PPO Resistance
A USA Perspective

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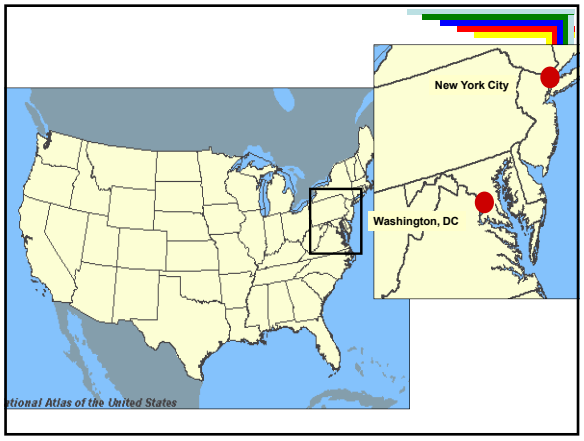
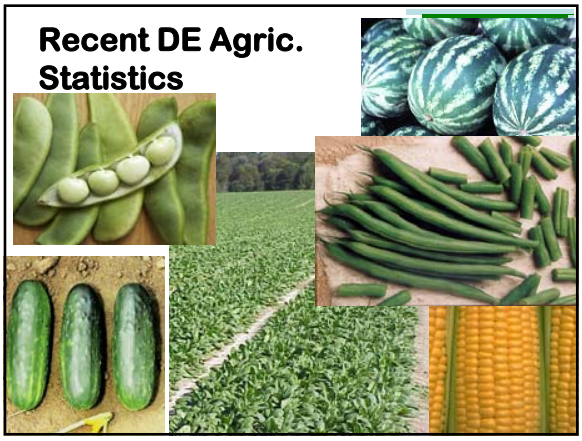
Topics

- Introductions
  - Where am I
- Overview of agriculture in US
- PPO herbicides (Group 14 / E)
  - MOA
  - resistance
- PPO-resistance in my region of US
- Trends for the future
- Resistance management



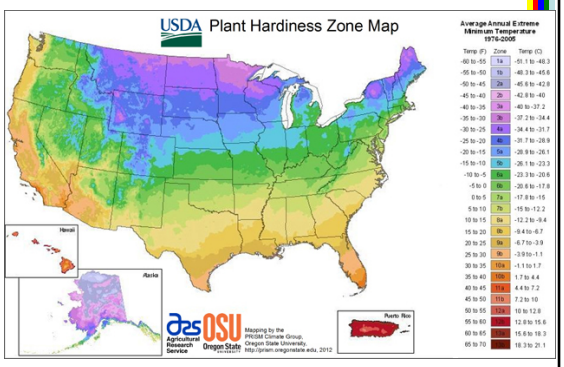
Recent DE Agric. Statistics



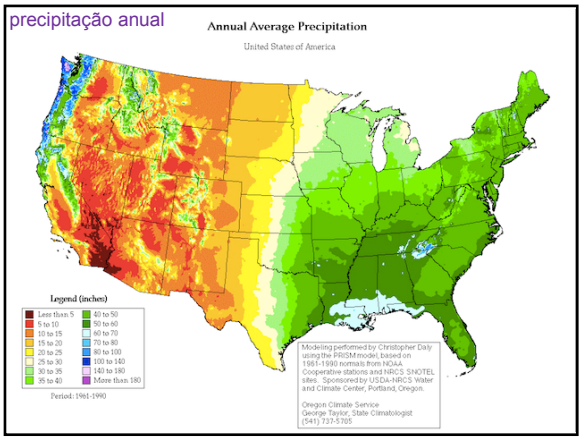
Recent DE Agric. Statistics

Milha 75,000 ha
Soja 80,000 ha (44,000 ha FSNT)
Trigo and cevada 35,000 ha
Vegetal (processo) 20,000 ha
Vegetal (fresco) 6,000 ha
Frango (carne) 252 million produced

zonas de robustez



precipitação anual

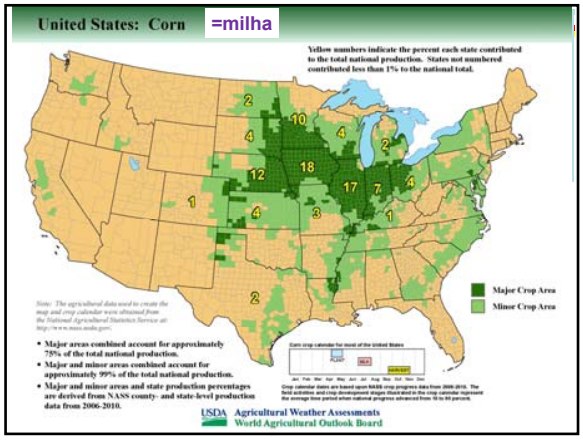


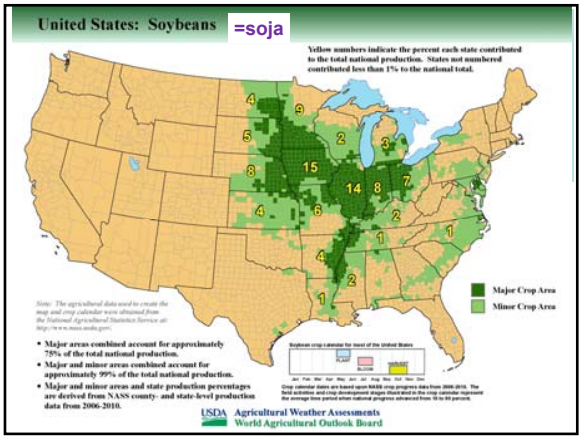
Area Planted

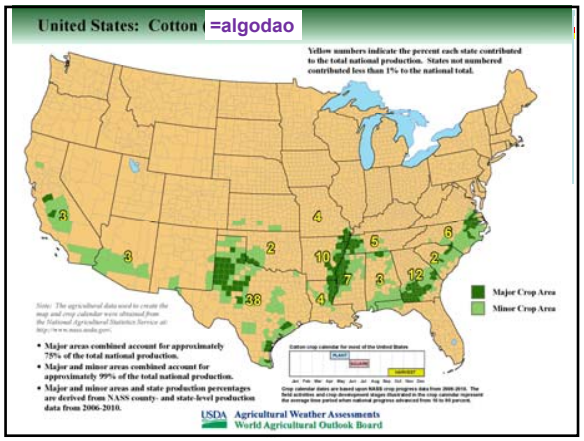
Crop	A	ha	Crop	A	ha
soybean	81	32.8	rice	2.6	1.1
corn	80.7	32.7	sunflower	1.9	0.8
wheat (all)	54.6	22.1	canola	1.8	0.7
__winter	39.5	16.0	dry beans	1.8	0.7
__spring	19	7.7	rye	1.6	0.6
hay crop	54.4	22.0	peanuts	1.6	0.6
__alalfa	17.7	7.2	sugarbeet	1.2	0.5
__other hay	36.7	14.9	dry peas	1.1	0.4
sorghum (grain)	8.5	3.4	potatoes	1.1	0.4
cotton	8.08	3.3	vegetables (fresh)	1.4	0.6
barley	3.6	1.5	vegetables (process)	1.1	0.4
oats	3.1	1.3			

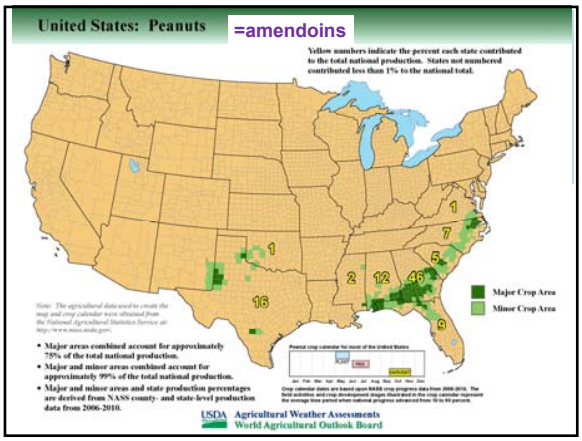
Area Planted

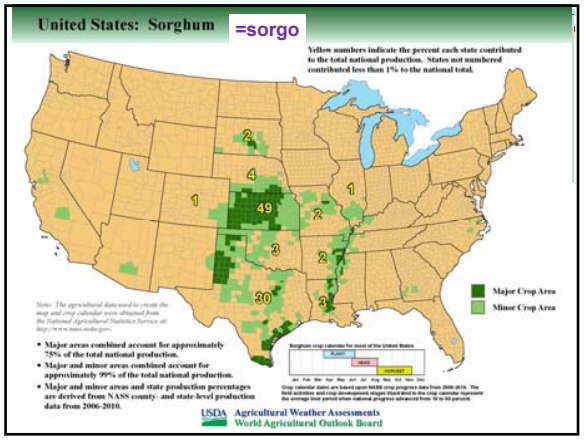
Crop	ha	%	Crop	ha	%
soja	32.8	24.9	arroz	1.1	0.8
milha	32.7	24.8	girassol	0.8	0.6
trigo (all)	22.1	16.8	canola	0.7	0.5
__inverno	16.0	12.1	feijoes secos	0.7	0.5
__primavera	7.7	5.8	centeio	0.6	0.5
choheita do feno	22.0	16.7	amendoins	0.6	0.5
__alalfa	7.2	5.5	beterraba	0.5	0.4
__other hay	14.9	11.3	ervilhas secas	0.4	0.3
sorgo	3.4	2.6	batatas	0.4	0.3
algodão	3.3	2.5	vegetal (fresco)	0.6	0.5
cevada	1.5	1.1	vegetal (processo)	0.4	0.3
aveia	1.3	1.0			

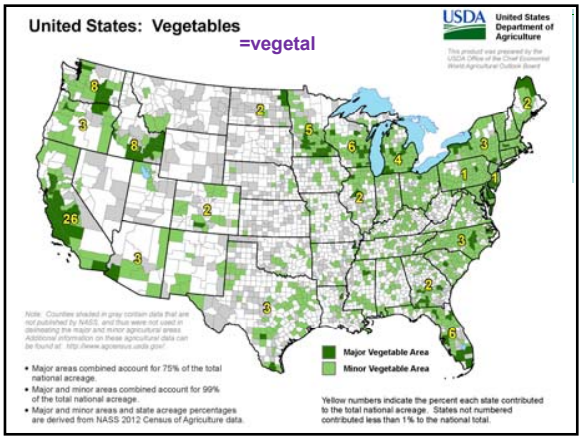


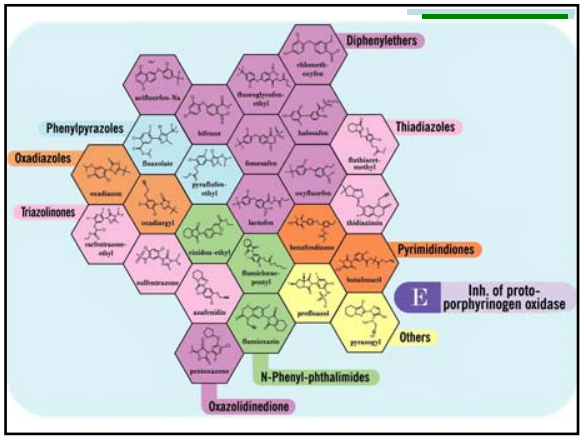












PPO 14 / E Herbicides

- First commercialized in 1960's
- Includes 9 herbicide families
- Can be used in annual crops, tree fruits/nuts, turf, and ornamentals
- Controls mostly broadleaf weeds

- "burning-type herbicide"

PPO 14 / E Herbicides

	Diphenyl ethers	Diphenyl ethers	Diphenyl ethers	Diphenyl ethers
active ingredient	acifluorfen	fomesafen	lactofen	oxyfluorfen
crops	soybean	soybean	soybean	vegetables
	peanut	*Phaseolus*		Brassicas
	rice			nut
use pattern	POST	PRE / POST	POST	PRE / POST
residual	none	yes	minimal	yes

PPO 14 / E Herbicides

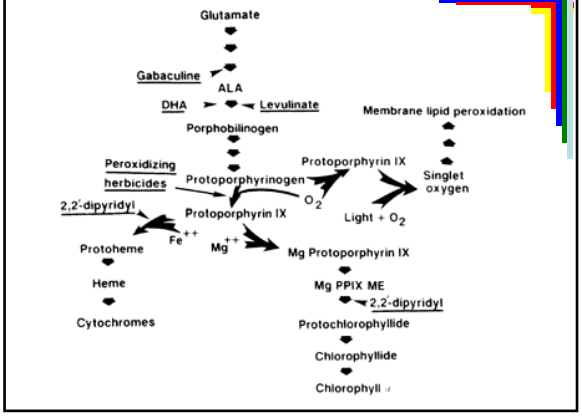
	Triazolinones	Triazolinones	Phenyl-phthalinon-ides	Thiadiazoles	Pyrimidine-dione
active ingredient	carfentrazone	sulfentrazone	flumioxazin	fluthiacet	saflufenacil
crops	soybean	soybean	soybean	soybean	soybean
	corn	tobacco		corn	corn
	wheat	sunflower			wheat
		vegetables			fruit tree
use pattern	POST	PRE	PRE	POST	POST
residual	none	yes	yes	none	rate dependent

Mechanism of Action PPO

- Inhibit chlorophyll synthesis
- Site of action is protoporphyrinogen oxidase (PPG oxidase or Protox)
  - an enzyme involved in chlorophyll synthesis
- Herbicide requires sunlight but photosynthesis is not necessary

Mechanism of Action PPO

- Inhibit protoporphyrinogen oxidase (PPO)
  - an enzyme of chlorophyll biosynthesis
  - leads to accumulation of protoporphyrin IX (PPIX)
    - the first light absorbing chlorophyll precursor
- light absorption by PPIX leads triple state PPIX and forms singlet oxygen
  - leads to chain reaction of lipid peroxidation
  - ultimately leaking membranes that allows cells and cell organelles to dry and disintegrate



Crop Plant Response

- Acifluorfen is metabolized in soybean by reduction => deesterificaiton => conjugation
- P450 involved with metabolism of sulfentrazone and carfentrazone

Can Cause Leaf Burn

PPO (E) Resistant Weeds

Country	Species	Year	Additional
Brazil	*Euphorbia heterophylla*	2004	+B
Bolivia	*Amaranthus hybridus*	2005	
China	*Descurainia sophia*	2011	
China	*Acalypha australis*	2011	
Israel	*Senecio vernalis*	2014	+B, C1, C2, F1
Canada	*Avena fatua*	2015	+A, B, K3, N

PPO (E) Resistant Weeds

State	Species	Year	Additional
Kansas	*Amaranthus tuberculatus*	2001	+B
Illinois		2002	+B, C1
Missouri		2005	+B, G
Illinois		2009	+B, C1, G
Iowa		2009	
Indiana		2014	
Minnesota		2014	
Delaware	*Ambrosia artemisiifolia*	2005	+B
Ohio		2006	+B
Arkansas	*Amaranthus palmeri*	2011	
NC, TN, MS		2015	
VA	*Eleusine indica*	2013	

Resistance to Group 14 / E

- No reports of non-target sites
- Target-site resistance in *Ambrosia artemisiifolia* and *Amaranthus tuberculatus*
  - codon of mitochondrial PPO was deleted in *A. tuberculatus*
  - Arg substitution for Leu for *A. artemisiifolia*
- Not as well understood as other MOA's

Expansion of PPO-resistant Species

Trait	*Amaranthus palmeri*		*Ambrosia artemisiifolia*
Life-cycle	summer annual		summer annual
Flowers	dioecious		monoecious / imperfect flowers
Competitiveness	very high		high
height	>1.7 m		1 m
Stress-tolerant	very high		fair to good
Roots	weak taproot		fiberous
Emergence pattern	very long		short (early spring)
Seed production	>1 mil		> 50,000
Seed longevity	3-4 yrs		3-4 yrs

Resistant Weeds in Delaware

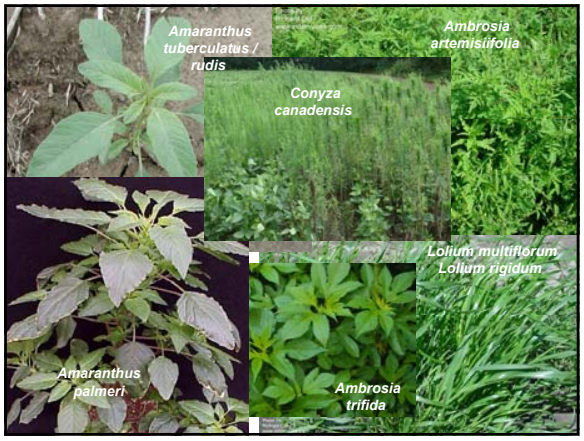
- *Amaranthus hybridus* atrazine (C1)
- *Chenopodium album* atrazine (C1)
- *Amaranthus hybridus* ALS-inhibitors (B)
- *Ambrosia artemisiifolia* ALS+PPO-inhibitors
- *Conyza canadensis* glyphosate (G)
- *Conyza canadensis* paraquat (D)
- *Conyza canadensis* ALS-inhibitors +glyphosate (B+G)

Resistant Weeds in Delaware

- *Stellaria media* ALS-inhibitors (B)
- *Amaranthus palmeri* ALS-inhibitors +glyphosate (B+G)
- *Lolium multiflorum* ALS-inhibitors (B)
- *Amaranthus tuberculatus* ALS-inhibitors +glyphosate (B+G)

Resistant Weeds of Note in the Region

- *Ambrosia artemisiifolia* glyphosate (G)
- *Lolium multiflorum* ACCase-inhibitor (A)
- *Sorghum bicolor* ALS-inhibitor (B)

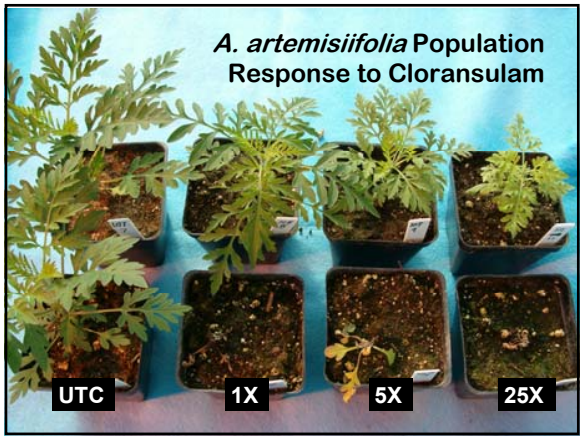


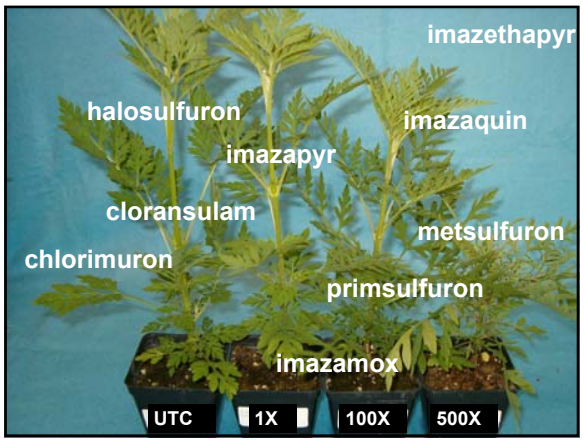
PPO-resistant *A. artemisiifolia* (Group E)

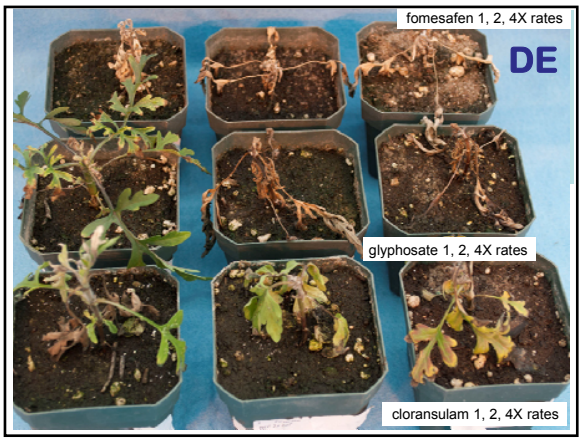
fomesafen

flumioxazin
lactofen flumiclorac

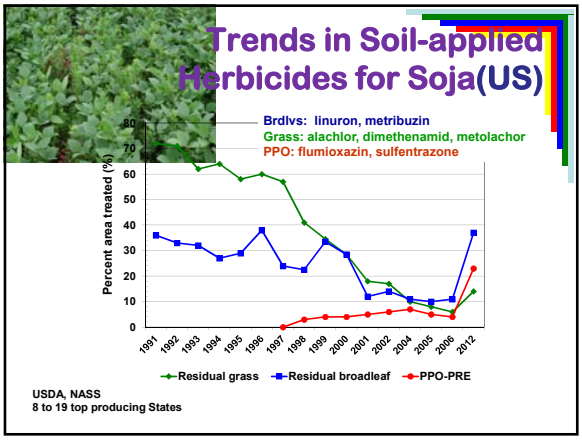
Not shown:
carfentrazone, sufentrazone
aciflurofen, oxyflurofen

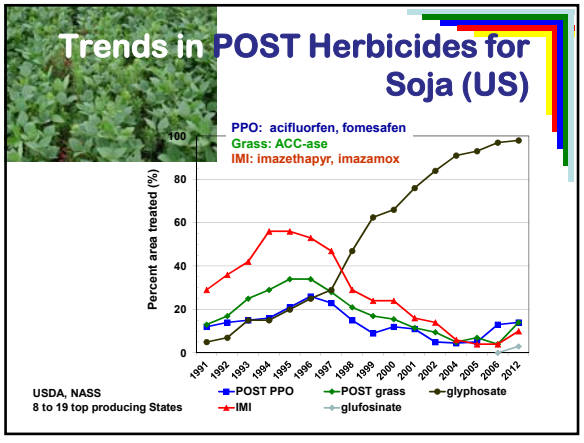


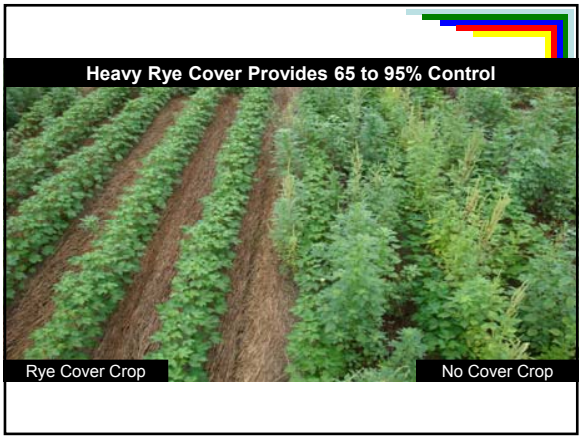

imazethapyr
halosulfuron
imazaquin
imazapyr
cloransulam
metsulfuron
chlorimuron
primsulfuron
imazamox
UTC
1X
100X
500X


fomesafen 1, 2, 4X rates
DE
glyphosate 1, 2, 4X rates
cloransulam 1, 2, 4X rates


fomesafen 1, 2, 4X rates
MD
glyphosate
1, 2, 4X rates
cloransulam 1, 2, 4X rates


Trends in Soil-applied Herbicides for Soja(US)
Brdlvs: linuron, metribuzin
Grass: alachlor, dimethenamid, metolachor
PPO: flumioxazin, sulfentrazone
Percent area treated (%)
0
10
20
30
40
50
60
70
80
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2004
2005
2006
2012
Residual grass
Residual broadleaf
PPO-PRE
USDA, NASS
8 to 19 top producing States


Trends in POST Herbicides for Soja (US)
PPO: acifluorfen, fomesafen
Grass: ACC-ase
IMI: imazethapyr, imazamox
Percent area treated (%)
0
20
40
60
80
100
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2004
2005
2006
2012
POST PPO
POST grass
glyphosate
IMI
glufosinate
USDA, NASS
8 to 19 top producing States


Heavy Rye Cover Provides 65 to 95% Control
Rye Cover Crop
No Cover Crop

Sources

- Shaner, DL 2014. Herbicide Handbook, 10th edition, Weed Science Society of America
- Dyan FE et al 2014. Evolution of resistance to phytoene desturase and protoporphyrinogen oxidase inhibitors - state of knowledge. Pesticide Management Science 70:1358-1366