Effectiveness of Acid-Mine Drainage Residuals in Reducing Phosphorus Concentrations in Runoff from Agricultural Soils

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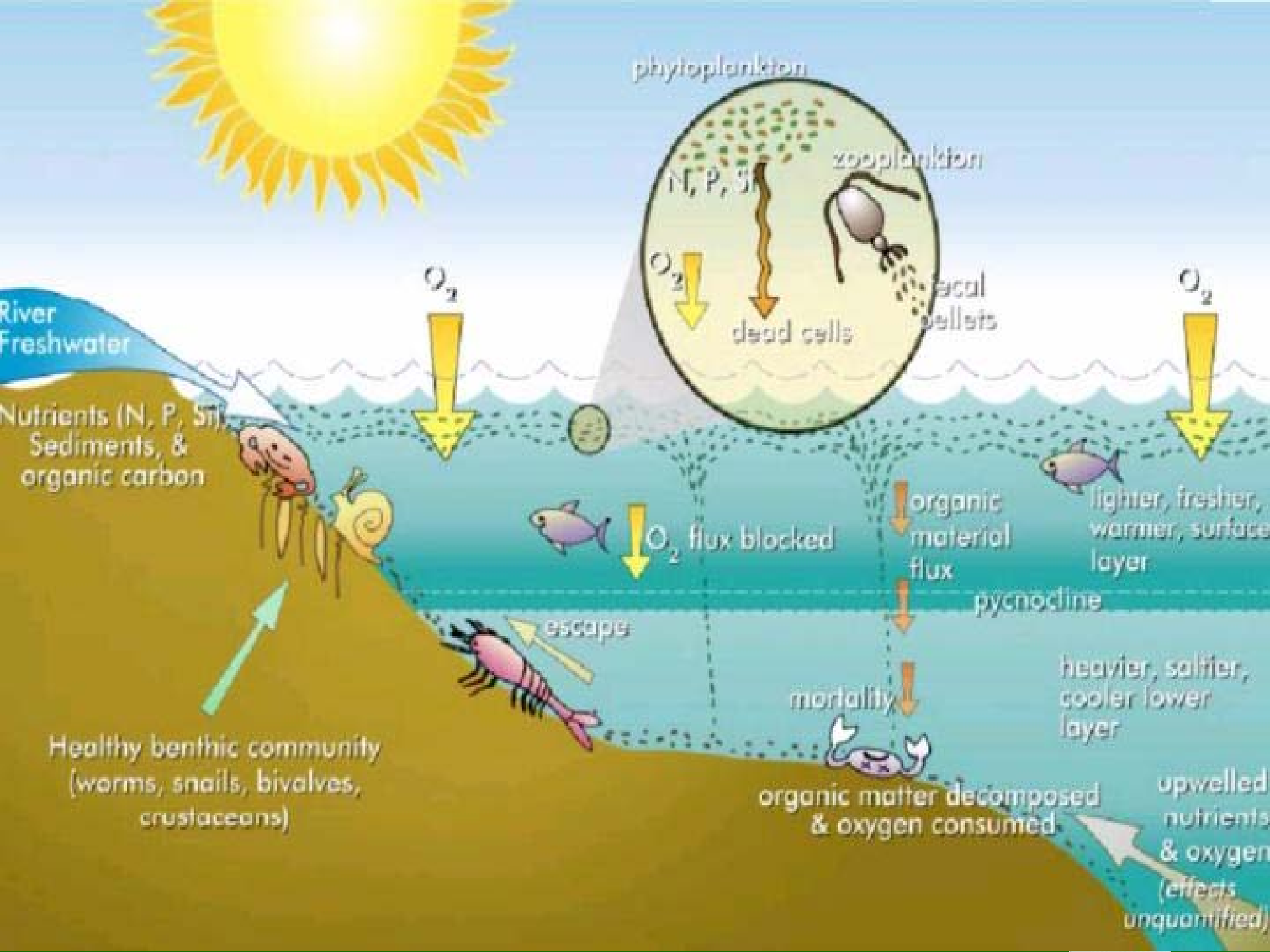
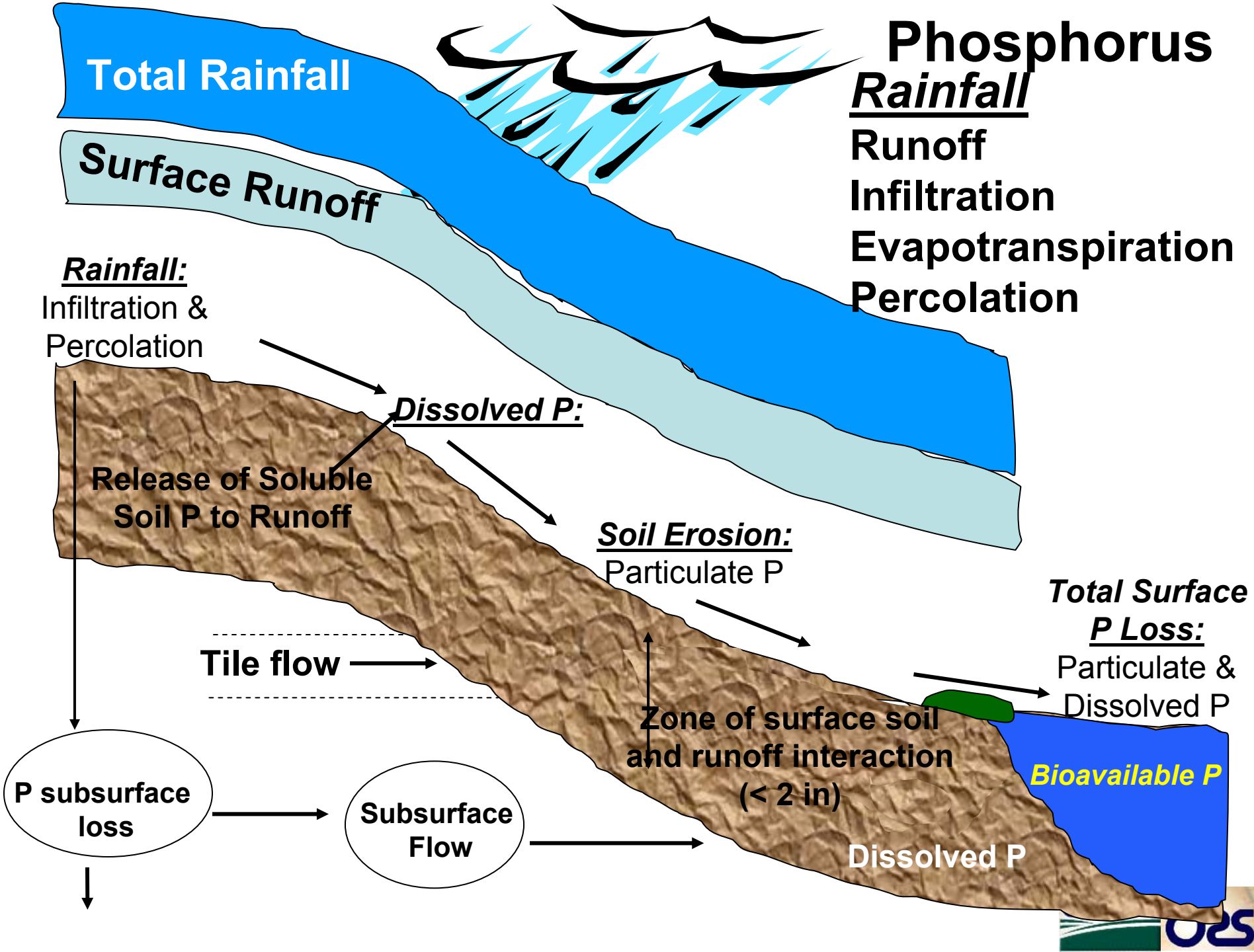
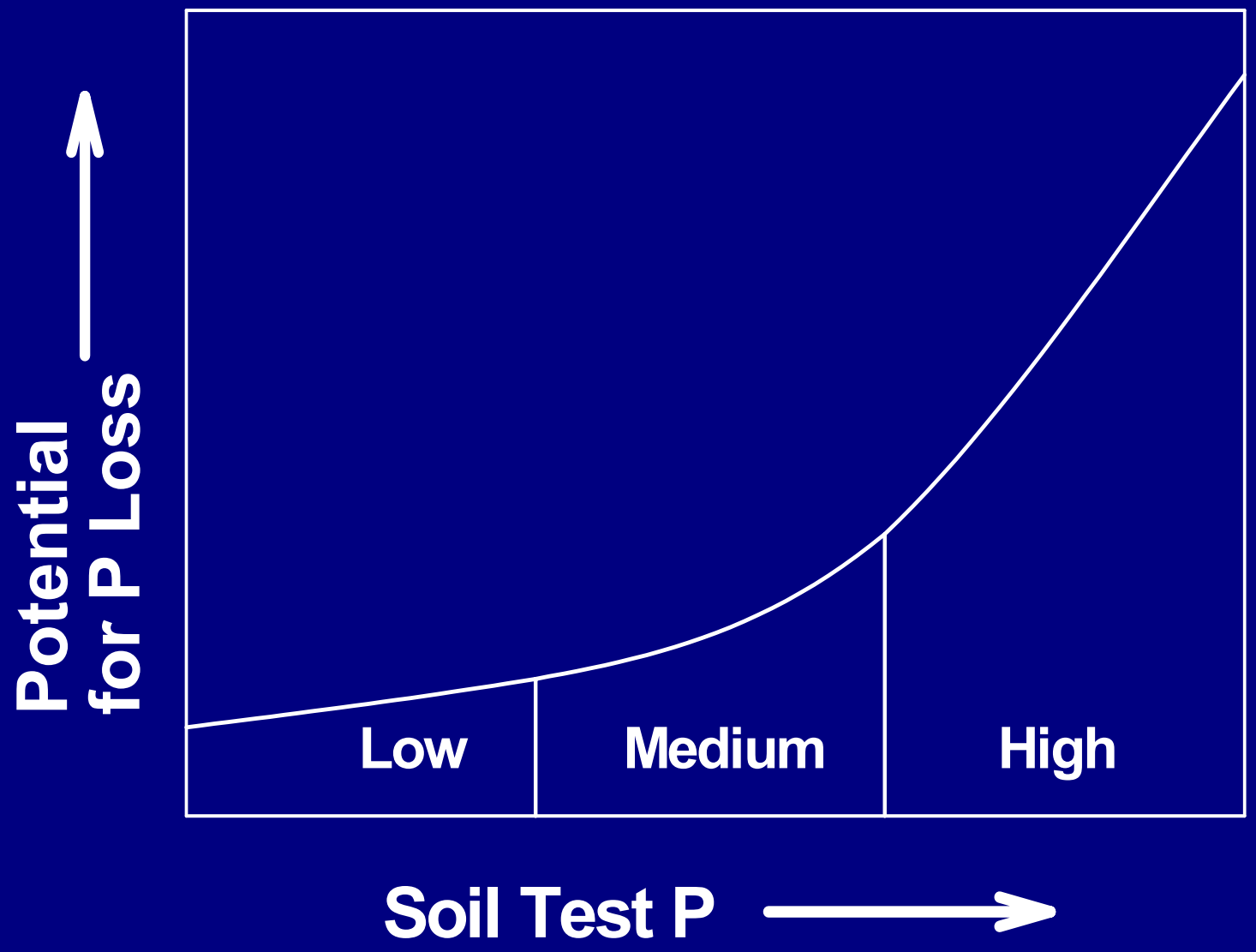
Introduction

- Problem: phosphorus (P) in surface waters
  - P is a limiting nutrient among surface waters
    - Excessive P concentrations leads to eutrophication
      - Fish kills, odors, problems with water treatment processes (drinking water) and recreation
- Potential source: Agriculture
  - P in runoff
    - Both dissolved and particulate P (erosion)
    - Soils considered "high" in soil P
    - recent surface P applications (manure, biosolids, chemical fertilizers


phytoplankton
zooplankton
N, P, Si
O_2
dead cells
fecal pellets
O_2
O_2
River Freshwater
Nutrients (N, P, Si), Sediments, & organic carbon
O_2 flux blocked
organic material flux
lighter, fresher, warmer, surface layer
pycnocline
escape
heavier, saltier, cooler lower layer
mortality
Healthy benthic community (worms, snails, bivalves, crustaceans)
organic matter decomposed & oxygen consumed
upwelled nutrients & oxygen (effects unquantified)

- Erosion – Sediment P
- Runoff – Soluble P (Soil & applied P)
- Subsurface – Soluble soil P


Phosphorus
Rainfall
Runoff
Infiltration
Evapotranspiration
Percolation
Total Rainfall
Surface Runoff
Rainfall:
Infiltration &
Percolation
Dissolved P:
Release of Soluble
Soil P to Runoff
Soil Erosion:
Particulate P
Total Surface
P Loss:
Particulate &
Dissolved P
Tile flow
Zone of surface soil
and runoff interaction
(< 2 in)
Bioavailable P
P subsurface
loss
Subsurface
Flow
Dissolved P


Potential
for P Loss
Low
Medium
High
Soil Test P

Introduction

- Several potential remedies/prevention
  - Timing and placement of P applications
  - Limitation of P applications
    - P index, P thresholds
  - P reductions in manure
    - Animal diet manipulations and supplements
    - Chemical treatment of manures
  - Reduction of soil P solubility
    - Chemical treatment of soils

Introduction

- Chemical additions to soils and manures
  - Al, Fe, and Ca containing materials that chemically bind with P, reducing soluble P concentrations.
    - Al and Fe oxides/hydroxides: precipitation, ligand exchange, and electrostatic attraction
    - Ca: precipitation and electrostatic attraction
  - Many waste products contain potential P sorbing minerals
    - Power production industry
    - Mining industry
    - Water treatment

Introduction

- Waste products from the coal mining industry
  - Flocculation and precipitation of Fe in acid mine drainage (AMD)
  - Neutralization of acidity in AMD
    - Results in a material which is typically high in Fe oxides/hydroxides with an elevated pH
    - Depending upon treatment process, Ca may also be present at high concentrations

Objectives

- Assess and compare several AMD residuals to other P sorbing materials in their ability to reduce P concentrations in:
  - Soils
  - Runoff
  - Manure

Methods

- Material characterization
- Soil incubation
- Simulated rainfall experiment
- Manure P solubility experiment

Methods

- Material Characterization
  - Total metals: EPA 3050 digestion method
  - Amorphous Al and Fe: ammonium oxalate extraction
  - pH: 1:1 ratio of material:DI water
  - Conductivity: 1:1 ratio of material:DI water

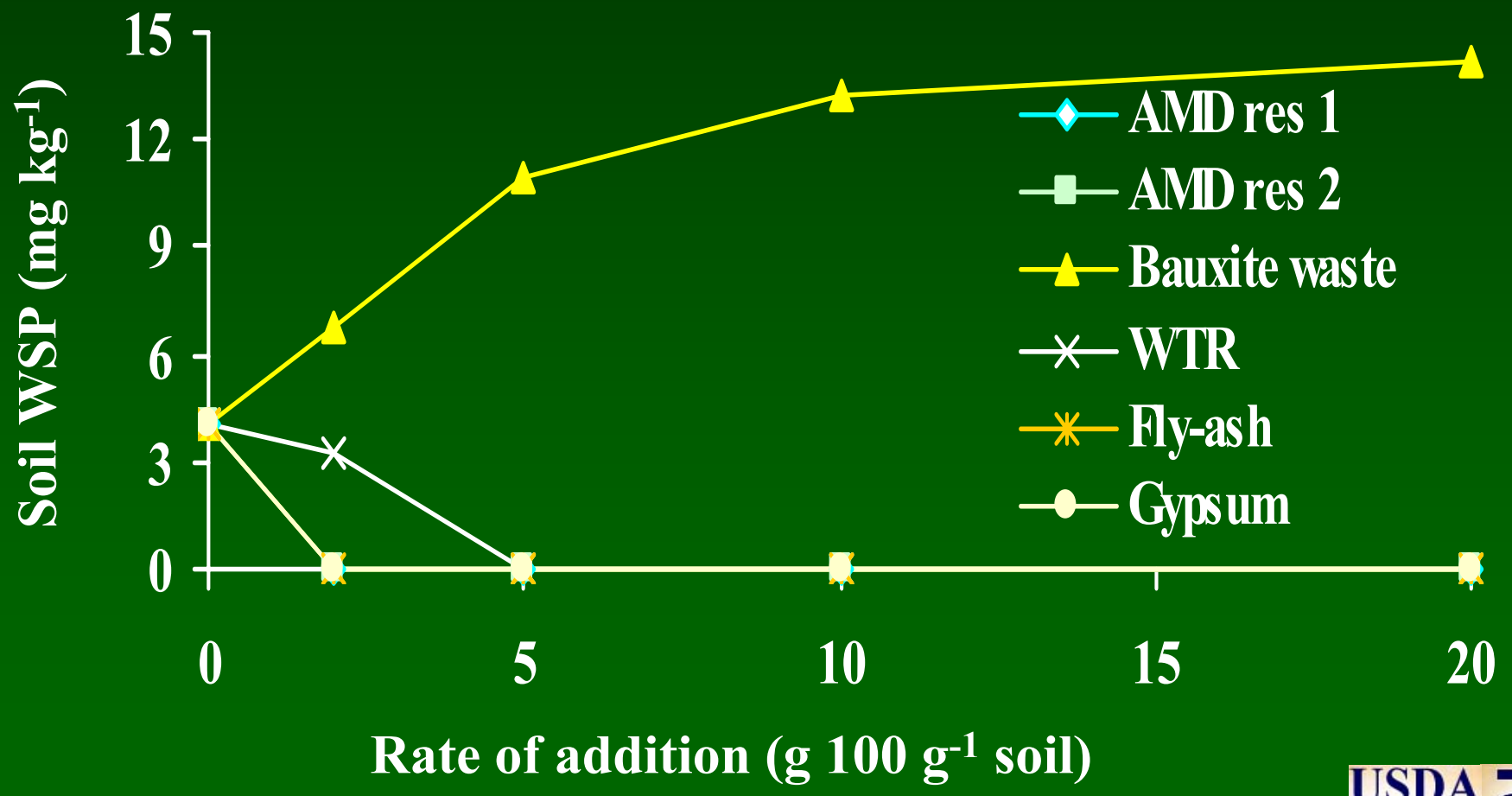
Material	Total				Amorphous	pH	Cond.
	Ca	Al	Fe	Na	Al + Fe		(mS cm^{-1})
	---------- mg kg^{-1} ----------						
AMD Residual 1	252014	1179	60623	5286	6132	8.2	3.3
AMD Residual 2	22708	49409	108096	26261	17279	9.1	3.4
Bauxite waste	14236	64170	64630	47045	8958	9.8	4.2
WTR	5471	75266	28166	245	13651	7.5	2.2
Fly-Ash	38578	26998	8778	905	2027	8.2	1.5
Gypsum	206620	349	793	37	111	7.9	2.1

Soil Incubation

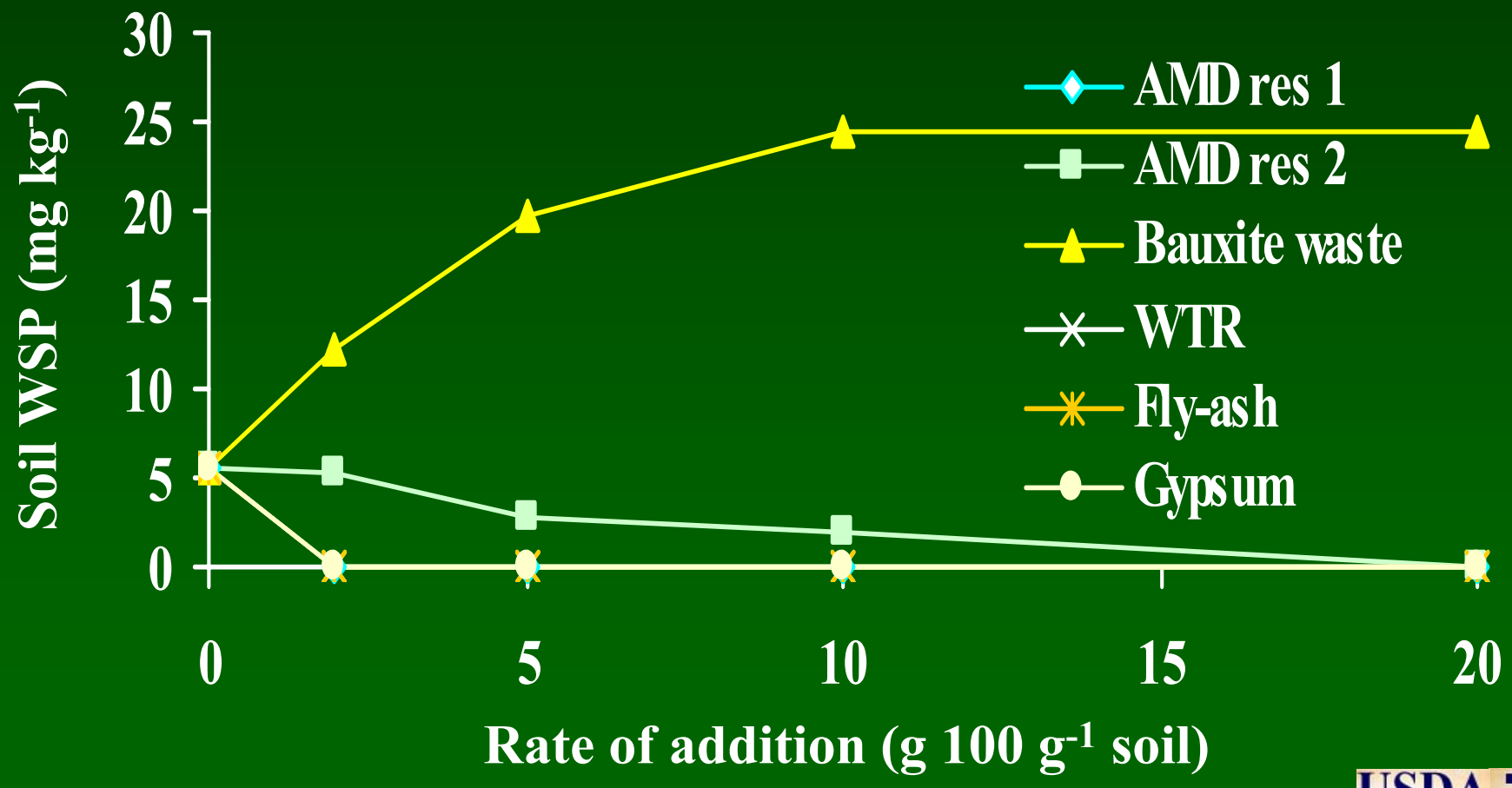
Methods

- Soil incubation
  - Amend 200 g soil with each amendment at the rate of 0, 2, 5, 10, and 20 % (g 100 g^{-1} soil), replicated 3 times
  - Incubate at field capacity moisture for 2 w
  - Analyze dried and sieved soils for water soluble P (WSP), Mehlich-3 P (M3-P), and pH (1:1, DI water)
  - All soil extracts analyzed for P by ICP-AES

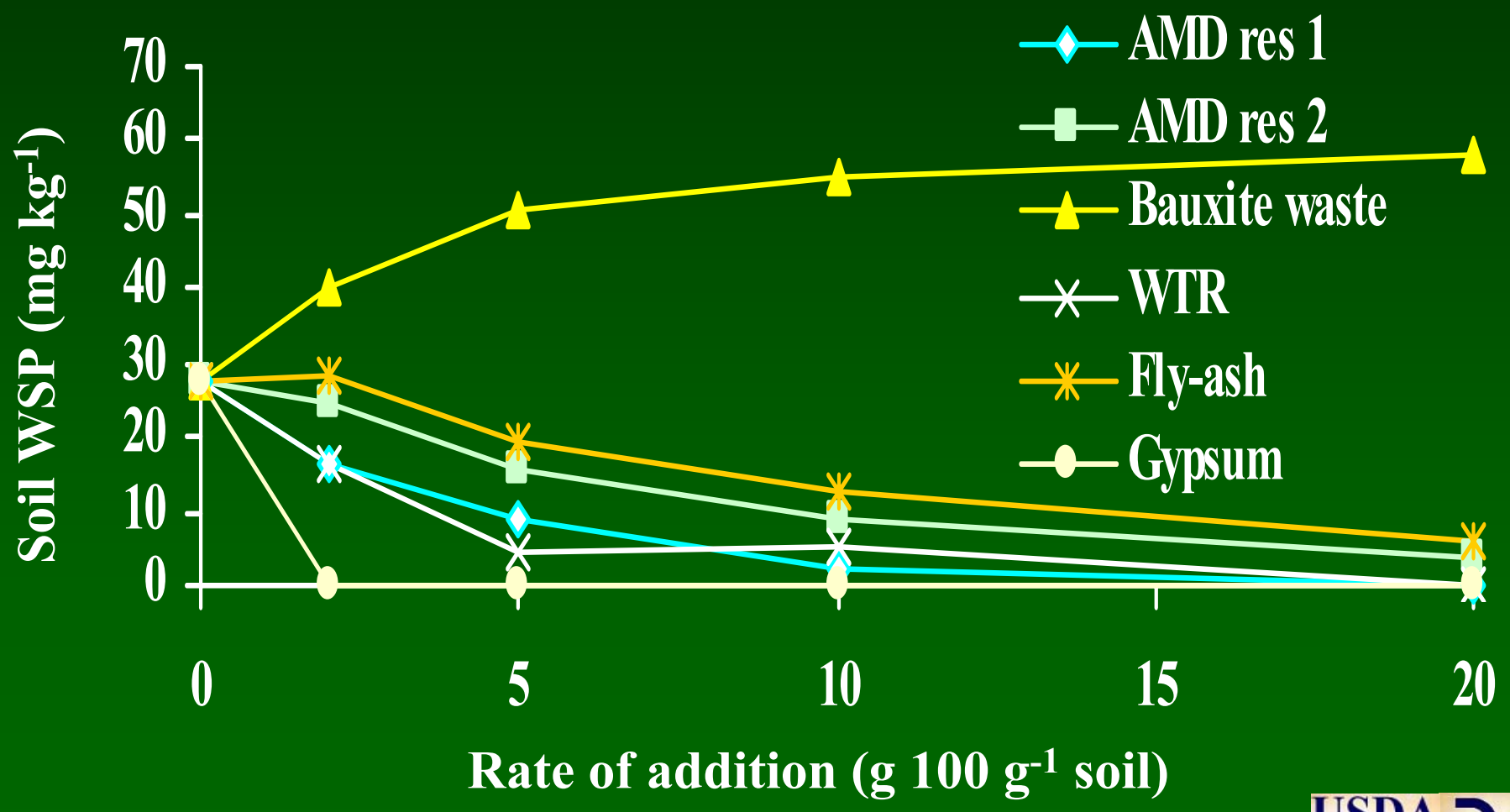
Effect of amendments on soil WSP: Berks



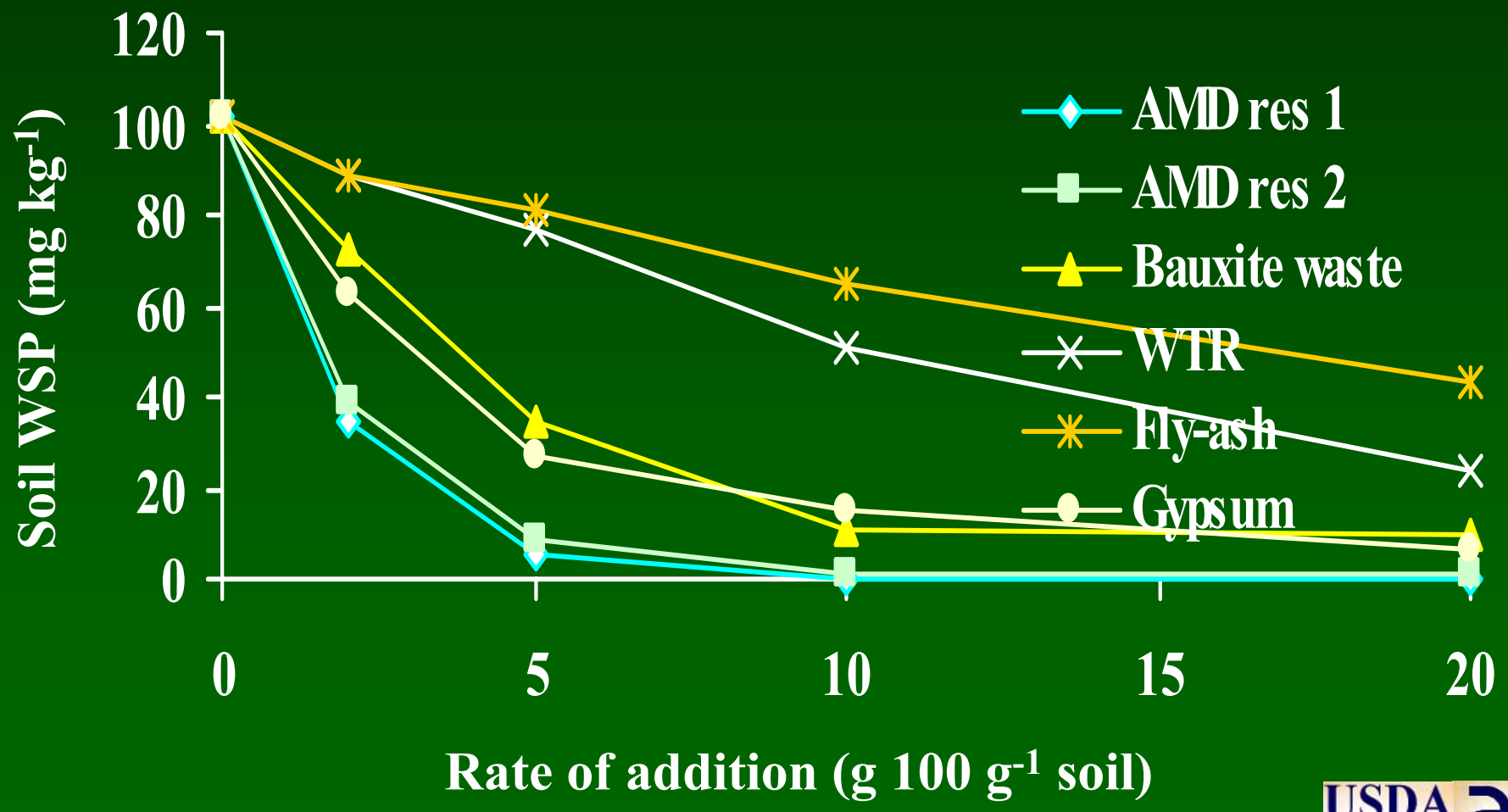
Effect of amendments on soil WSP: Hagerstown



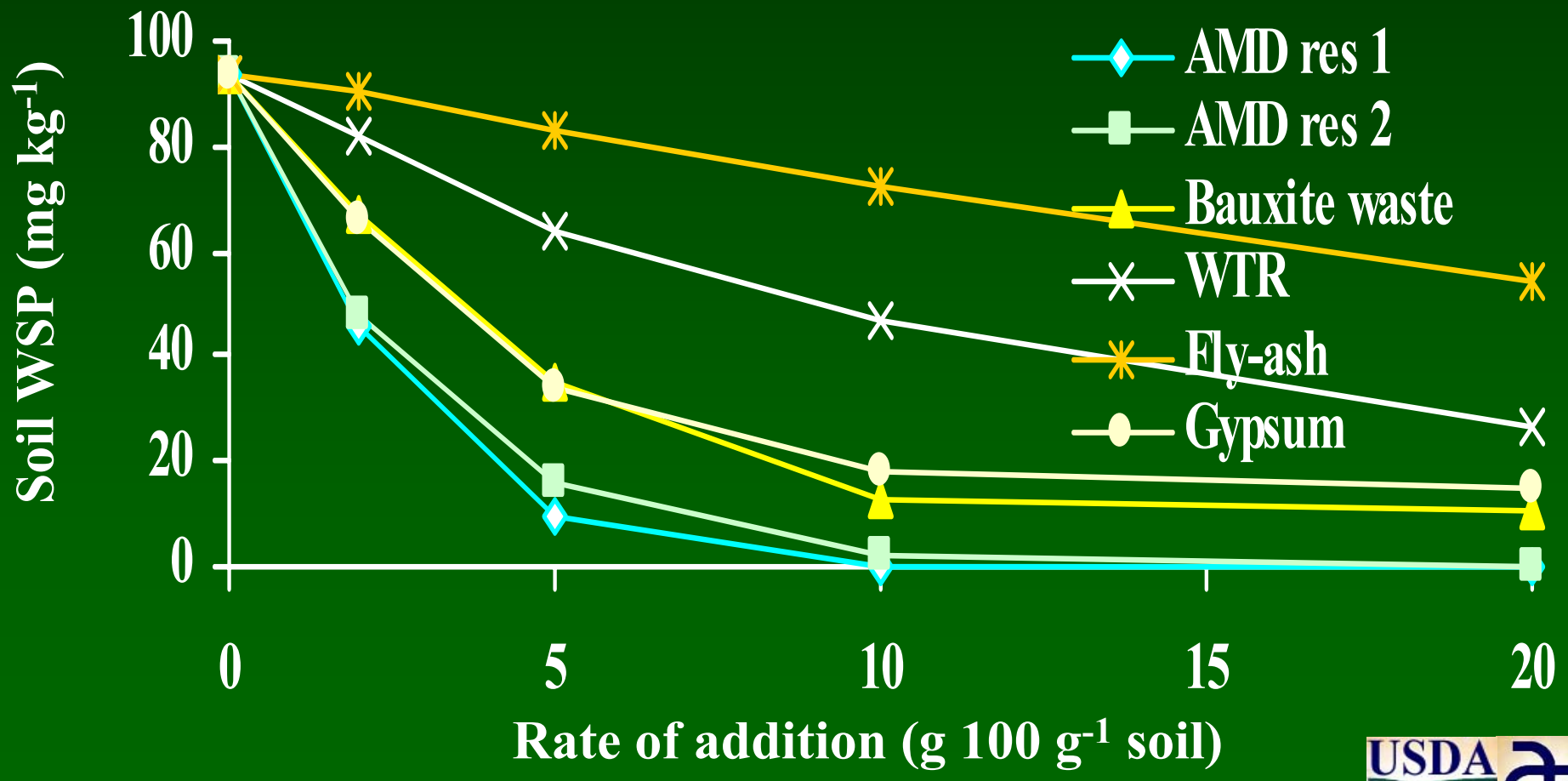
Effect of amendments on soil WSP: Othello



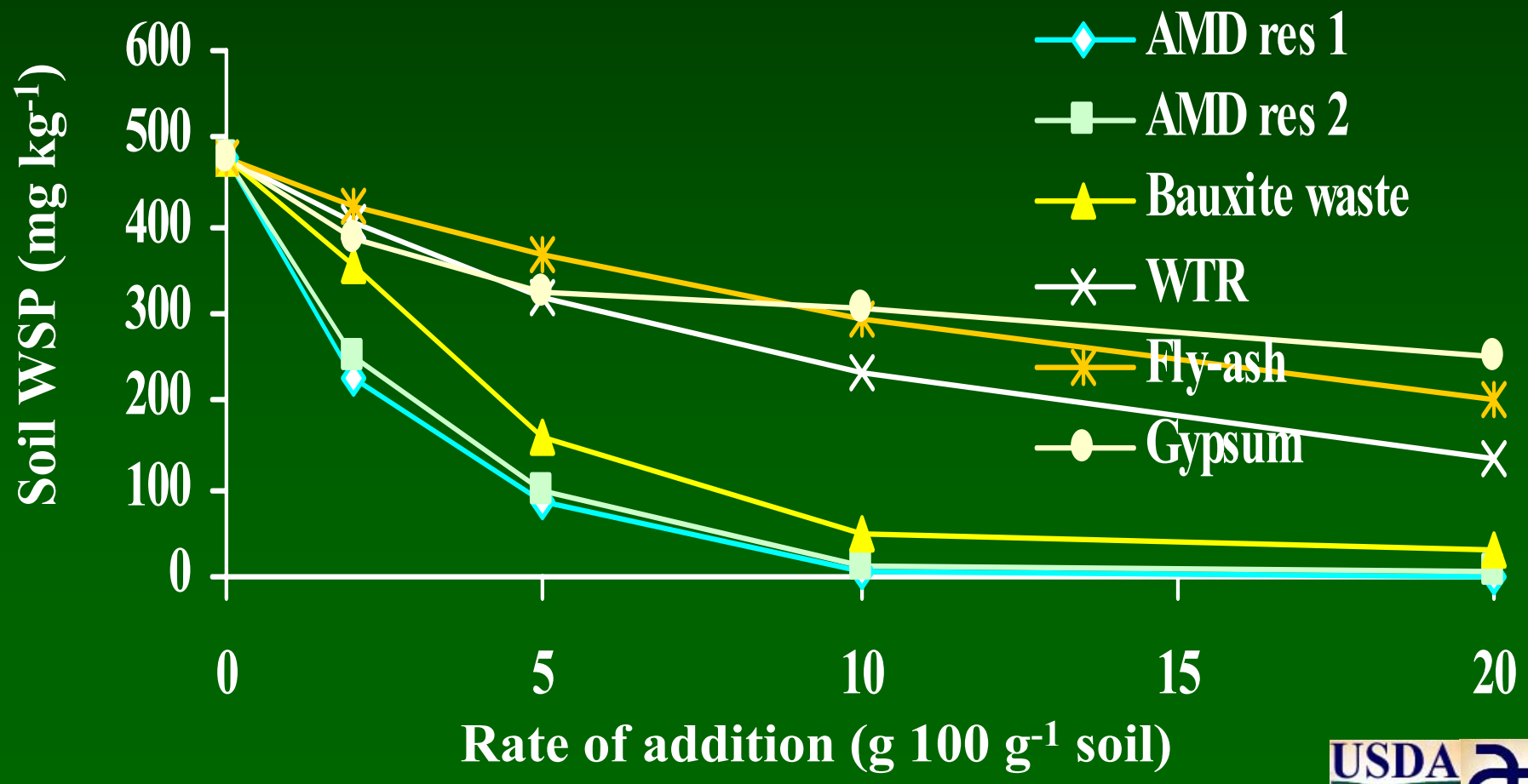
Effect of amendments on soil M3-P: Berks



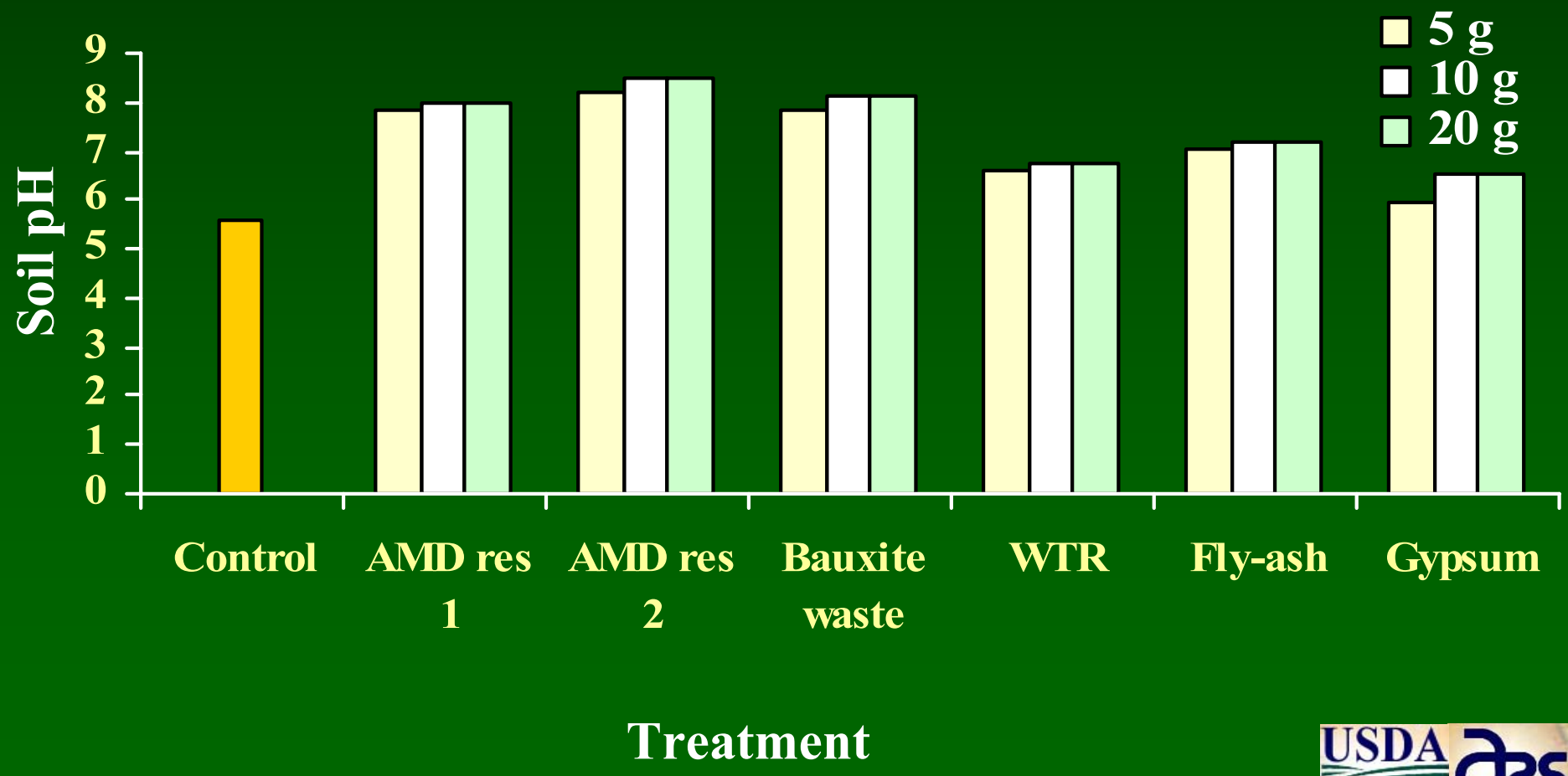
Effect of amendments on soil M3-P: Hagerstown



Effect of amendments on soil M3-P: Othello



Effect of amendments on Othello soil pH



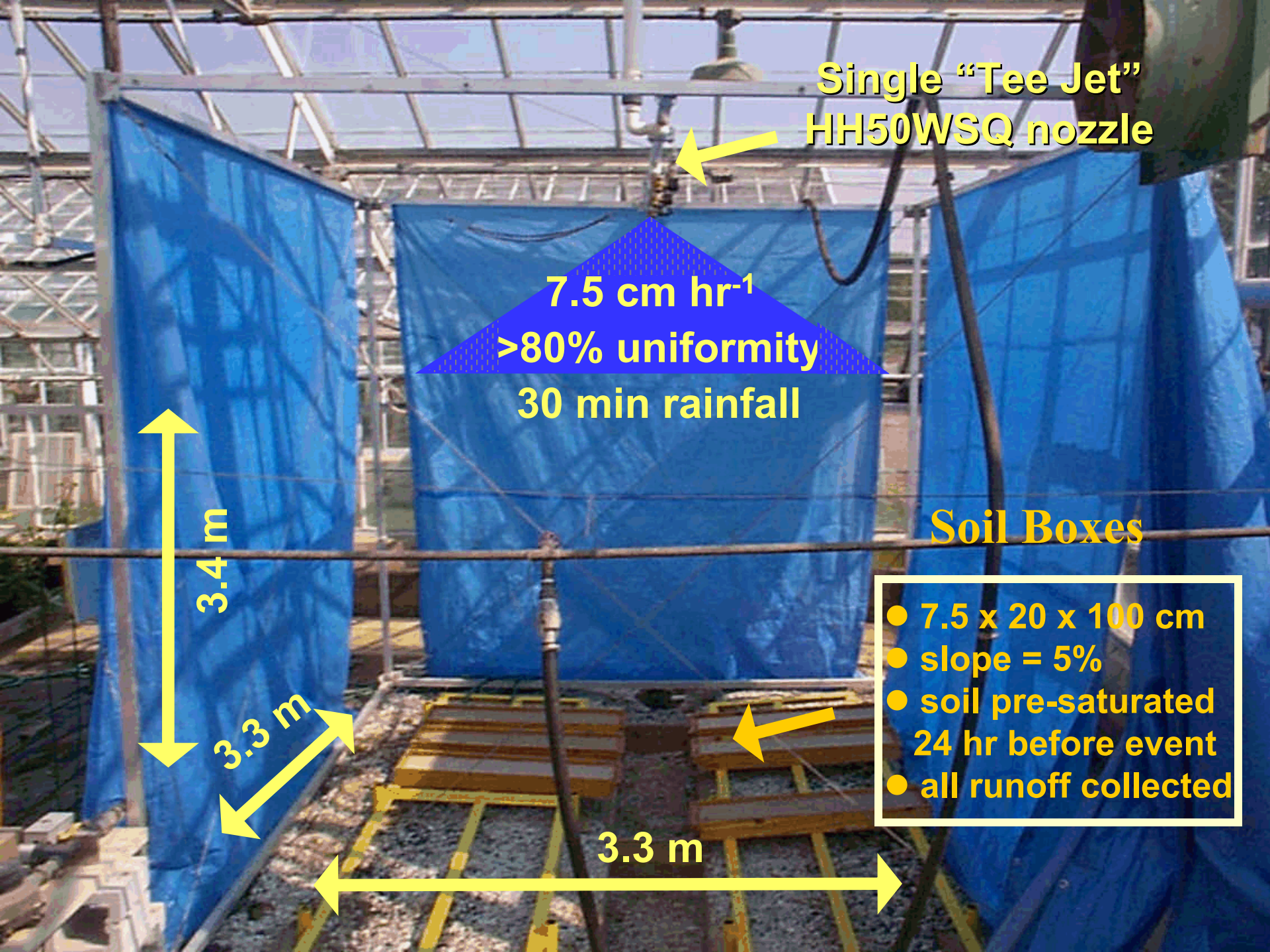
Discussion

- AMD residuals were highly effective at reducing soil WSP concentrations
  - Based on Mehlich 3 extractions, AMD residuals appeared to reduce P concentrations better than other materials
- Potential value as liming material
  - At high rates of addition, AMD materials increased soil pH to high levels

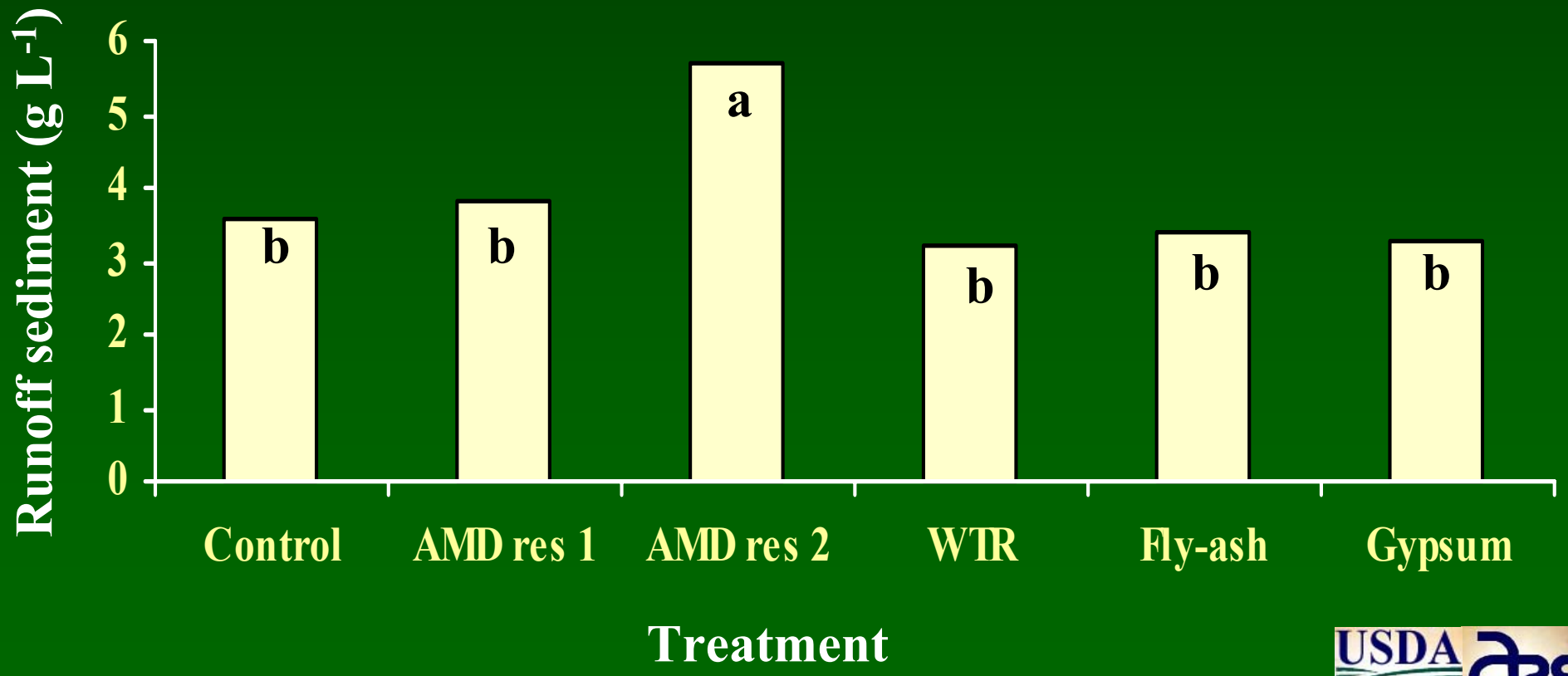
Rainfall Simulation

Methods

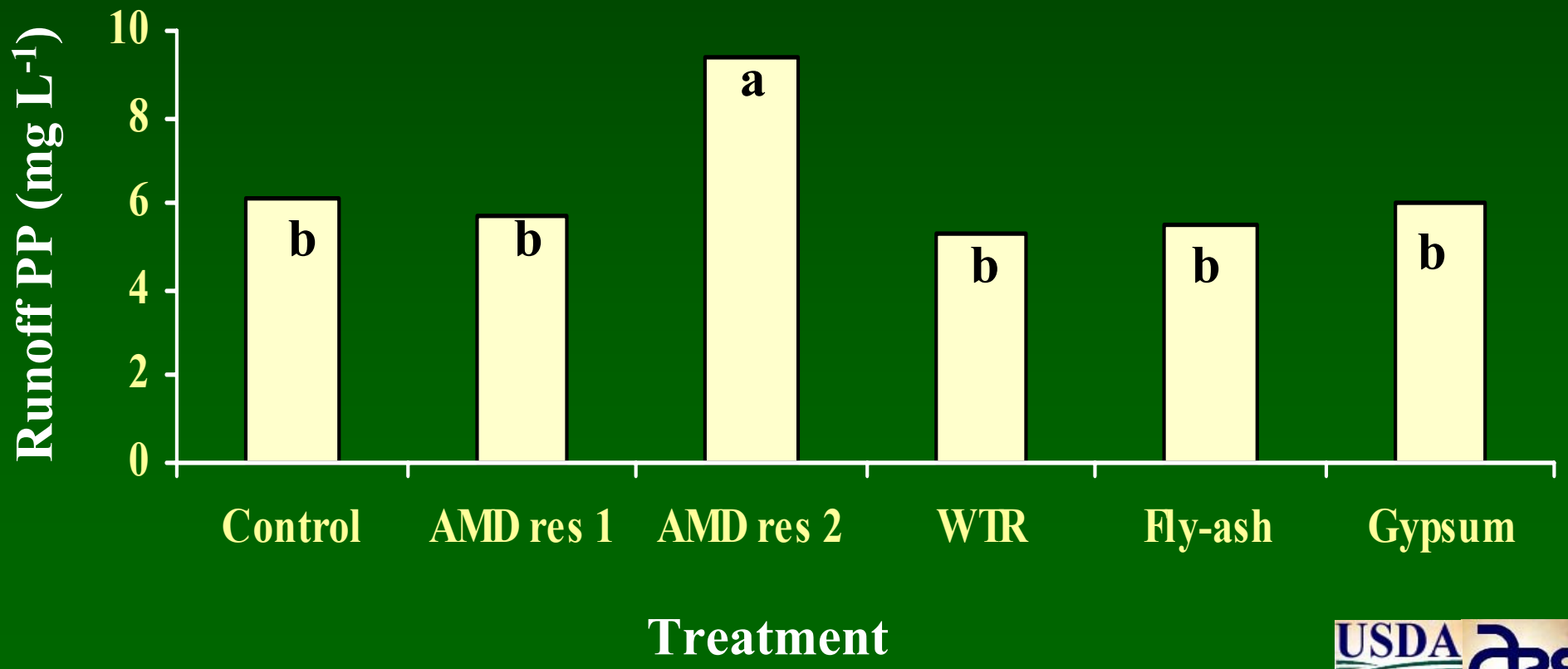
- Rainfall simulation
  - Amended Othello soil with each amendment at a rate equivalent to a M3-P reduction of 50 mg P kg^{-1}
  - Mixed thoroughly in soil boxes (100 x 20 x 5 cm) and allow to incubate for 2 w: replicated 3 times
  - Boxes saturated 24 h before being placed under rainfall simulator for a 30 min event at 7.5 cm hr^{-1}
    - All runoff collected
      - Analyzed for total P (TP: unfiltered, digested), dissolved P (DP: filtered, undigested), total dissolved P (TDP: filtered, digested), particulate P (PP: TP - TDP), and sediment (evaporation).
      - All solutions analyzed for P by ICP-AES


Single "Tee Jet"
HH50WSQ nozzle
7.5 cm hr-1
>80% uniformity
30 min rainfall
3.4 m
3.3 m
3.3 m
Soil Boxes
• 7.5 x 20 x 100 cm
• slope = 5%
• soil pre-saturated 24 hr before event
• all runoff collected

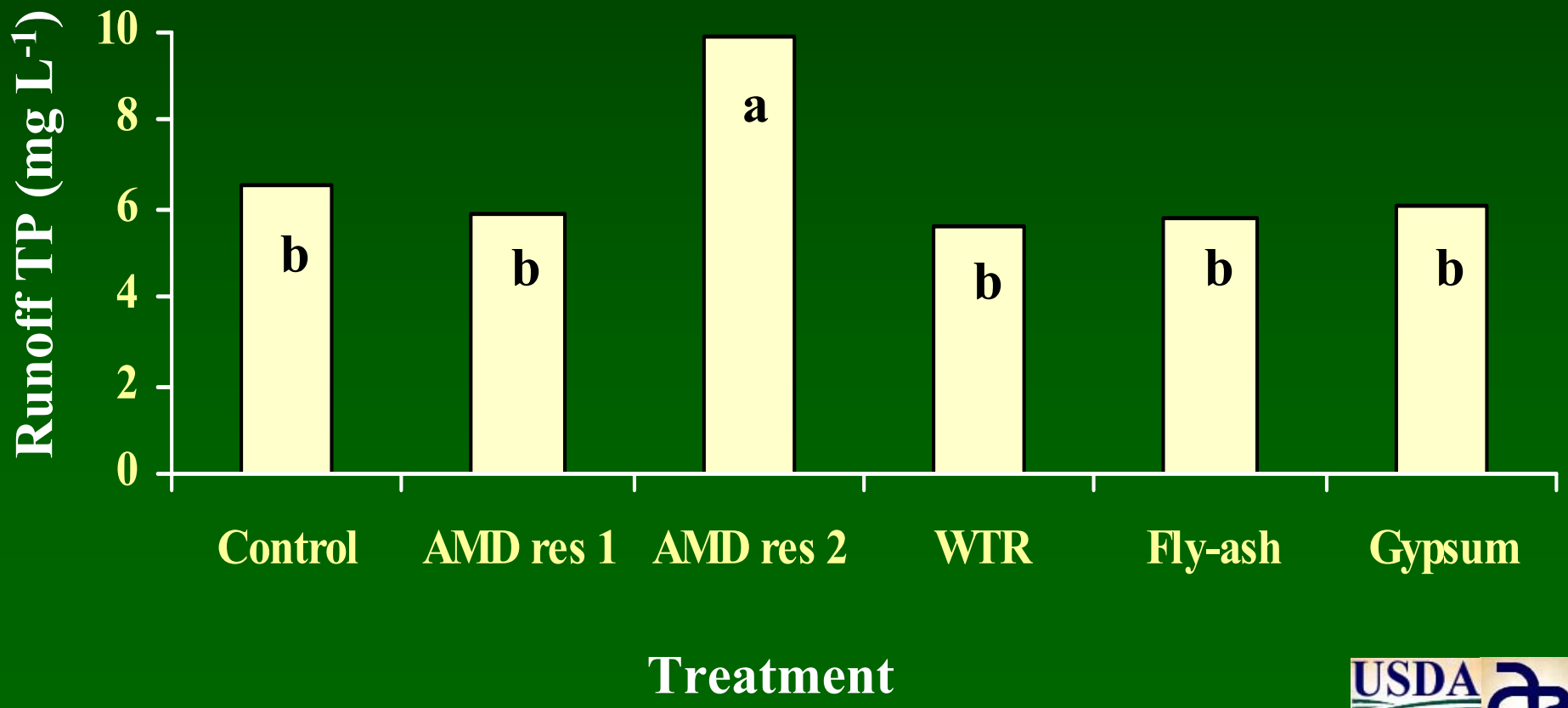
Runoff sediment concentrations



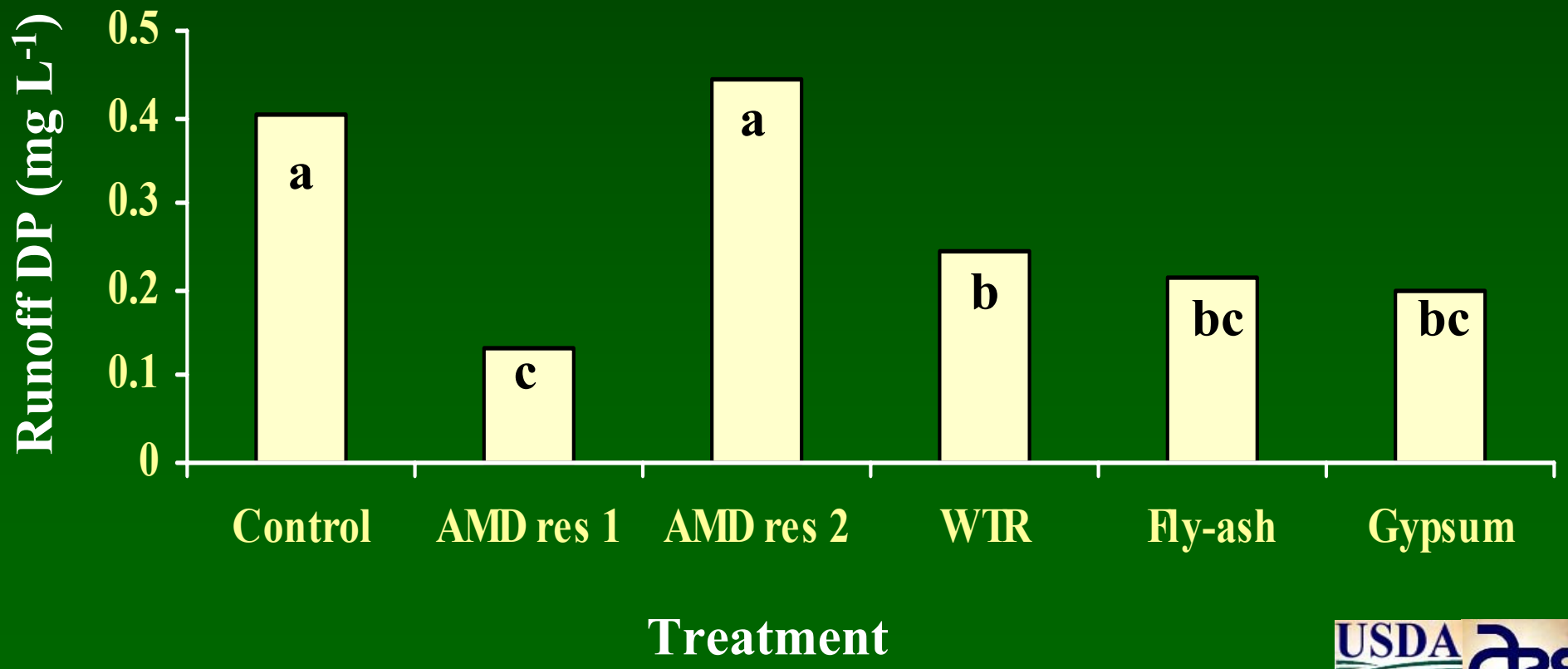
Runoff particulate P concentrations



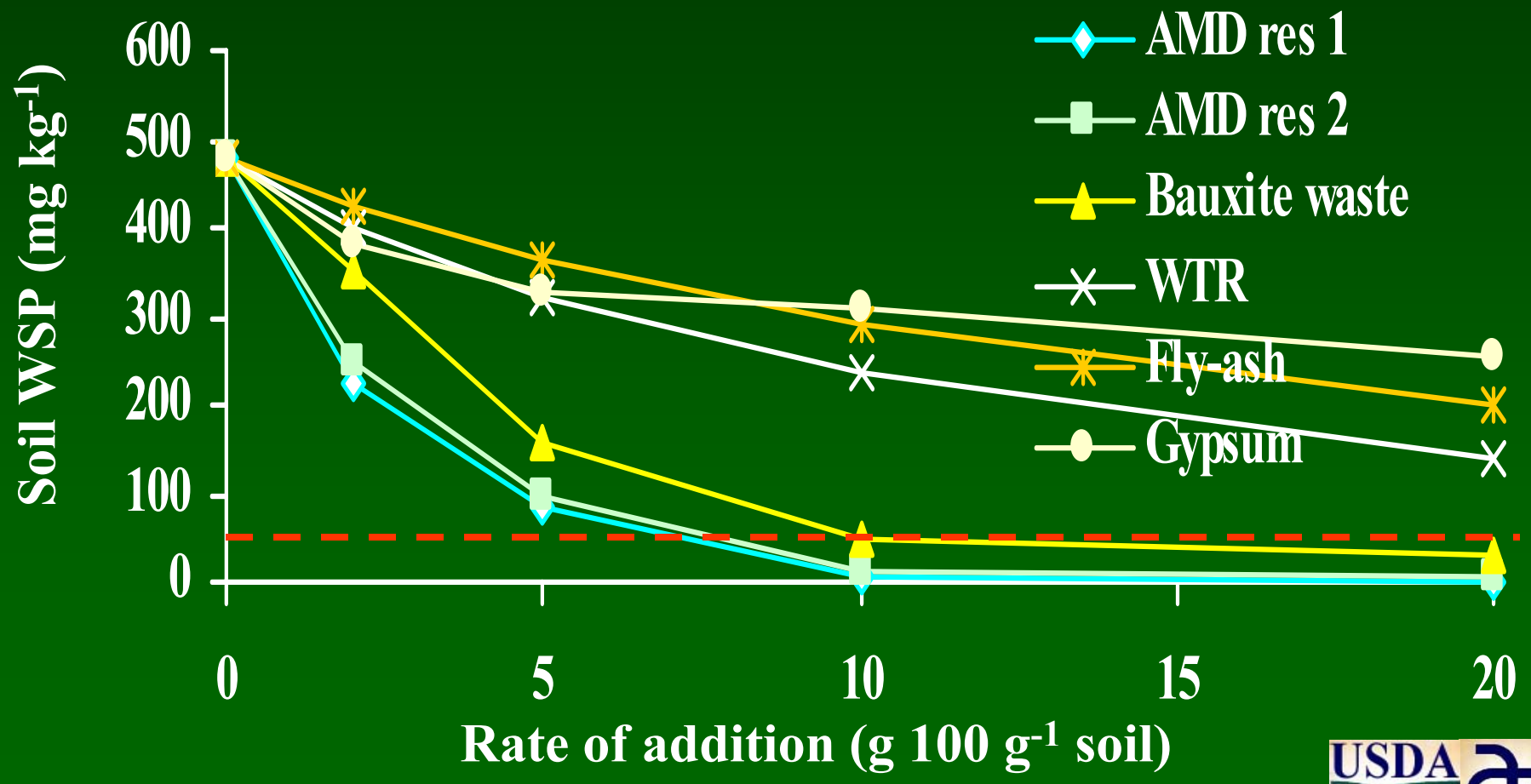
Runoff total P concentrations



Runoff dissolved P concentrations



Effect of amendments on soil M3-P: Othello



Discussion

Material	Rate of addition to achieve 50 mg M3-P kg^{-1} soil (g kg^{-1})	Estimated soil WSP at the respective rate of addition (mg kg^{-1})
AMD Residual 1	68	0
AMD Residual 2	79	15
WTR	200	0
Fly-Ash	200	6
Gypsum	200	0

Discussion

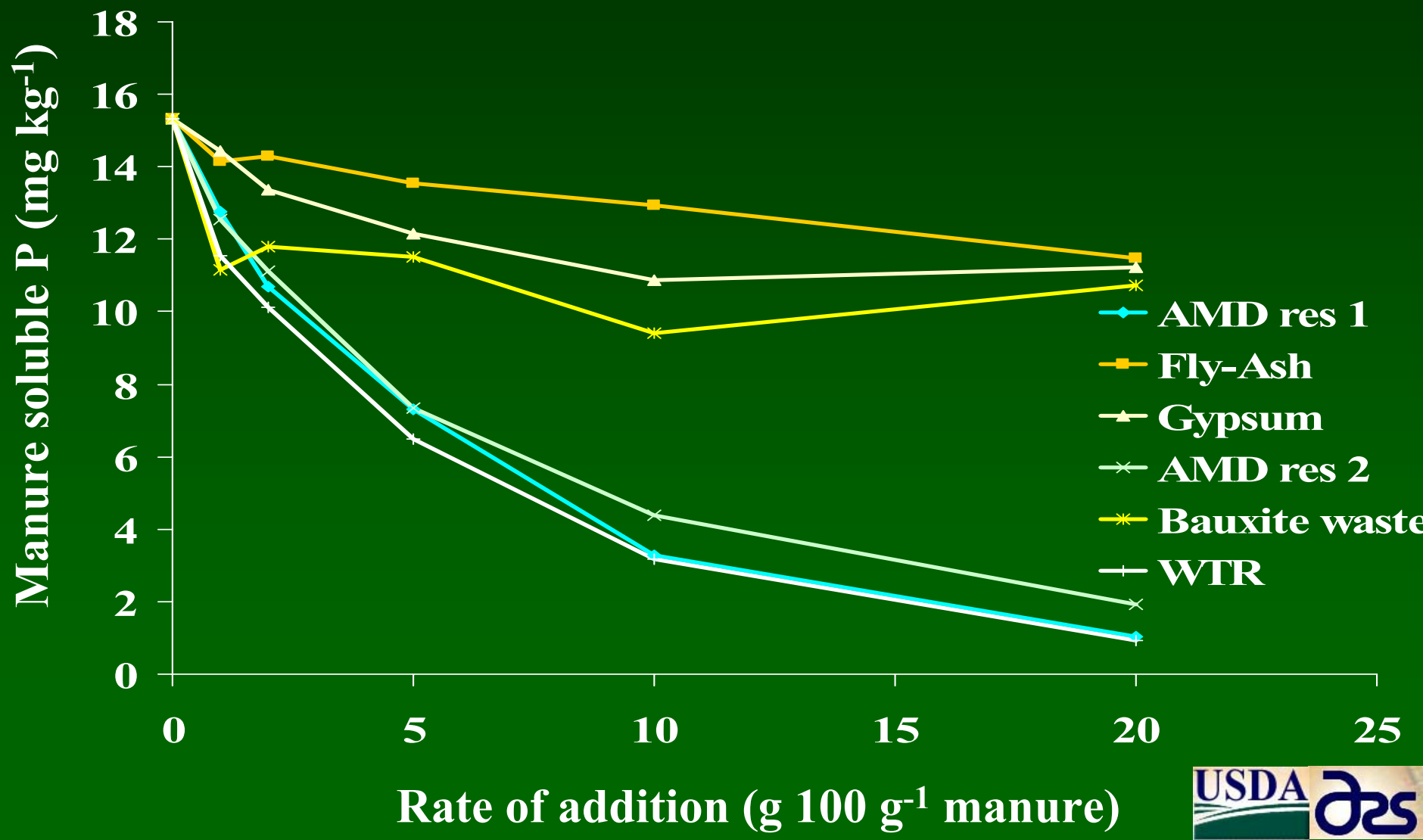
- No effects on sediment, total P, or particulate P losses *except*
  - Materials high in Na, resulting in a swelled double layer and increased erosion of soil particles
    - AMD residual 2
- AMD res 1 resulted in the greatest reduction of runoff dissolved P when applied at lowest rate
  - AMD res 2 did not reduce runoff dissolved P relative to control
    - Likely a combination of low rate applied and dispersion/erosion effects

Manure P Solubility

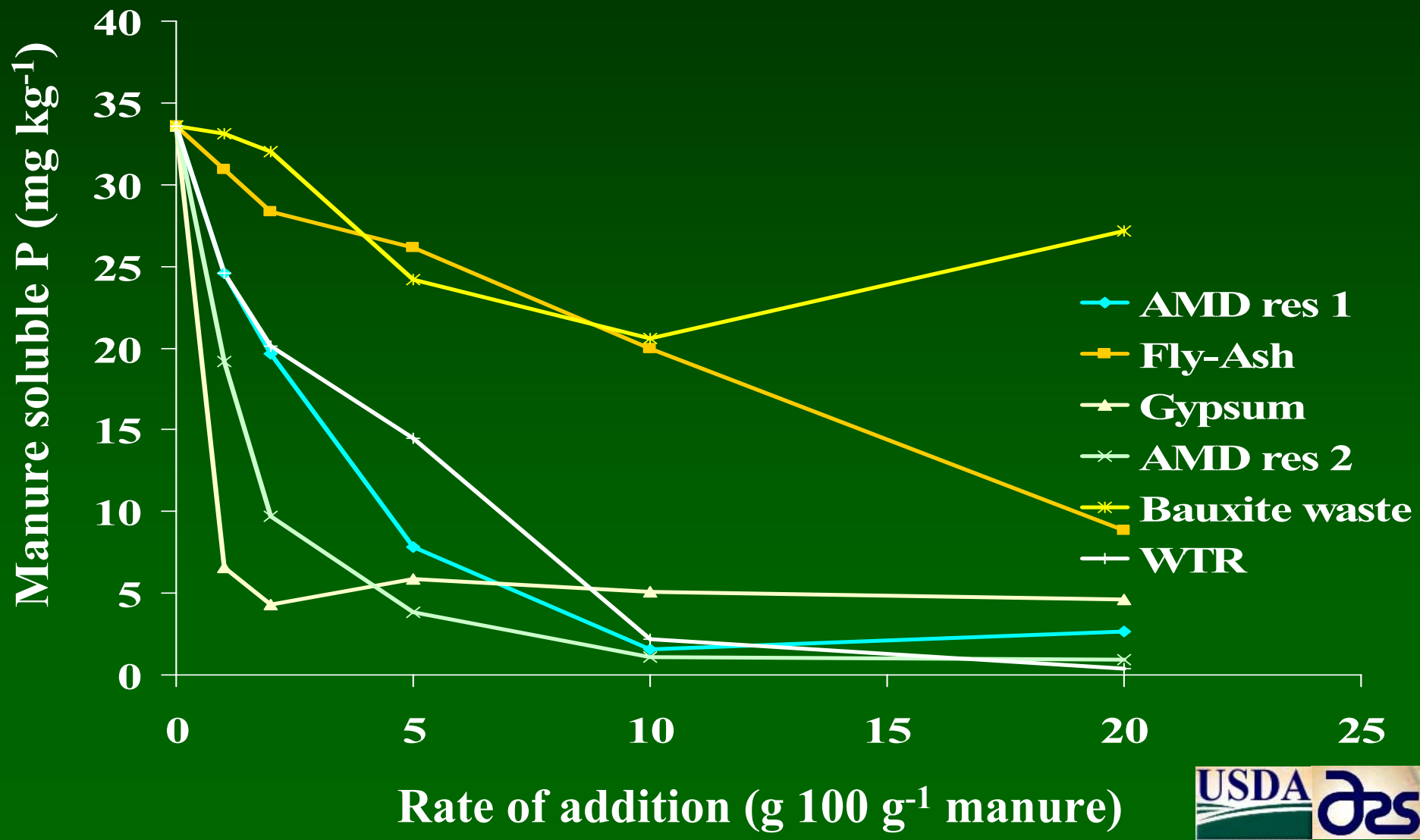
Methods

- Manure P solubility experiment
  - Dairy, swine, and poultry manure samples initially analyzed for total P and metals, pH, and % solids
  - Manure samples amended with each material at 0, 1, 2, 5, 10, and 20% (g 100 g^{-1} manure: dry wt basis)
  - Placed in 250 ml plastic bottles at the ratio of 1:200 manure + amendment:DI water
  - Shaken for 24 h followed by filtration with 0.45 micron filter and P analysis by ICP-AES

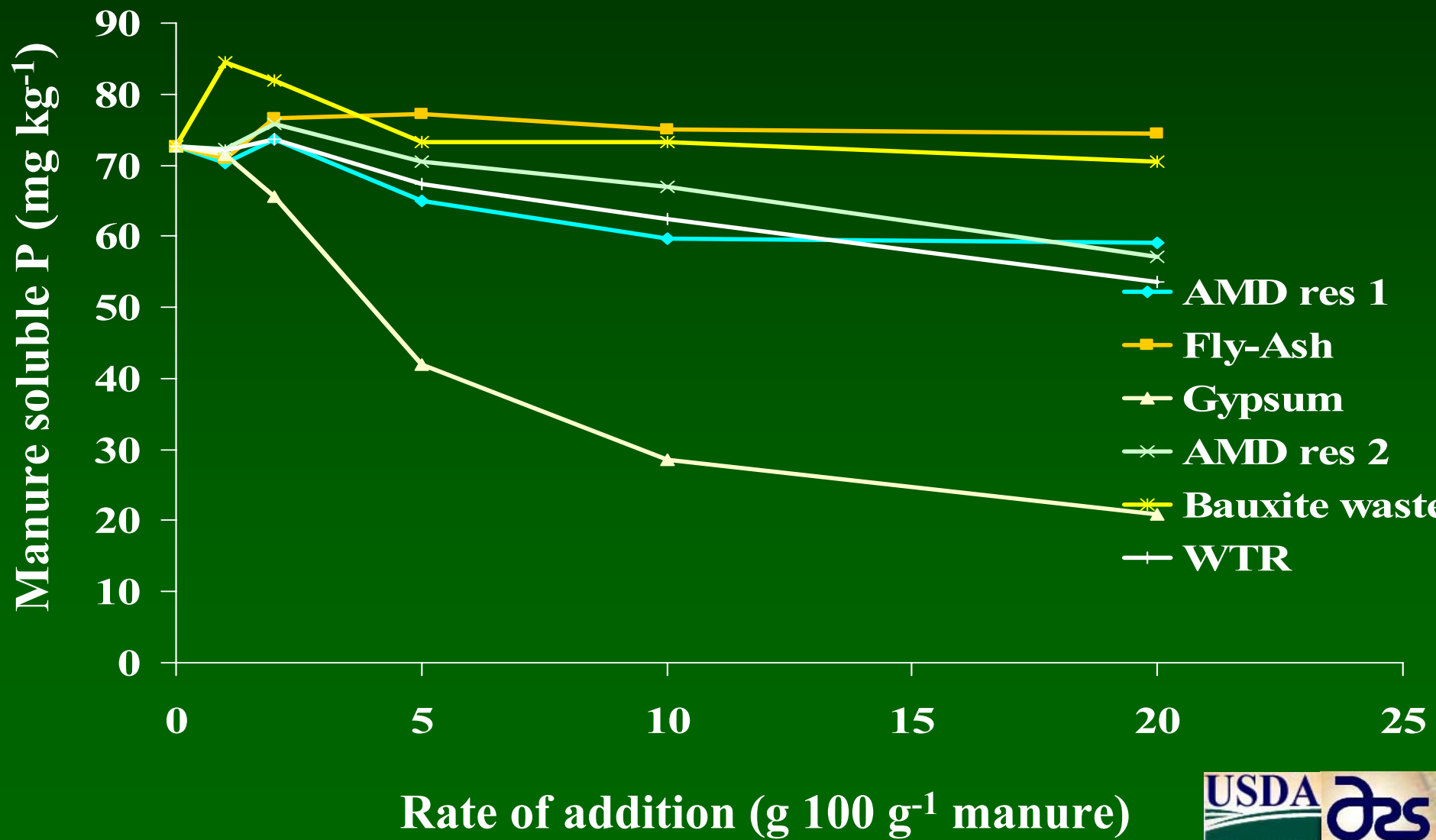
Effect of materials on dairy manure soluble P concentrations



Effect of materials on swine manure soluble P concentrations



Effect of materials on poultry manure soluble P concentrations



Discussion

- AMD residuals were most effective in reducing soluble P concentrations in dairy and swine manure
  - However, they were not very effective in regard to poultry manure
    - Likely due to the extremely high Ca content of the poultry manure, P was present in the form of Ca phosphates
      - As a result, only a high Ca material, highly soluble at pH > 7 such as gypsum could effectively reduce soluble P concentrations

Conclusions

- AMD residuals are effective at reducing soil P, runoff dissolved P, and manure soluble P concentrations
  - Depending on treatment process, materials can be rich in Ca
    - More effective at high pH's
    - Materials with little Ca, dominated by Fe would be more effective if the pH was lowered
  - Materials with high concentrations of Na are hazardous to agricultural production and water quality