



***THE ENVIRONMENTAL  
EFFECTS OF PARTICULATE  
MATTER (PM)  
AND OZONE (O<sub>3</sub>)***

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# **DIRECT EFFECTS OF PM ON PLANT FOLIAGE**

- ***DEPOSITION OF COARSE PARTICLES (AERODYNAMIC DIAMETER  $>2.5 \mu\text{m}$ ) IS NOT A MAJOR CONCERN EXCEPT IN THE IMMEDIATE VICINITY OF ITS SOURCES.***
- ***WATER INSOLUBLE COARSE PARTICLES (E.G., FLYASH FROM COAL COMBUSTION) CAN FORM ENCRUSTATIONS ON THE FOLIAGE, REDUCE THE AVAILABILITY OF SUNLIGHT; CLOG THE STOMATA AND CONSEQUENTLY LEAD TO CHLOROSIS AND DEFOLIATION.***
- ***WHERE ALKALINE COARSE PARTICLES (E.G., VICINITY OF CEMENT MILLS) ARE INVOLVED, INCREASES IN LEAF SURFACE pH AND SLOW RELEASE OF VARIOUS ELEMENTS (E.G., Ca) CAN RESULT IN NUTRIENT IMBALANCES; CHLOROSIS AND DEFOLIATION.***

# DIRECT EFFECTS OF PM ON PLANT FOLIAGE

- *EXPOSURES TO MONODISPERSE FINE PARTICLE  $H_2SO_4$  (SULFURIC ACID) AEROSOLS ALONE DID NOT RESULT IN VISIBLE FOLIAR INJURY.*
- *BOTH FINE PARTICLE  $H_2SO_4$  AEROSOLS AND  $O_3$  ARE REGIONAL SCALE PROBLEMS AND ARE THE RESULT OF PHOTOCHEMICAL REACTIONS.*
- *SEQUENTIAL EXPOSURES TO  $H_2SO_4$  AEROSOLS AND  $O_3$  RESULTED IN A MORE THAN ADDITIVE EFFECT OF  $O_3$  (VISIBLE FOLIAR INJURY), PRESUMABLY DUE TO INCREASED EFFECTIVE DOSE OF  $O_3$  AT THE LEAF SURFACE UNDER ACIDIC CONDITIONS.*

*(From: CHEVONE, CHAPPELKA, HERZFELD AND KRUPA, 1985)*

# INDIRECT EFFECTS OF PM ON PLANTS

- *THE INDIRECT EFFECTS OF DRY AND WET DEPOSITION OF PM ON SOILS AND ITS EFFECTS ON PLANTS IS OF MAJOR CONCERN.*
- *SUCH EFFECTS CAN RESULT IN SOIL ACIDIFICATION, NUTRIENT IMBALANCES AND CHANGES IN ECOSYSTEM HEALTH.*
- *EARLY CHANGES IN ECOSYSTEM HEALTH ARE MANIFESTED AS ALTERATIONS IN CARBON AND WATER BUDGETS (INPUT-OUTPUT).*
- *SOIL MEDIATED EFFECTS CAN ALSO LEAD TO ALTERATIONS OF PLANT RESPONSE TO OTHER STRESS FACTORS (E.G., O<sub>3</sub>, WINTER FROST, PATHOGENS AND PESTS).*



Trembling aspen canopy floor with understory (Normal)  
(Courtesy of A.H. Legge)



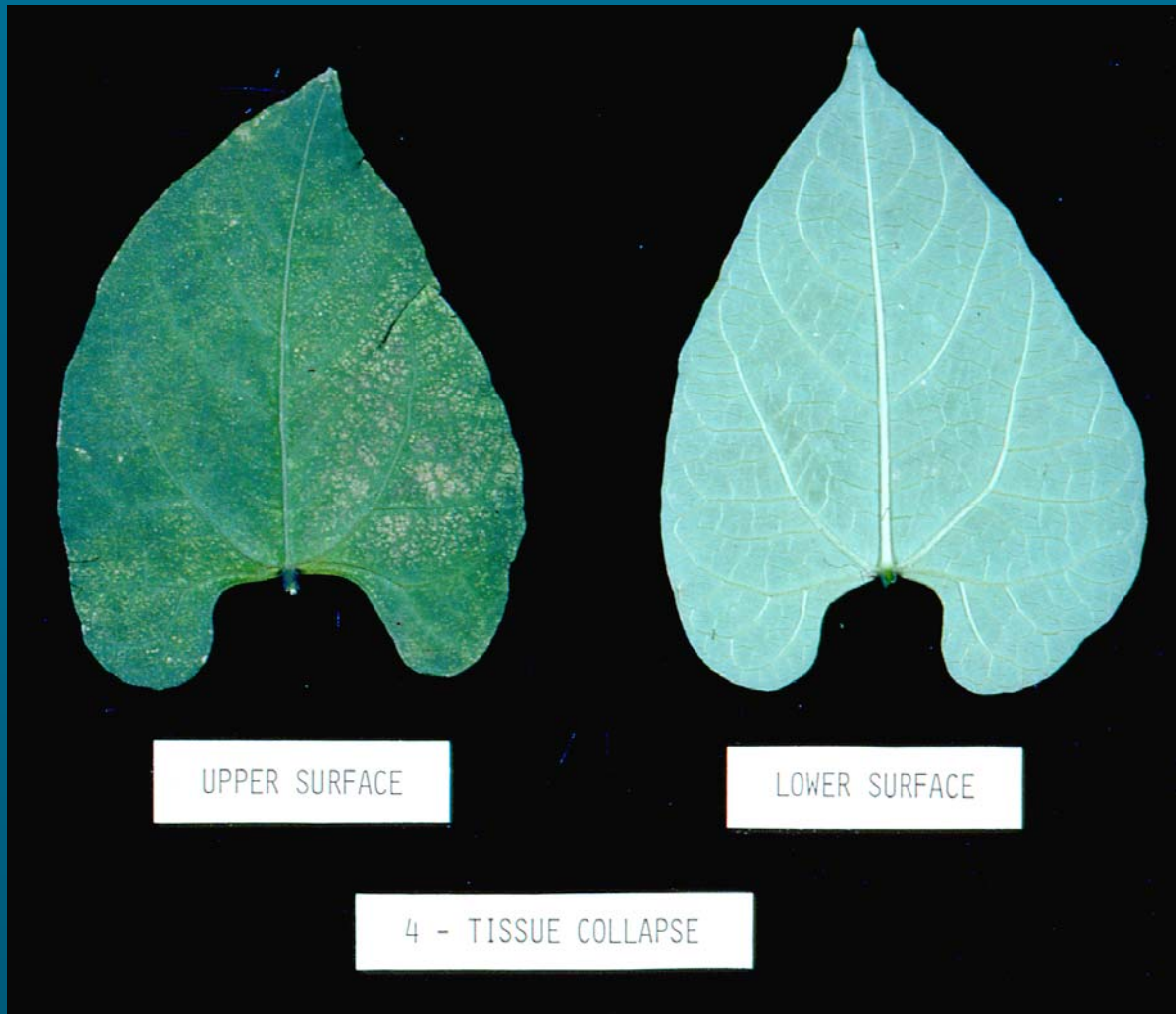
Trembling aspen canopy floor after soil acidification due to elemental “S” dust deposition. Note the change in the understory in comparison to the previous figure. (Courtesy of A.H. Legge)

# **EFFECTS OF O<sub>3</sub> ON THE PHYSIOLOGY AND FUNCTIONALITY OF HIGHER PLANTS (SOME EXAMPLES)**

## ***ADVERSE EFFECTS ON:***

- ***NUTRIENT BALANCE***
- ***MATURATION RATE***
- ***POLLINATION***
- ***SEED FILLING***





Acute effects of  $O_3$  on bean. Note: Symptoms (chlorotic flecks) occur only on the upper leaf surface.



Symptoms of O<sub>3</sub> injury on watermelon (bleaching and flecking)

(Courtesy of B. Sanchez)





Symptoms of chronic O<sub>3</sub> injury on bean (Bronzing) (Courtesy of A.S. Heagle)

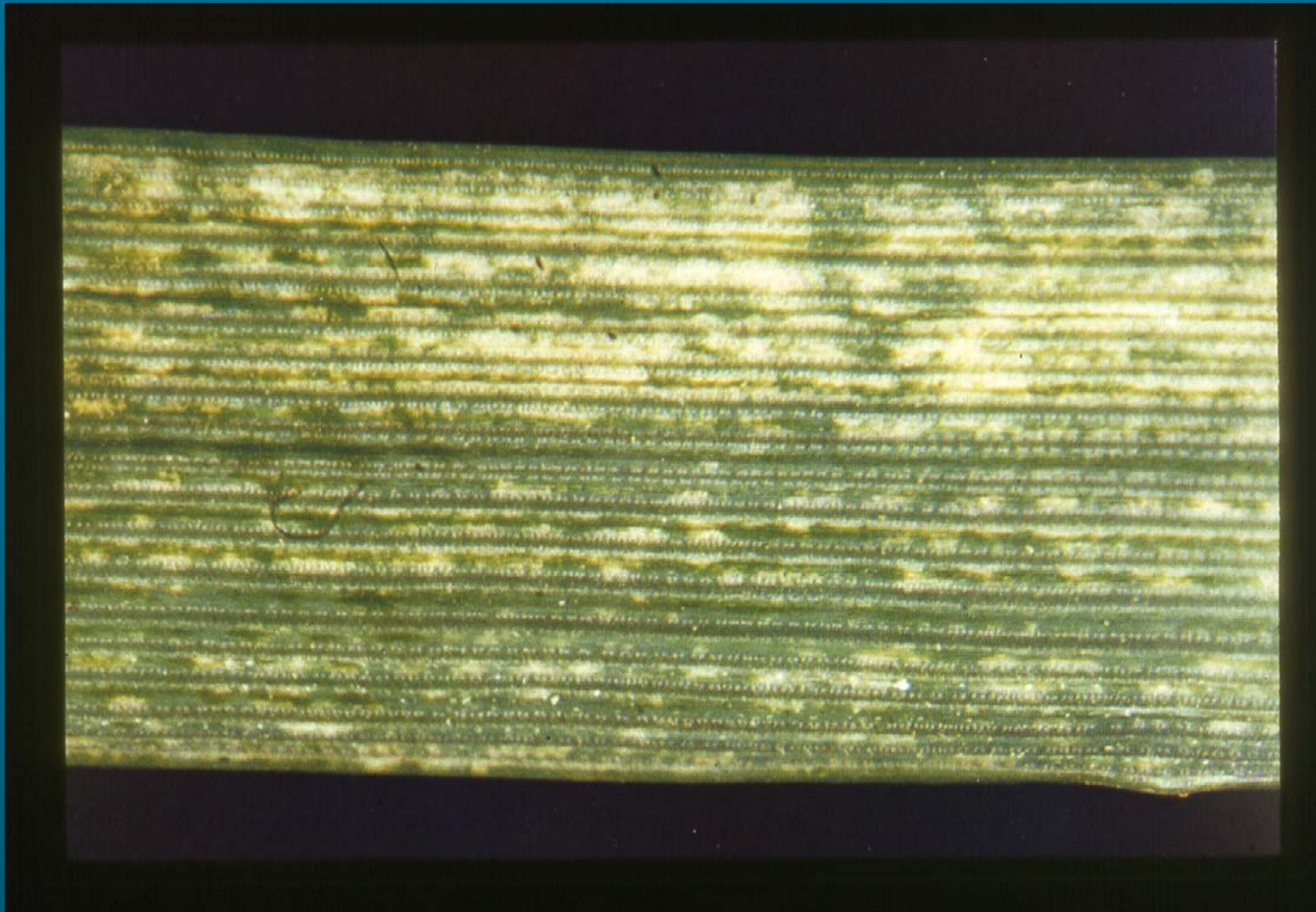


Symptoms of O<sub>3</sub> injury on bean (bifacial, inter-veinal necrosis or tissue death)  
(Courtesy of P. Temple)





Symptoms of O<sub>3</sub> injury on the flag leaf of wheat (Chlorosis between veins)  
(Courtesy of H. Heggstad)

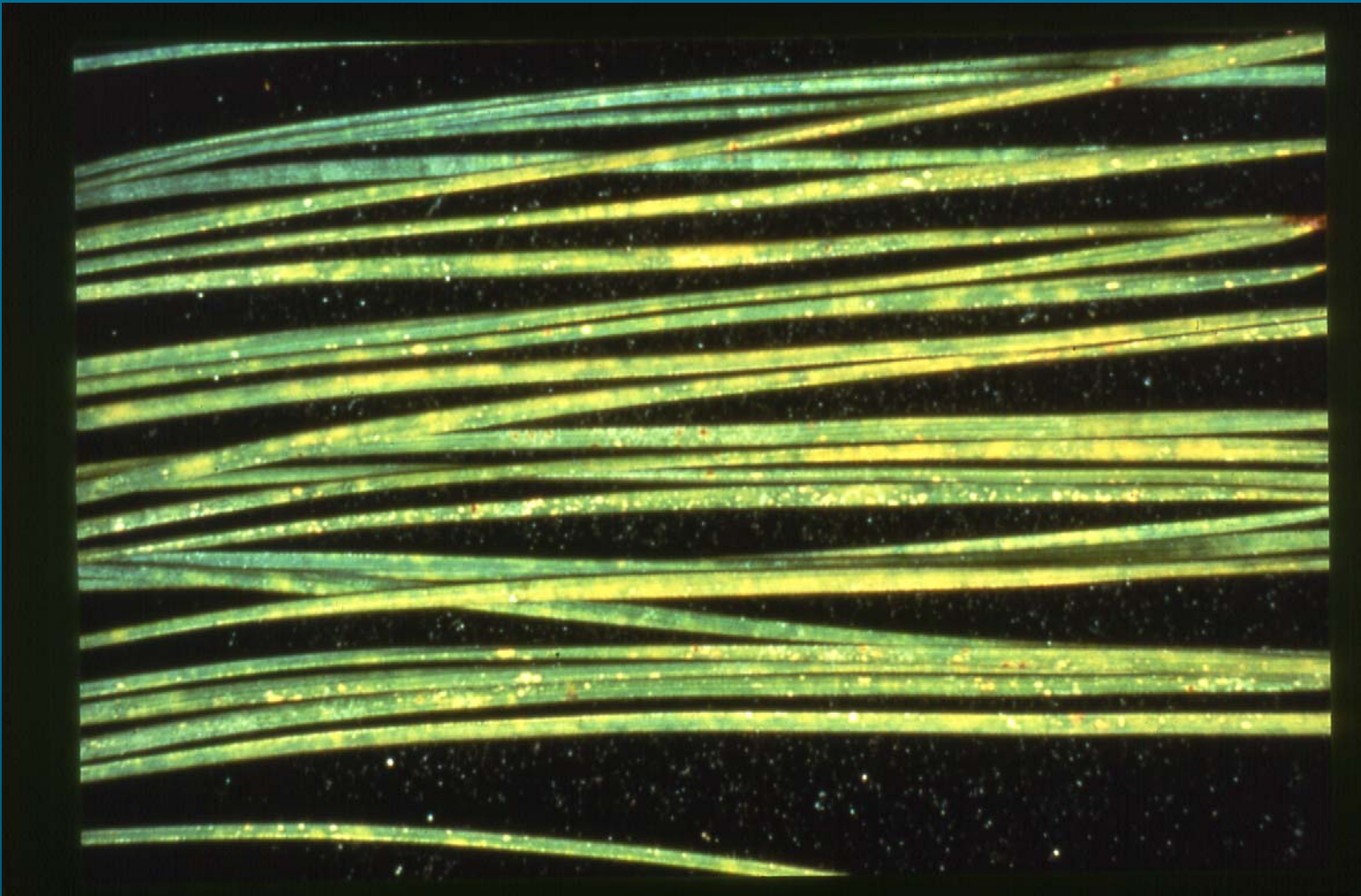


Symptoms of O<sub>3</sub> injury on wheat (Chlorosis and flecking between veins)  
(Courtesy of H. Heggestad)





Symptoms of O<sub>3</sub> injury on green ash (Upper surface purple stippling)  
(Courtesy of F.A. Wood)



Symptoms of O<sub>3</sub> injury on Ponderosa pine (Close-up of needle chlorotic mottle)  
(Courtesy of P.R. Miller)





Symptoms of O<sub>3</sub> injury on White pine (Needle tip chlorosis and necrosis)  
(Courtesy of J.M. Skelly)

# **CHRONIC EFFECTS OF OZONE ON PLANTS**

## ***ADVERSE EFFECTS THROUGH CHANGES IN:***

- ***ONSET OF SCENESENCE AND DEFOLIATION***
- ***GROWTH AND PHENOLOGY***
- ***BIOMASS***
- ***YIELD***
- ***FLOWERING, SEED VIABILITY AND REGENERATION (SPECIES FITNESS)***



Healthy Ponderosa pine in the San Bernardino mountains, CA in 1962  
(Courtesy of P.R. Miller)





Same tree as in the previous figure, but after 10 years in 1972. Tree mortality after chronic exposure to  $O_3$  followed by bark beetle attack of the weakened tree. (Courtesy of P.R. Miller)

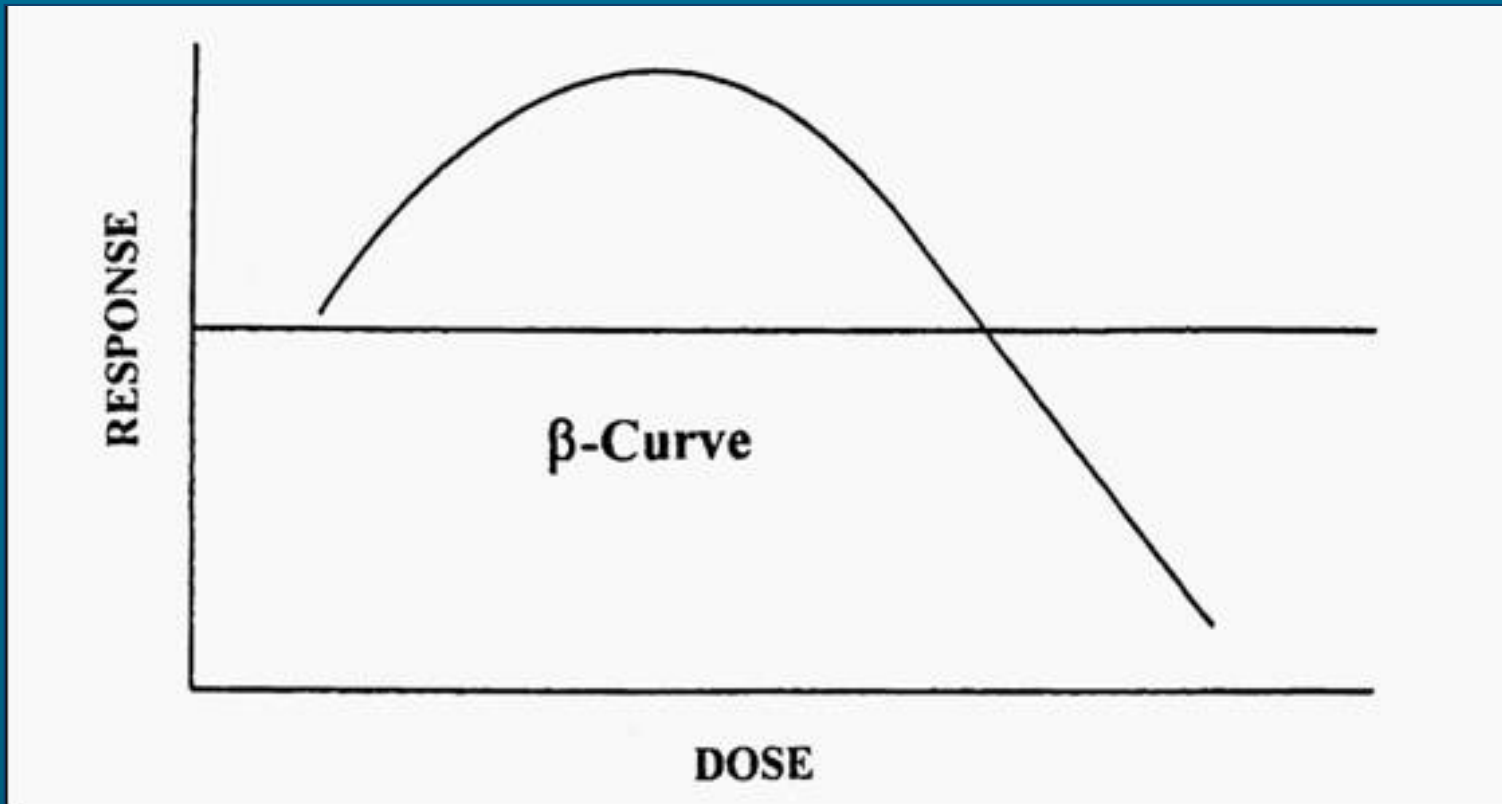
# **CHRONIC EFFECTS OF OZONE ON PLANTS**

## ***ADVERSE EFFECTS THROUGH CHANGES IN:***

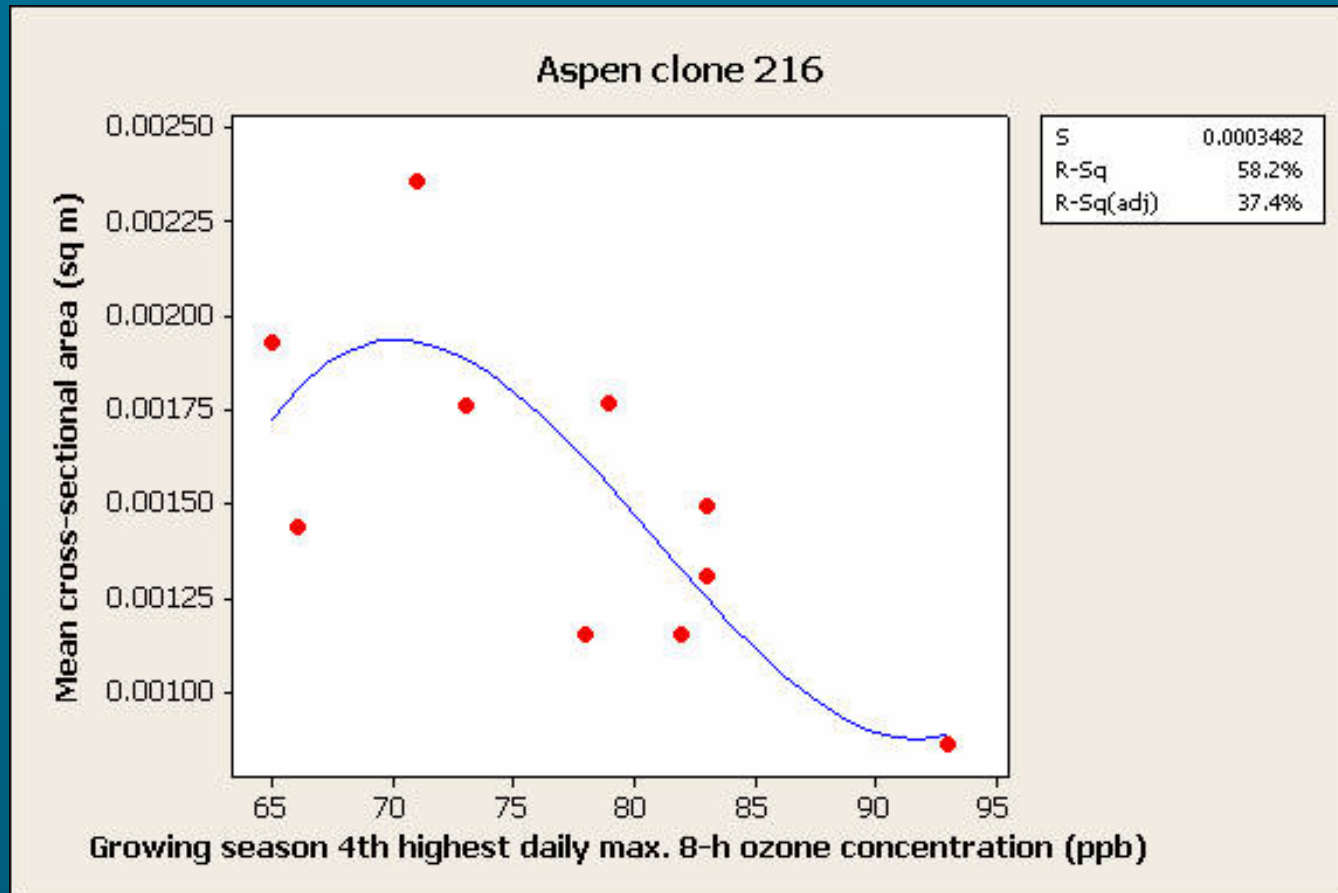
- ***FOLIAR NUTRIENT QUALITY FOR HERBIVORS, INCLUDING RUMINANTS***
- ***PLANT COMPETITION, COMMUNITY STRUCTURE AND BIODIVERSITY***
- ***PLANT RESIDUE DECOMPOSITION AND SOIL NUTRIENT TURNOVER RATES***
- ***DISPOSITION TO PATHOGENS (E.G., ROOT ROTTS AND FOLIAR DISEASES) AND INSECT PESTS (E.G., APHIDS AND BEETLES)***



**Joint effects of  $O_3$  and  $SO_2$  on soybean. Right: Healthy leaf; Center: Exposed to  $O_3$  only (Chlorosis); Left: Exposed to  $O_3$  and  $SO_2$  (more than additive effect, bifacial inter-veinal necrosis) (No symptoms from  $SO_2$  alone)**  
**(From Pratt, Kromroy and Krupa, 1983)**



Typical dose-response curve in toxicology. Stimulation (hormesis) at low doses followed by negative effects at higher doses. Virtually all studies in plant effects research have emphasized the higher doses and ignored the low end of the curve.



Relationship between growing season 4<sup>th</sup> highest daily maximum 8-hour O<sub>3</sub> concentration and mean cross-sectional steam area growth response of an O<sub>3</sub> sensitive Aspen (*Populus tremuloides*) clone in a free air (FACE) exposure experiment. Note the hormetic effect at the low end of the curve. (Adopted from Percy et al. 2006)



