

PPO Resistance for Grain and Food Crops A USA Perspective

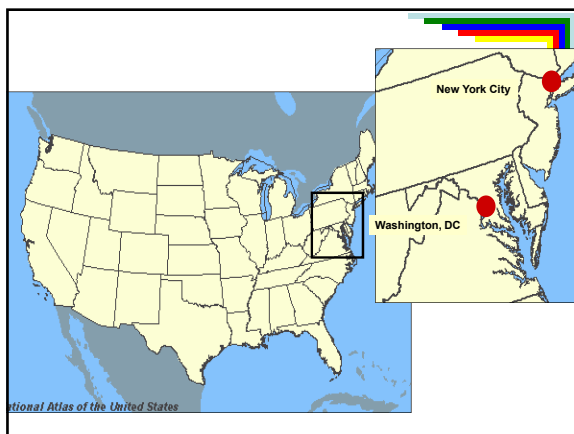


Mark VanGessel



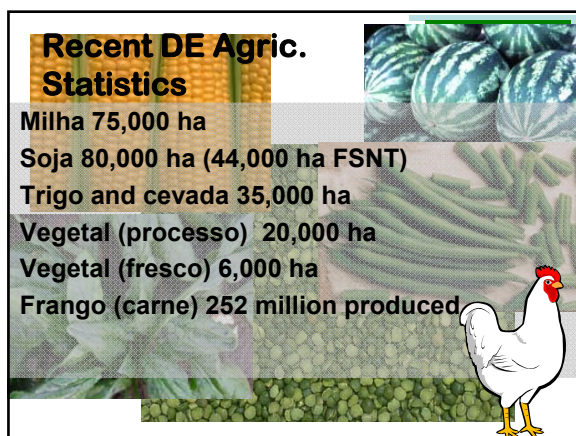
Topics

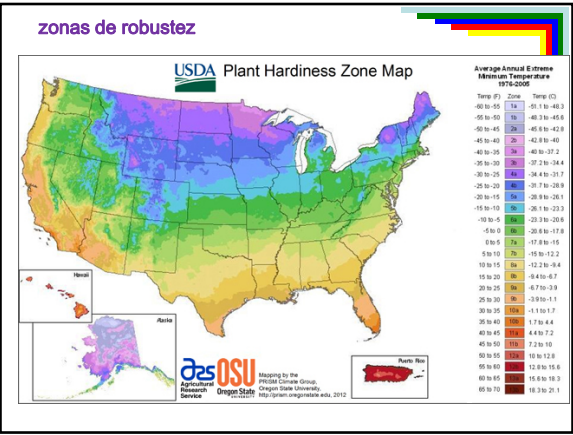
- Introductions
 - Where am I
- Overview of agriculture in USA
- Herbicide-resistance in USA
- PPO herbicides (Group 14 / E)
 - MOA
 - resistance
- PPO-resistance in my region of the USA
- Trends for the future
- Resistance management

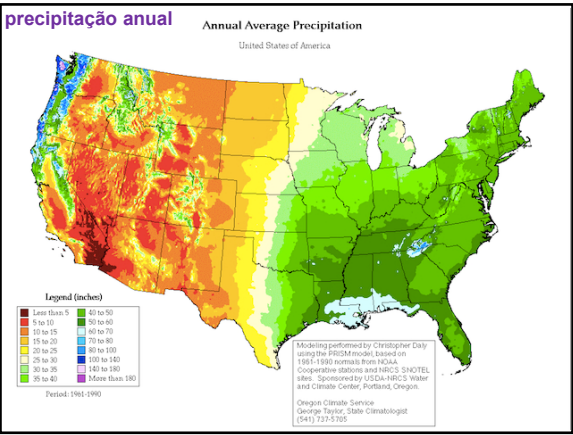






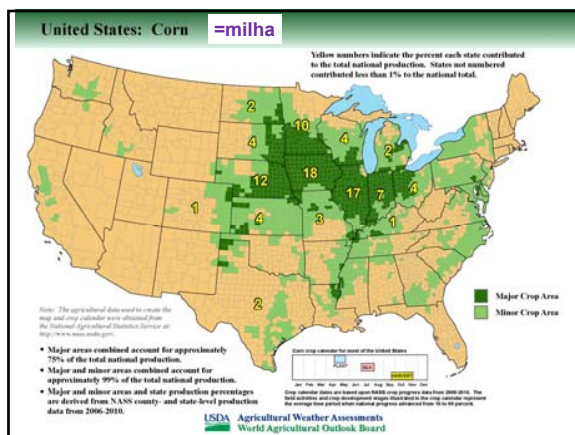


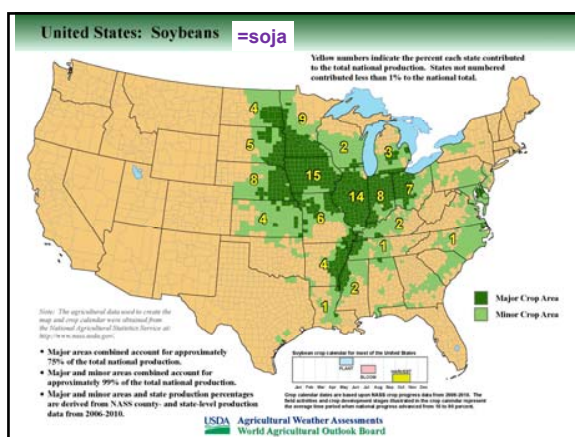


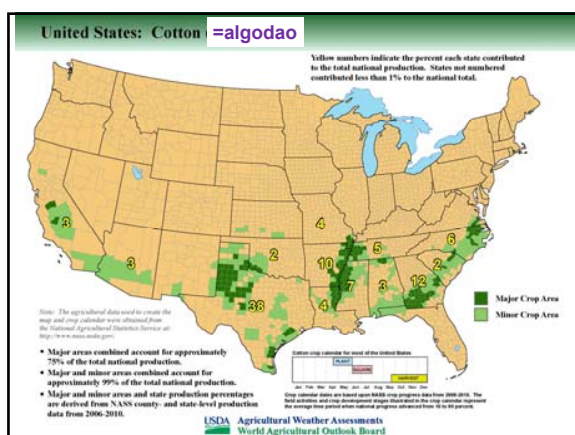


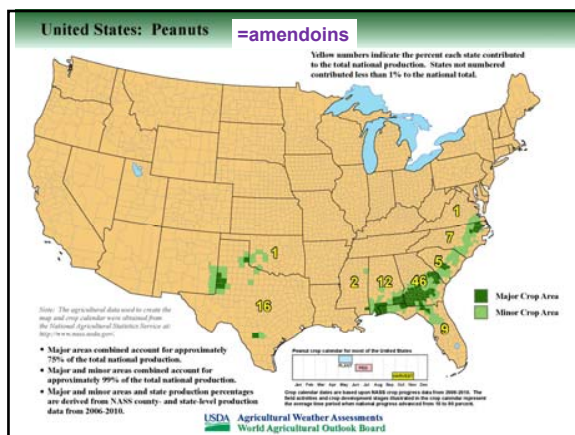
Area Planted

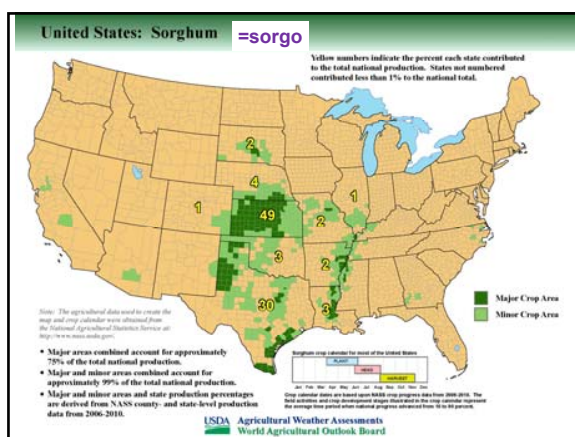
Crop	ha	%	Crop	ha	%
soja	32.8	24.9	arroz	1.1	0.8
milha	32.7	24.8	girassol	0.8	0.6
trigo (all)	22.1	16.8	canola	0.7	0.5
_inverno	16.0	12.1	feijoes secos	0.7	0.5
_primavera	7.7	5.8	centeio	0.6	0.5
chocheita do feno	22.0	16.7	amendoins	0.6	0.5
_alfalfa	7.2	5.5	beterraba	0.5	0.4
_other hay	14.9	11.3	ervilhas 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			

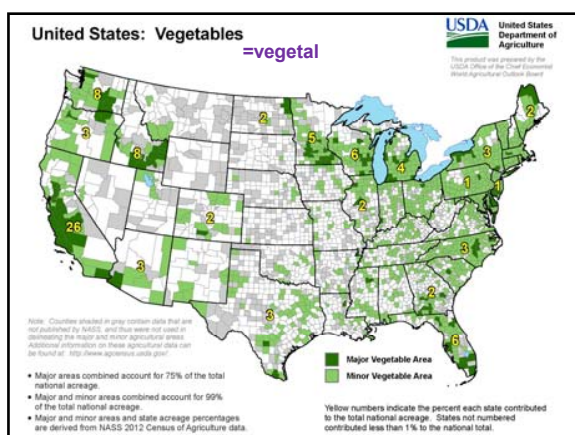


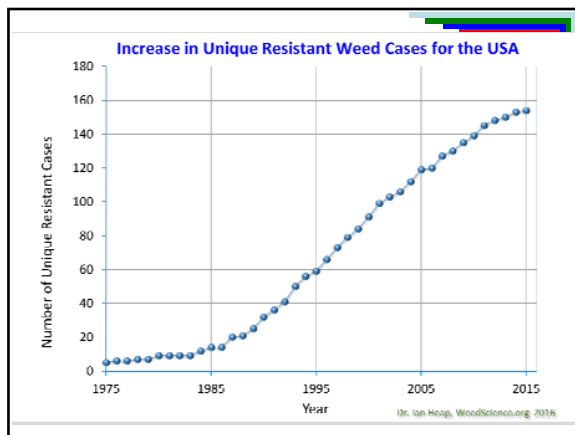


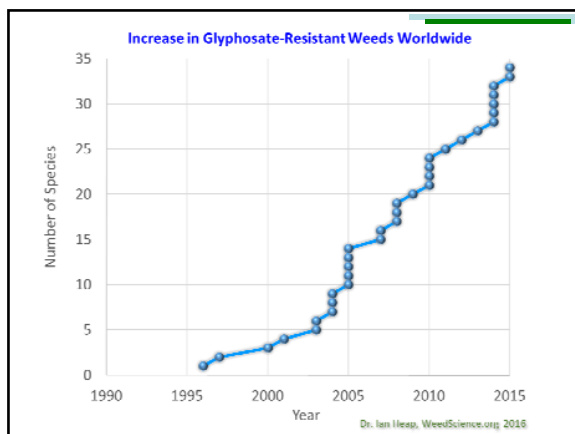


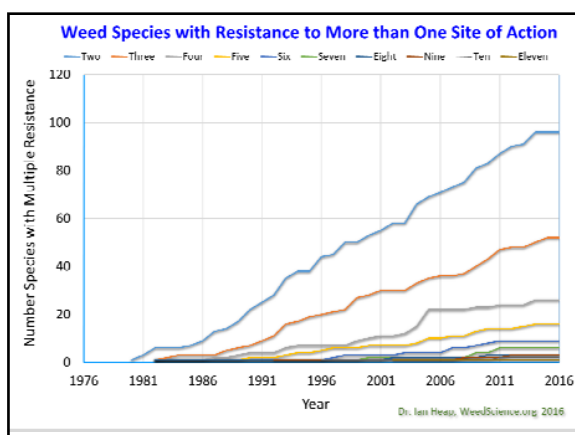


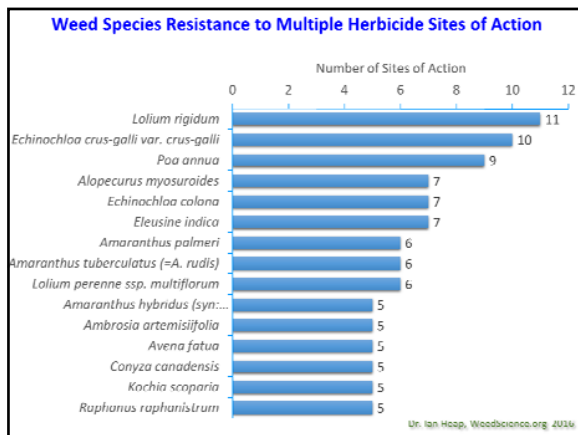




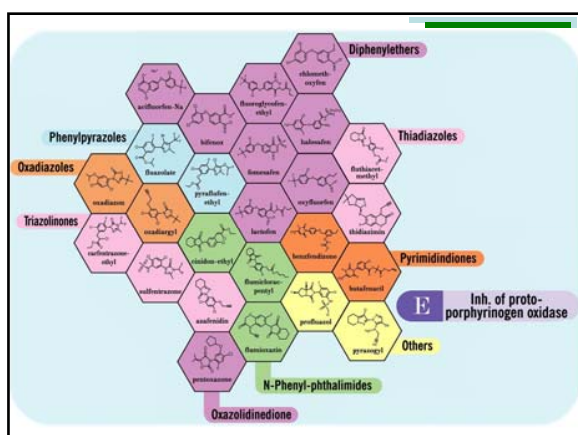












PPO 14 / E Herbicides

- 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

family:	Diphenyl ethers	Diphenyl ethers	Diphenyl ethers	Diphenyl ethers
active ingredient	acifluorfen	fomesafen	lactofen	oxyfluorfen
crops	soja	soja	soja	vegetal
	amendoim	algodão	amendoim	fruta
	arroz	<i>Phaseolus</i>		castanheira
use pattern	POST	PRE / POST	POST	PRE / POST
residual	none	yes	minimal	yes

PPO 14 / E Herbicides

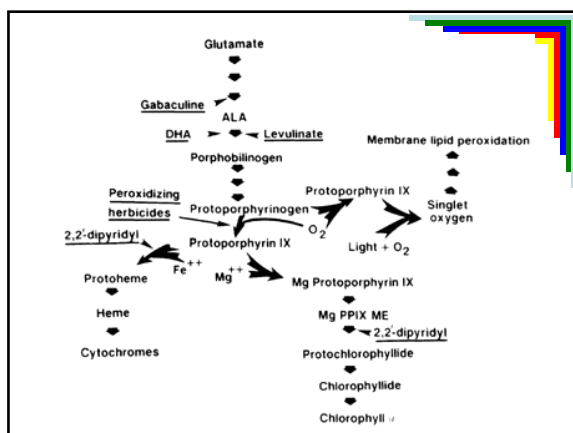
family:	Triazolinones	Triazolinones	Phenyl-phthalinon-ides	Thiadiazoles	Pyrimidine-dione
active ingredient	carfentrazone	sulfentrazone	flumioxazin	fluthiacet	saflufenacil
crops	soja	soja	soja	soja	soja
	milha	tobaco	algodão	milha	milha
	trigo	girassol	amendoim		algodão
		vegetal	trigo		trigo
			árvore frutífera		árvore frutífera
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
- Causes cell membranes to leak
- 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 => de-esterification => conjugation
- P450 involved with metabolism of sulfentrazone and carfentrazone

Can Cause Leaf Burn



PPO (E) Resistant Weeds

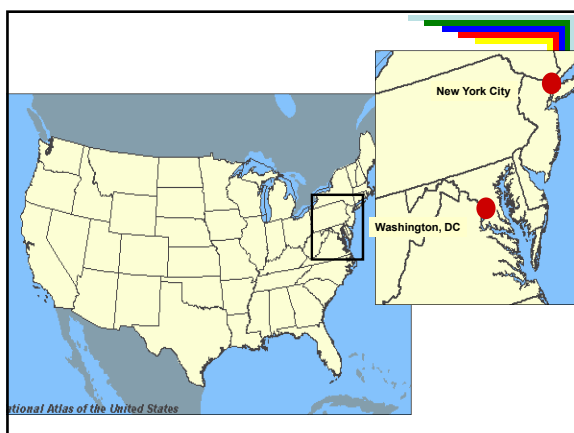
Country	Species	Year	Additional
Brazil	<i>Euphorbia heterophylla</i>	2004	+B
Bolivia	<i>Amaranthus hybridus</i>	2005	
China	<i>Descurainia sophia</i>	2011	
China	<i>Acalypha australis</i>	2011	
Israel	<i>Senecio vernalis</i>	2014	+B, C1, C2, F1
Canada	<i>Avena fatua</i>	2015	+A, B, K3, N

PPO (E) Resistant Weeds

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



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)



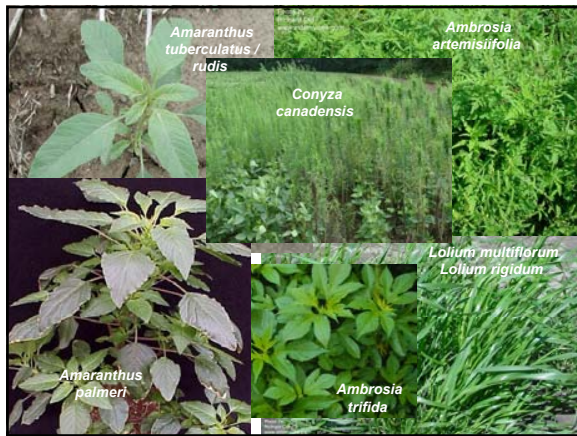
Resistant Weeds in Delaware

- *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)



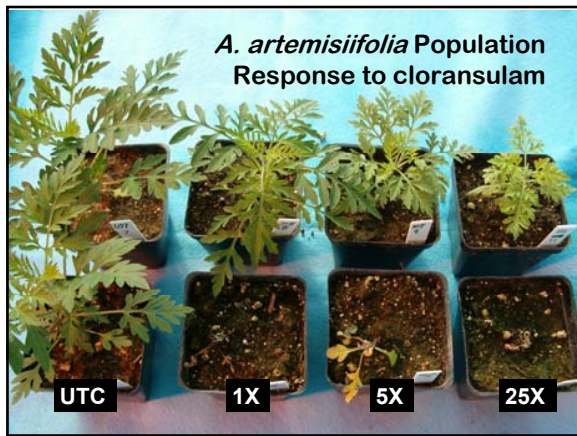


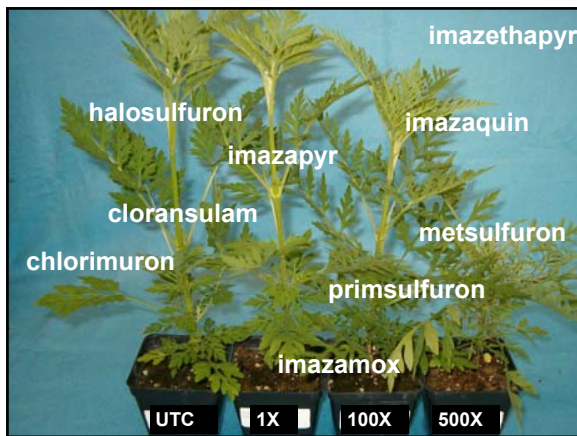
PPO-resistant *A. artemisiifolia* (Group E)

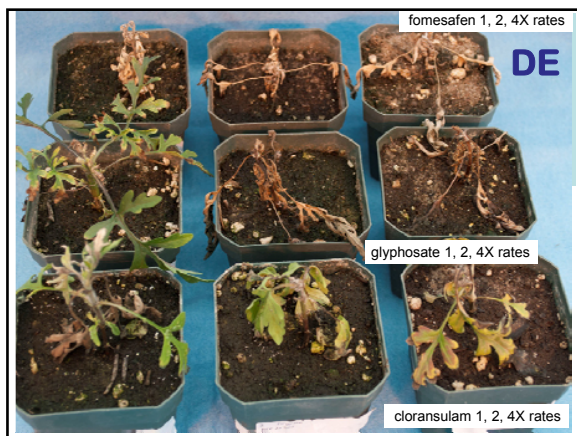
Not shown:
carfentrazone, sufentrazone
acifluorfen, oxyfluorfen

fomesafen

flumioxazin
lactofen flumiclorac



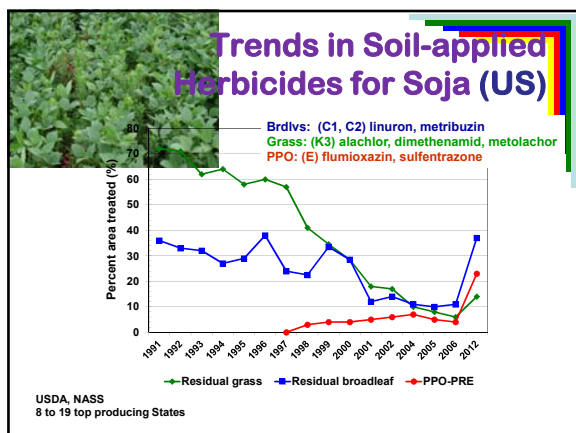


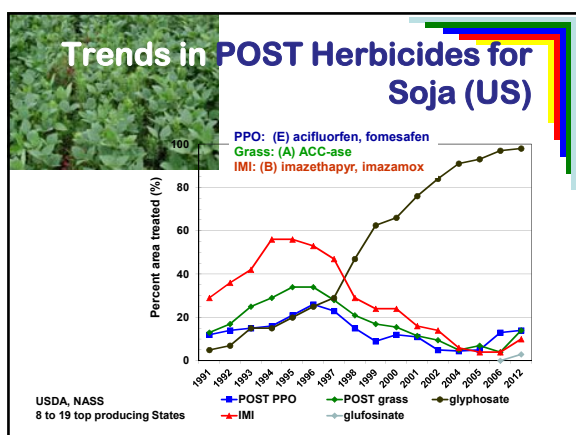






Expansion of PPO-resistant Species		
Trait	<i>Amaranthus palmeri</i>	<i>Ambrosia artemisiifolia</i>
Life-cycle	summer annual	summer annual
Flowers	dioecious	monoecious / imperfect flowers
Competitiveness	very high	high
height	>1.7 m	1 m
Stress-tolerant	very high	fair to good
Roots	weak taproot	fibrous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





Weed Management Programs

- plant into a clean seedbed
 - use tillage or an effective burndown herbicide for no-till;
- use an effective soil-applied herbicide program shortly before or at planting;
- use multiple herbicide sites of action
 - herbicides need to be **EFFECTIVE** not just different
 - consider herbicides sprayed previous year and what will be used in coming years;
- never apply glyphosate by itself when species prone to resistance are present;

Weed Management Programs

- postemergence applications must be made to small (less than 8-cm) plants;
 - If PRE herbicide is used this is typically 3 to 4 weeks after planting
- need to conserve some herbicide groups for vegetables and small grains;
 - consider not using some herbicide groups where other options exist
 - avoid use of ALS-inhibiting herbicides (Group B) outside of vegetables, small grains, and soybeans
 - avoid use of PPO (Group E) outside of soybeans and vegetables
- AND limit weed seed production of problem species

Rotations Are A Large Part of Weed Management

Following comments are assuming crop rotations

- Continuous corn or soybeans OR two-yrs back-to-back may require different approaches



Increasing Use of PPO's

GROUP 14 HERBICIDE

Soja

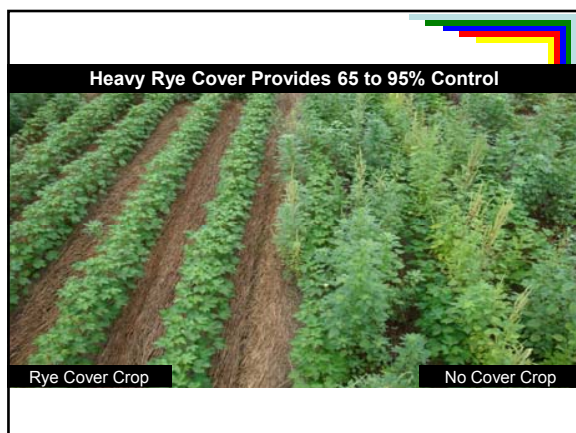
- saflufenacil
- sulfentrazone
- flumioxazin
- fomesafen
- acifluorfen
- carfentrazone
- fluthiacet
- lactofen

Milha

- saflufenacil
- carfentrazone
- fluthiacet

Others

- oxyfluorfen



Sources

- Duke SO 1991. Protoporphyrinogen Oxidase-Inhibiting Herbicides. *Weed Science* 39:465-473
- Dyan FE et al 2014. Evolution of resistance to phytoene desaturase and protoporphyrinogen oxidase inhibitors - state of knowledge. *Pesticide Management Science* 70:1358-1366
- Riggins CW and PJ Tranel 2012. Will the *Amaranthus tuberculatus* resistance mechanism to PPO-inhibiting herbicides evolve in other *Amaranthus* species. *International Journal of Agronomy*
- Scalla R and M Matringe 1994. Inhibitors of protoporphyrinogen oxidase as herbicides: diphenyl ethers and related photobleaching herbicides. *Reviews of Weed Science* 6:103-132
- Shaner DL (editor) 2014. *Herbicide Handbook*, 10th edition, Weed Science Society of America

