# Herbicide Choices and Issues for Vegetable Production

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*World Class. Face to Face.*

# Today's Class

- Herbicide Carryover
- Herbicide Discussion by Application Timing, Mode of Action, and Crop
  - Preplant-incorporated Herbicides
  - Preemergence Herbicides
  - Postemergence Herbicides

# Carryover Concern

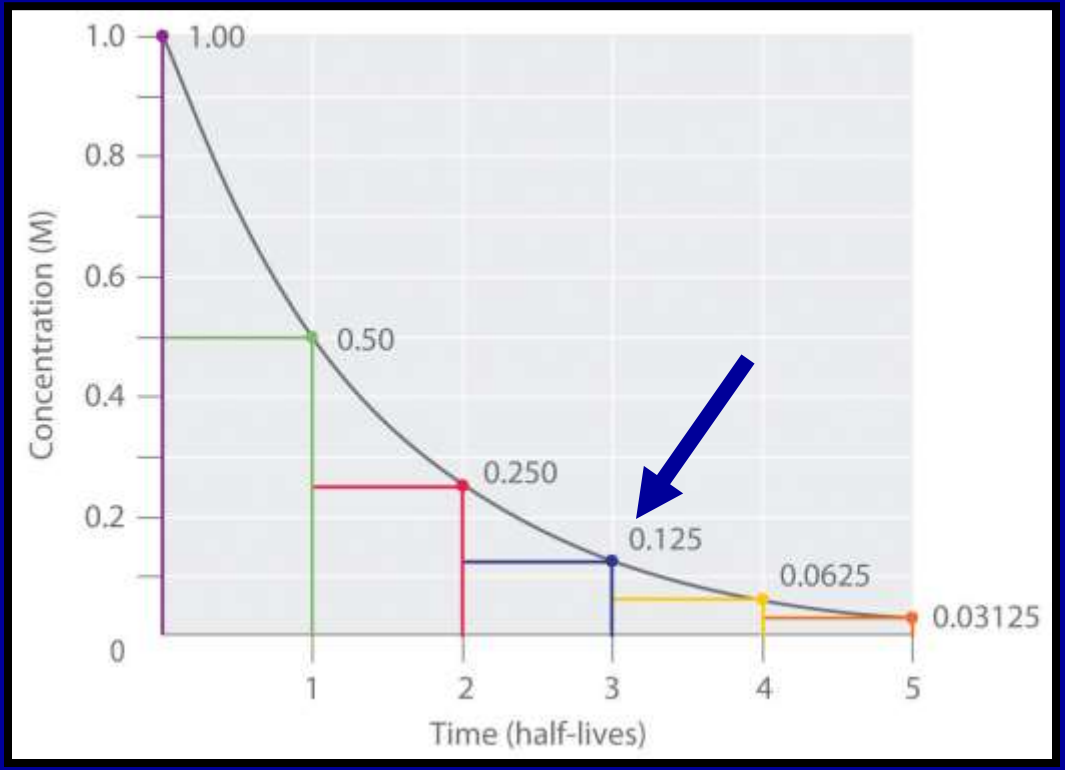
- Herbicides are designed to kill (or at least injure) plants
- Most growers desire some level of residual activity to control late-germinating weed seeds
- However, many herbicides applied to horticultural crops have the potential to persist in soil and to injure rotationally-grown crops

# Herbicide Persistence is Influenced by Several Factors

- pH
  - Some herbicides are very long-lived in alkaline soil
- Temperature
  - Cold or hot soils reduce microbial activity and tend to increase persistence
- Moisture
  - Dry soil also reduces microbial activity
- Herbicide application rate
  - While it doesn't affect how quickly degradation takes place, the greater the dose that is applied, the longer it will take the herbicide to break down to a non-herbicidal level

# Herbicide Half-life

- Herbicide persistence in soil can be described using the concept of "half-life"
- A half-life is the amount of time required for the concentration of herbicide to be reduced by 50%
- For many herbicides, 3 half-lives results in no further herbicidal activity



# Some Common Horticultural Herbicides Sometimes Carryover

- Aatrex (atrazine) is commonly used in sweet corn
  - Half-life of about 60 days
- Command (clomazone) is often used in cucurbits and Brassica crops
  - Half-life of about 24 days
- Raptor (imazamox) is commonly used in bean
  - Half-life of about 25 days
- Stinger (clopyralid) is used in beet, Brassicas, and spinach
  - Half-life of about 40 days

# Half-life is Only Half the Story

- While herbicide persistence is important, the sensitivity of the rotational crop to the herbicide in question is also an important factor to consider when discussing carryover
- Sandea (halosulfuron) is used in sweet corn and cucurbits
  - Half-life about 12 days
  - Crops in Brassicaceae and Chenopodiaceae are very sensitive to this chemistry

# Cucumber

## Very Little Injury

No Sandea

1 oz Sandea

2 oz Sandea

# Rate Response With Green Pea

No Sandea

1 oz Sandea

2 oz Sandea

# Rate Response With Potato

No Sandea

1 oz Sandea

2 oz Sandea

# Ouch.

2 oz Sandea

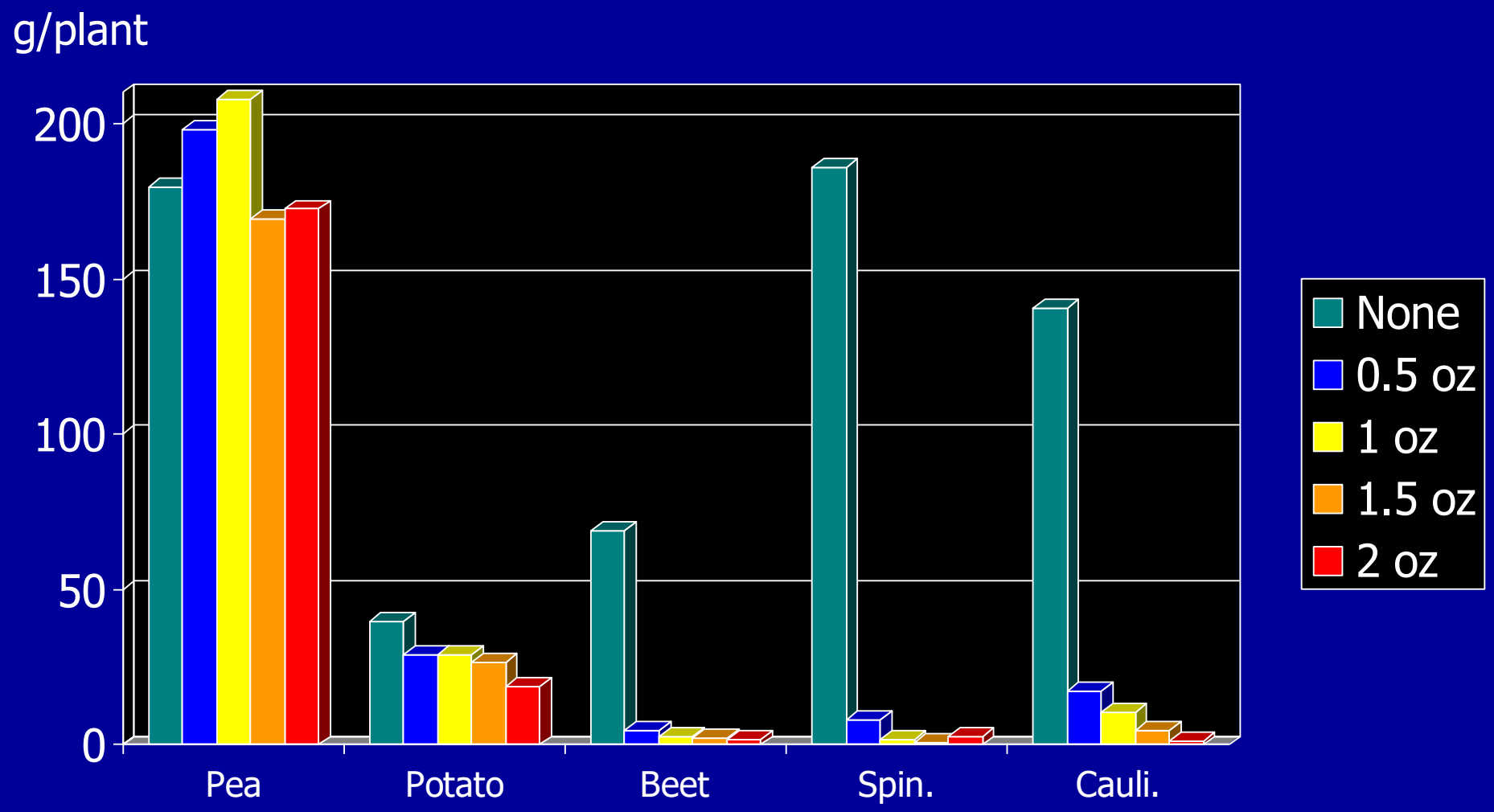
Cauliflower

No Sandea

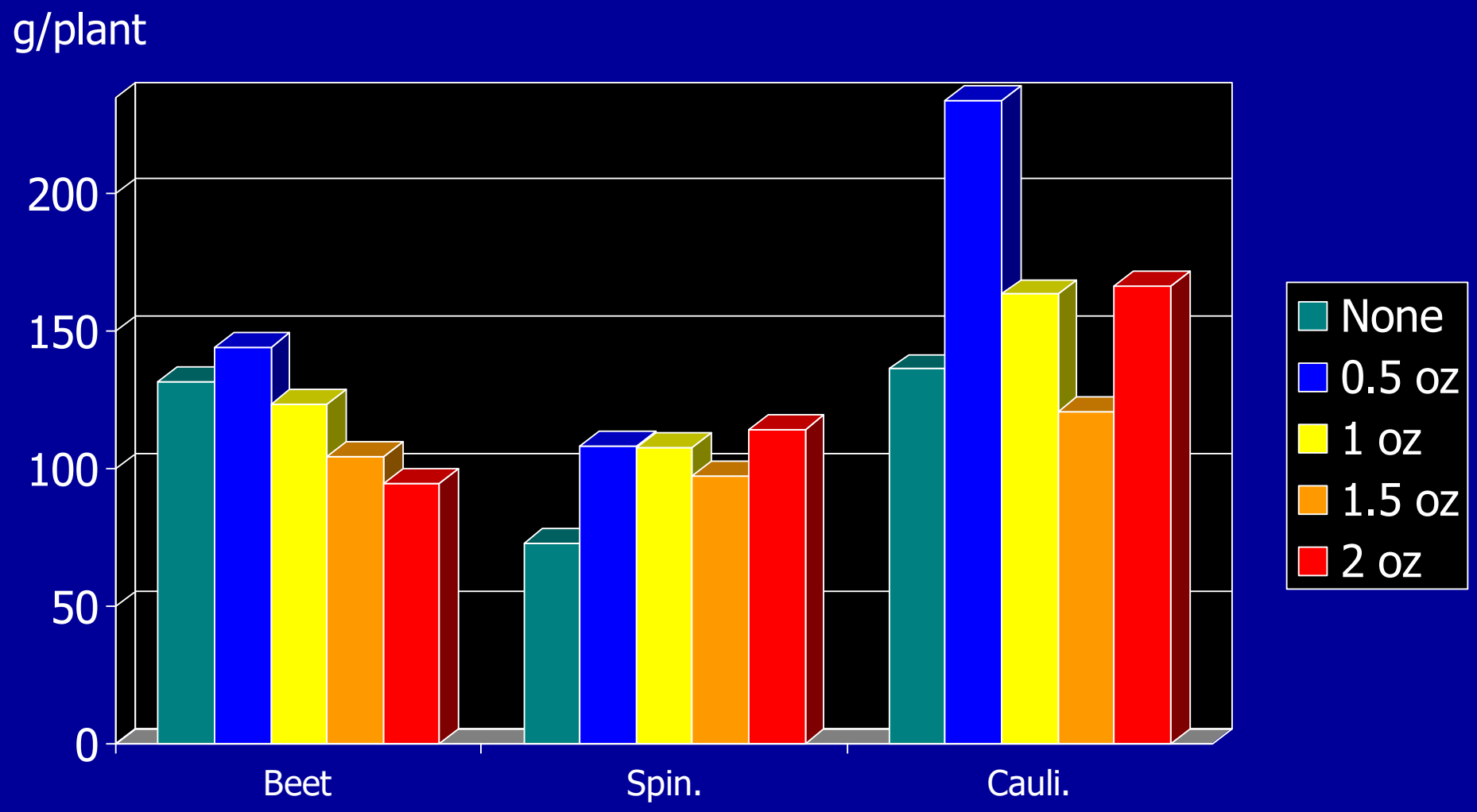
Spinach

Beet

# Crop Biomass at 4.5 MAT



# Crop Biomass at 15.5 MAT



# Herbicides and Compost

- Some picolinic acid herbicides degrade more slowly in compost than in soil
  - Even very low levels in compost can severely injure sensitive plant species
- In 2001, compost at Washington State University and in Spokane, WA was found to contain residues of clopyralid (the active ingredient in Stinger) and Tordon (picloram)
  - Clopyralid was labeled for use in residential turf
  - Mandatory curbside recycling of grass clippings (sometimes as soon as one week after herbicide application) resulted in clopyralid entering the compost stream

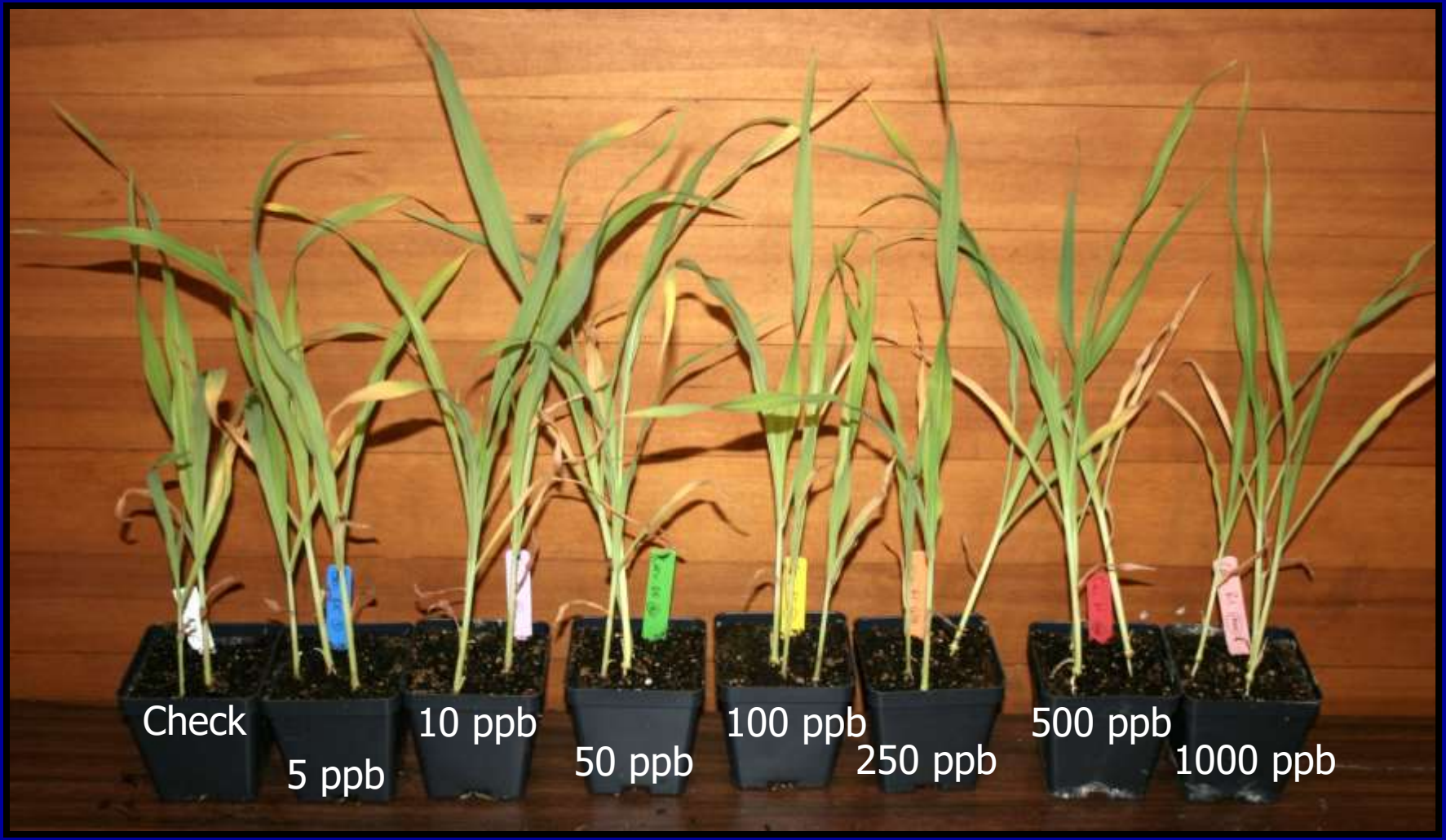
# Not Just Clopyralid

- Milestone (aminopyralid) was applied to perennial ryegrass in northwestern Washington and resulting forage was fed to dairy cattle (2009 to 2011)
- Although the label required manure to be sequestered, manure solids were collected and used to make compost
- The next year, that compost was applied to sensitive vegetable plants (the most common being tomato)

Clopyralid and aminopyralid cause classic epinastic symptoms

# Least Sensitive: Sweet Corn

## At 6 WAT

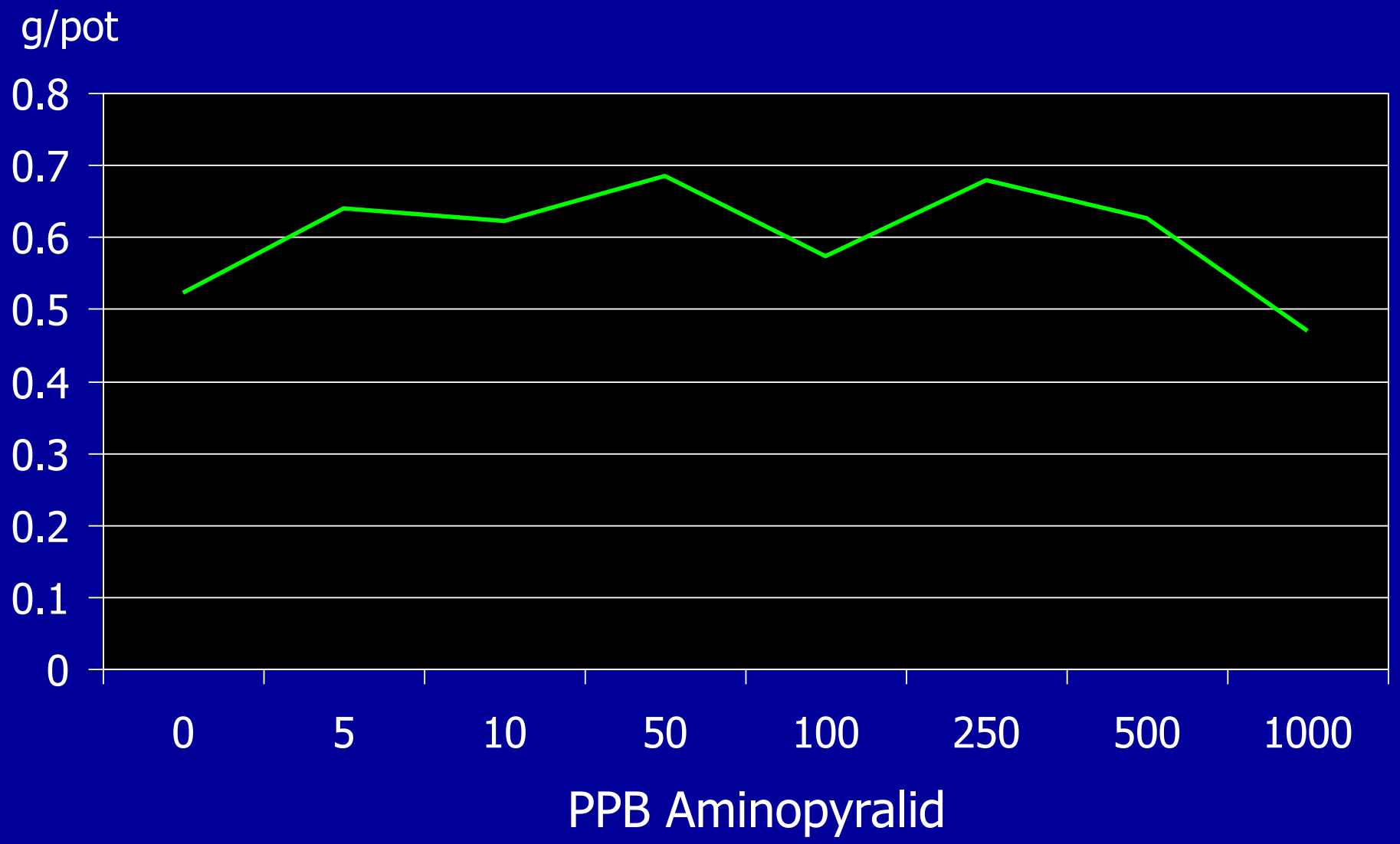


# Most Sensitive: Green Pea

## At 6 WAT

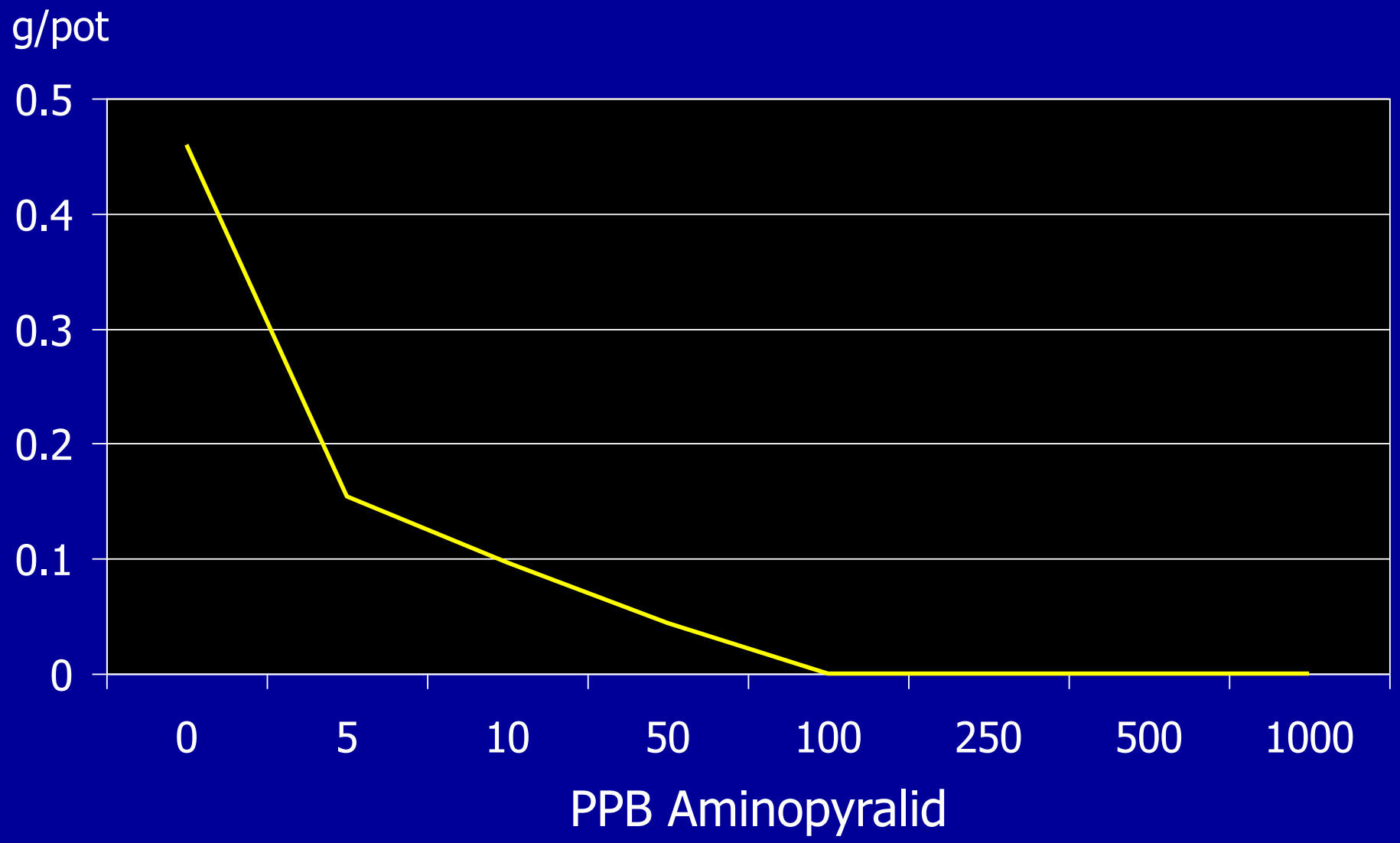
# Aminopyralid Dose Response

## Sweet Corn Biomass



# Aminopyralid Dose Response

## Green Pea Biomass



# If You Use Compost or Manure

- Know the source of your material!
- Ask about the use of herbicides on the compost feedstock or the forage fed to the livestock (whether silage, grass hay, or pasture)
- Remember about crop sensitivity to particular herbicides (you may be able to use "contaminated" material on certain crops with no concern about injury)

# Discussion of Selected Herbicides Used in Vegetables



- And we'll still finish on time for lunch!

# Preplant-Incorporated

- These are relatively volatile products that are applied PPI to reduce losses due to evaporation from the soil surface
- Most PPI products are seedling inhibitors (herbicides that kill the weed immediately upon germination)
  - Taken up by shoots or roots

# Prowl (pendimethalin)

- Two formulations (standard and H2O)
- Stops growth of seedling roots by inhibiting cell division (Group 3)
- Usually not translocated much in the plant, as uptake is by newly-germinated seedlings in the soil
- Is often used PRE and incorporated by rainfall or irrigation

# Prowl (pendimethalin)

- Registered in artichoke, asparagus, carrot, edamame, eggplant, garlic, onion, pea, peppers, potato, sweet corn, and tomato
- Dr. Peachey has seen lodging of sweet corn following Prowl applications
- 12 species have become resistant to Group 3 herbicides

# Treflan (trifluralin)

- Stops growth of seedling roots by inhibiting cell division (Group 3)
- Usually not translocated much in the plant, as uptake is by newly-germinated seedlings in the soil
- Registered in asparagus, bean, Brassicas, carrot, celery, chicory, cucurbits, edamame, endive, pea, and tomato

# Prefar (bensulide)

- Inhibits root elongation and cell division by inhibiting biosynthesis of fatty acids and lipids (Group 8)
- Usually not translocated much in the plant, as uptake is by newly-germinated seedlings in the soil
- High soil organic matter content inactivates the herbicide
- Registered in Brassicas, celery, cucurbits, leafy greens, and onion (except in the Willamette Valley)

# Command (clomazone)

- "Bleaching" herbicide prevents biosynthesis of chlorophyll and other plant pigments (Group 13)
- Mostly absorbed through roots; primarily translocated in xylem
- Although the micro-encapsulated formulation lessens the chance of vapor drift, it is usually best to mechanically incorporate this product prior to seeding the crop

# Command (clomazone)

- Registered in bean, Brassicas, cucurbits, pea, and peppers (except banana)
- Remember the potential for drift to nearby sensitive crops—the bleaching effect on leaves is very noticeable!

# Preemergence Herbicides

- Usually relatively nonvolatile, these herbicides are applied after seeding but prior to emergence of crops or weeds
- Primary uptake is via roots
- These products are also often band-applied as lay-by herbicides at last cultivation to maintain a weed-free condition between rows

# Sandea (halosulfuron)

- Stops biosynthesis of branched-chain amino acids (ALS inhibitors, Group 2)
- Translocation is via both xylem and phloem (new growth affected first)
- Seedlings emerge after PRE, but generally do not grow beyond cotyledon stage
- Growing points of POST-treated weeds die within 7 to 14 days, although plant death may take as long as 3 weeks

# Sandea (halosulfuron)

- If used POST, must be mixed with a surfactant
- Registered in artichoke, asparagus, bean, cucurbits, eggplant, pea, peppers, rhubarb, sweet corn, and tomato
- Significant carryover potential (up to 3 years in sensitive species such as beets and leafy/head Brassica crops)
- Nearly 160 species have developed resistance to Group 2 herbicides

# Caparol (prometryn)

- Inhibits photosynthesis at PS II (Group 5)
- Primary uptake is via roots followed by xylem translocation to foliage
  - Some uptake by leaves, but it moves via xylem to the leaf margins
- Older leaves show symptoms first
- Registered in Apiaceae crops and rhubarb
- Over 70 species have developed resistance to Group 5 herbicides

# Tricor (metribuzin)

- Inhibits photosynthesis at PS II (Group 5)
- Primary uptake is via roots followed by xylem translocation to foliage
  - Some uptake by leaves, but it moves via xylem to the leaf margins
- Older leaves show symptoms first
- Registered in asparagus, carrot, pea, potato, and tomato

# Tricor (metribuzin)

- Do not apply POST to early-maturing, smooth-, white- or red-skinned potatoes
- Sensitive potato cultivars* include: Atlantic, Bellchip, CalWhite, Cascade, Centennial Russet, Cherry Red, Chieftan, Chipbelle, Dark Red Norland, Hi Plains, Hilite Russet, Jelly, Keystone Russet, Mazama, Modoc, Norchip, Nordonna, NorValley, Owyhee Russet, Red LaSoda, Red Norland, Shepody, Silverton Russet, Snowden, Superior, Wallowa Russet, Western Russet, White Pearl, and White Rose

*This list is included in the *PNW Weed Management Handbook*

# Lorox and Linex (linuron)

- Inhibits photosynthesis at PS II (Group 7)
- Primary uptake is via roots followed by xylem translocation to foliage
  - Uptake by leaves is much less than by roots, but linuron is absorbed more readily than Karmex (diuron) when applied to foliage
- Older leaves show symptoms first
- Registered in Apiaceae crops, asparagus, Brassicas, edamame, potato, and rhubarb
- Nearly 30 species have become resistant to Group 7 herbicides

# Nortron (ethofumesate)

- Two formulations (EC and SC)
- Stops growth of seedlings by inhibiting lipid biosynthesis (Group 8)
- Readily absorbed by shoots and roots of seedlings in treated soil, then is rapidly translocated to foliage
  - If applied POST, it does not easily pass through the cuticle of older leaves
- Registered in beet, carrot, garlic, and onion

# Protox (PPO) Inhibitors

- Inhibits the Protox enzyme (Group 14)
- Absorbed almost exclusively by leaves or emerging shoots; doesn't translocate
- These don't control grasses
- Protox inhibitors include Aim (carfentrazone), Chateau (flumioxazin), Cobra (lactofen), Reflex (fomesafen), Sharpen (saflufenacil), and Spartan (sulfentrazone)
  - Selectivity varies among the products
- 13 species have become resistant to Group 14 herbicides

# Protox (PPO) Inhibitors

- Aim registered in eggplant, garlic, onion, peppers, potato, rhubarb, sweet corn, and tomato
- Chateau registered in artichoke, asparagus, garlic, and potato
- Cobra registered in bean
- Goal/GoalTender registered in artichoke, Brassicas, garlic, and onion
- Reflex registered in bean, cucurbits, edamame, and potato
- Sharpen registered in pea
- Spartan registered in asparagus, Brassicas, pea, rhubarb, and tomato

# Dual (metolachlor)

- Inhibits biosynthesis of very long chain fatty acids (Group 15)
- The "*S*" enantiomer is the most active of two metolachlor molecules found in any manufacturing run
  - Latin words are *rectus* or "right" (R); *sinister* or "left" (S)
  - Syngenta was able to isolate that enantiomer and it is marketed as Dual Magnum
  - Older metolachlor products are still available
  - Dual II and Dual II Magnum contain an additional "safener" for corn

# Dual (metolachlor)

- Usually not translocated much in the plant, as uptake is by newly-germinated seedlings in the soil
- Registered in asparagus, bean, beet, Brassicas, carrot, cucurbits, edamame, onion, parsnip, pea, peppers, potato, rhubarb, sweet corn, and tomato
- 5 species have developed resistance to Group 15 herbicides

# Outlook (dimethenamid-p)

- Inhibits biosynthesis of very long chain fatty acids (Group 15)
- Similar in activity and spectrum of weed control as metolachlor, but is three times more soluble in water
- Dimethenamid-p is the "*S*" enantiomer of the active ingredient (dimethenamid, the old Frontier herbicide), and BASF was able to isolate that enantiomer
- Registered in Brassicas, garlic, onion, potato, sweet corn, and winter squash

# Devrinol (napropamide)

- Inhibits biosynthesis of very long chain fatty acids and blocks cell division (Group 15)
- Absorbed primarily by germinating seedlings and roots, although foliar uptake can occur
- Translocation differs among plant species and is the basis of selectivity
- If not incorporated by rainfall or irrigation, the herbicide is likely to photodegrade
- Registered in asparagus, Brassicas, eggplant, peppers, rhubarb, and tomato

# Postemergence Herbicides

- These products are foliar-active, so they are applied after crop/weed emergence
  - Some also have soil activity
- Often are selective in particular crops that are able to break down (metabolize) the herbicide after uptake
- If nonselective, they must be applied so as to avoid spraying the crop

# ACCase Inhibitors

- Inhibits biosynthesis of fatty acids and lipids in grasses (Group 1)
- Mostly absorbed by leaves, then translocates via phloem to meristems
- New growth affected first, but this meristem is not directly visible in grasses
- Must be applied with added surfactant
- ACCase inhibiting herbicides include Select (clethodim), Fusilade (fluazifop), Poast (sethoxydim), and Assure II (quizalofop)

# ACCase Inhibitors

- Assure II registered in bean and pea
- Fusilade registered in asparagus, carrot, garlic, and onion
- Poast registered in Apiaceae crops, artichoke, asparagus, bean, beet, Brassicas, cucurbits, eggplant, garlic, leafy greens, onion, pea, peppers, rhubarb, and tomato
- Select registered in artichoke, asparagus, bean, beet, Brassicas, Apiaceae, cucurbits, eggplant, garlic, leafy greens, onion, pea, peppers, potato, rhubarb, and tomato
- About 50 grass species have become resistant to Group 1 herbicides

# Stinger (clopyralid)

- Synthetic auxins affect cell wall plasticity and increase production of DNA/RNA (Group 4)
- Absorbed by both roots and foliage, although it is more effective applied to foliage at the low rates used in vegetable production
- Translocation is via phloem to meristems (new growth affected first)
- Registered in asparagus, beet, Brassicas, sweet corn, and spinach
- 36 species have become resistant to Group 4 herbicides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# 2,4-D/MCPA/MCPB

- Stops biosynthesis of branched-chain amino acids (Group 2)
- Translocation is via both xylem and phloem (new growth affected first)
- Registered in asparagus (2,4-D), pea (MCPA/MCPB), sweet corn (2,4-D)

# Basagran (bentazon)

- Inhibits photosynthesis at PS II (Group 6)
- Absorbed almost exclusively by leaves; very little translocation occurs
- Little activity on grasses or on plants with thick leaf cuticles
- Readily broken down in tolerant crops
- Registered in bean, edamame, pea, and sweet corn

# Banvel (dicamba)

- Stops biosynthesis of branched-chain amino acids (Group 2)
- Translocation is via both xylem and phloem (new growth affected first)
- Registered in asparagus

# Callisto (mesotrione)

- "Bleaching" herbicide prevents biosynthesis of chlorophyll and other plant pigments (Group 27)
- Absorbed by both roots and shoots; translocation is via both xylem and phloem (new growth affected first)
- Not likely to leach
- Does not control grass species
- Registered in asparagus, rhubarb, and sweet corn

# Dacthal (DCPA)

- Stops growth of seedling roots by inhibiting cell division and cell wall formation (Group 3)
- Usually not translocated much in the plant, as uptake is by newly-germinated seedlings in the soil
- Leaching in sandy soil is a problem
- Registered in Brassicas, eggplant, melons, onion, and tomato

# Eptam (EPTC)

- Stops growth of seedlings by inhibiting biosynthesis of fatty acids and lipids (Group 8)
- Usually not translocated much in the plant, as uptake is by newly-germinated seedlings in the soil
- May be applied through irrigation equipment in certain crops
- Registered in bean and potato

# Gramoxone (paraquat)

- Stops biosynthesis of branched-chain amino acids (Group 2)
- Translocation is via both xylem and phloem (new growth affected first)
- Registered in artichoke, asparagus, eggplant, garlic, onion, peppers, potato, rhubarb, sweet corn, tomato

# Matrix (rimsulfuron)

- Stops biosynthesis of branched-chain amino acids (Group 2)
- Translocation is via both xylem and phloem (new growth affected first)
  - Seedlings emerge after PRE, but generally do not grow beyond cotyledon stage
  - Growing points of POST-treated weeds die within 7 to 14 days, although plant death may take as long as 3 weeks
- Registered on potato and tomato

# Raptor (imazamox)

- Stops biosynthesis of branched-chain amino acids (Group 2)
- Translocation is via both xylem and phloem (new growth affected first)
- Registered in bean, chicory, edamame, and pea

# Ro-Neet (cycloate)

- Stops growth of seedlings by inhibiting biosynthesis of fatty acids and lipids (Group 8)
- Usually not translocated much in the plant, as uptake is by newly-germinated seedlings in the soil
- Registered for use in beet and spinach

# Spin-Aid (phenmedipham)

- Two formulations (standard and H2O)
- Stops growth of seedling roots by inhibiting cell division (Group 3)
- Usually not translocated in the plant, but as uptake is by newly-germinated seedlings in the soil, this is not a major factor
- Registered in beet and spinach

# UpBeet (triflusulfuron)

- Stops biosynthesis of branched-chain amino acids (Group 2)
- Translocation is via both xylem and phloem (new growth affected first)
- Registered in beet, chicory, endive,

# Individual Weed Species

# Shepherd's-purse

*Capsella bursa-pastoris*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Surflan, Diuron

# Common Chickweed

*Stellaria media*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Surflan, Devrinol, Diuron

# Pineappleweed

*Matricaria matricarioides*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Devrinol, Diuron

# Common Groundsel

*Senecio vulgaris*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Surflan, Devrinol

# Common Lambsquarters

*Chenopodium album*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Surflan, Devrinol, Diuron

# Henbit and Purple Deadnettle

*Lamium amplexicaule* and *L. purpureum*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Surflan

# Ryegrasses
## *Lolium* spp.

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Surflan, Devrinol

# Annual Bluegrass

*Poa annua*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Surflan, Devrinol, Diuron

# Prostrate Knotweed

*Polygonum aviculare*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Surflan, Devrinol

# Wild Buckwheat

*Polygonum convolvulus*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Diuron

# Ladysthumb and Pale Smartweed

*Polygonum persicaria* and *P. lapathifolium*

- PRE to bulb foliage
  - Roundup
  - Paraquat
- PRE
  - Surflan (suppression)

# Horsetail

*Equisetum* spp.

Yeah, right.