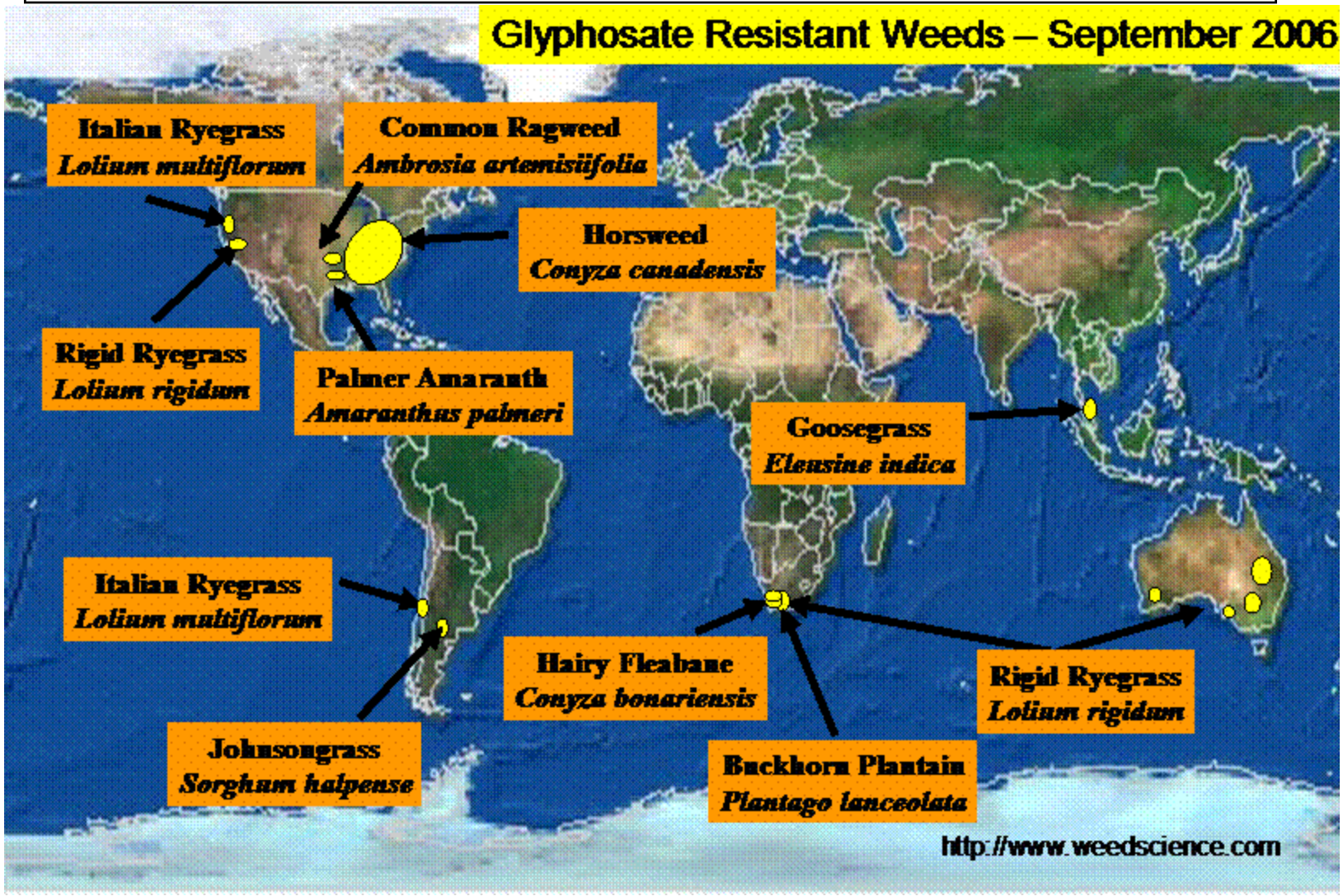
- 2 possible mutations in EPSPS can confer resistance
- First reported in 1996 in rigid ryegrass (*Lolium rigidum*) in Australia
- Next in California 1998 in Italian ryegrass (*Lolium multiflorum*)



Substituting Ala for Gly at the residue site 96 Confers glyphosate resistance. The other numbers correspond to active site residues for glyphosate and substrate binding.

Roundup (6qt./A) at highest labeled rate

Glyphosate resistance



ALS Inhibitor resistance

- 10+ possible mutations on ALS that can confer resistance to a plant
- Highest number of cases of resistance (95 biotypes)
- Latest mode of action

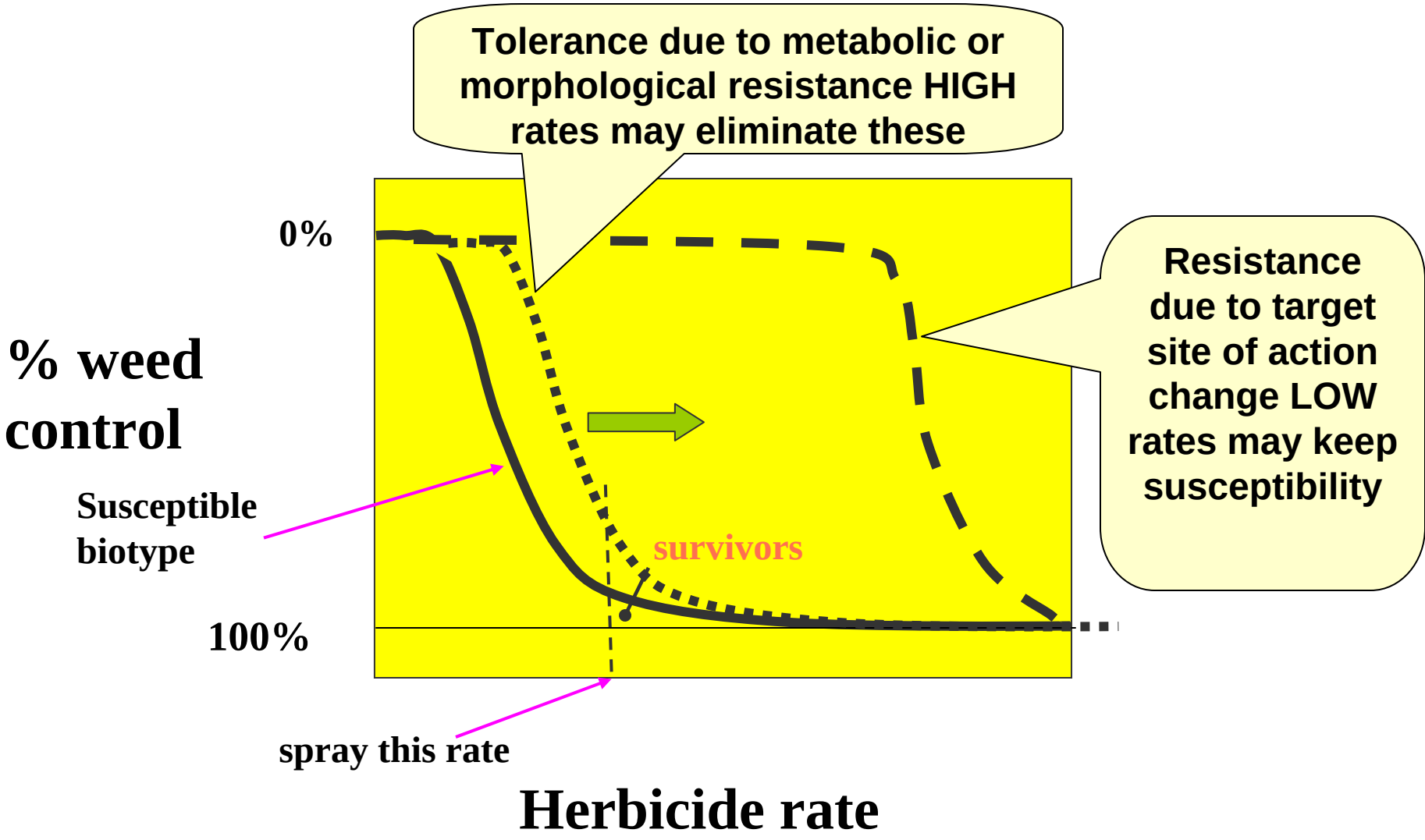
Rate of evolution depends on:

- Generation time
- Initial frequency of resistant allele
- Threshold at which resistance is recognized
- Strength of selection: intensity and duration

Herbicide characteristics that influence weed resistance

- herbicides with a single target site
- selection intensity: rate and duration
- herbicides used multiple times during the growing season
- herbicides with long residual activity
- herbicides used for consecutive growing seasons
- Herbicides used alone without other control strategies

How weeds are resistance determines how to manage them



Summary

- Herbicides began as non-selective, highly toxic, used at high rates
- They became selective, non-toxic, and used at low rates
- Resistance developed primarily because of reliance one single modes and methods of action
- Resistance is "micro"-evolution: a function of selection pressure

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