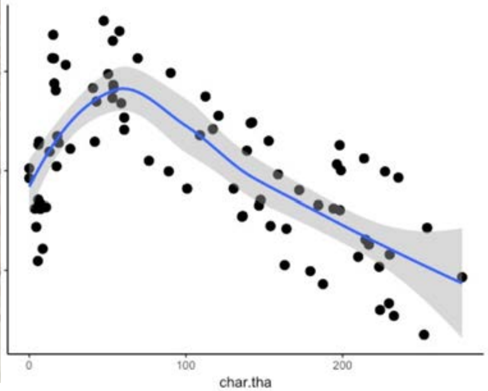
Optimal dosages for biochar:
a synthesis of dose-response studies



Sean C. Thomas
Faculty of Forestry, University of Toronto

Mine tailings remediation: potential for large-scale applications

How much biochar is necessary?

OMA
ONTARIO MINING ASSOCIATION

GOLDCORP

Biochar as replacement product for lime in hardwood forests?

Forest liming:

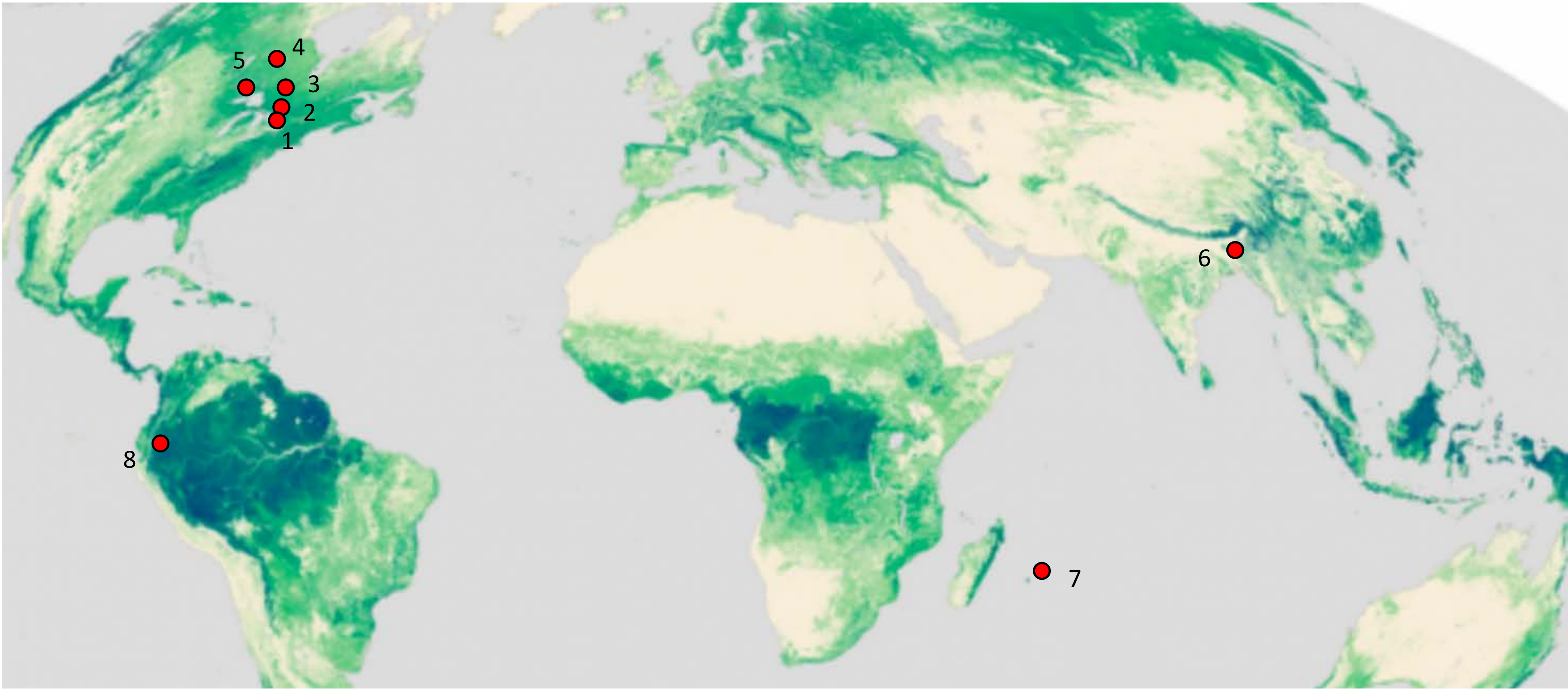
- Lime (crushed limestone – mainly $CaCO_3$ and/or $CaMg(CO_3)_2$)) is added to increase soil pH.
- Chemical dissolution is important source of CO_2 (~1% of global emissions)

Forest charring:

- Use of biomass waste converts C with ~1-2y half-life to 1000+ y half-life.
- Addresses nutrient imbalance
- Enhances responses of fire-adapted species
- Combats mesophytification

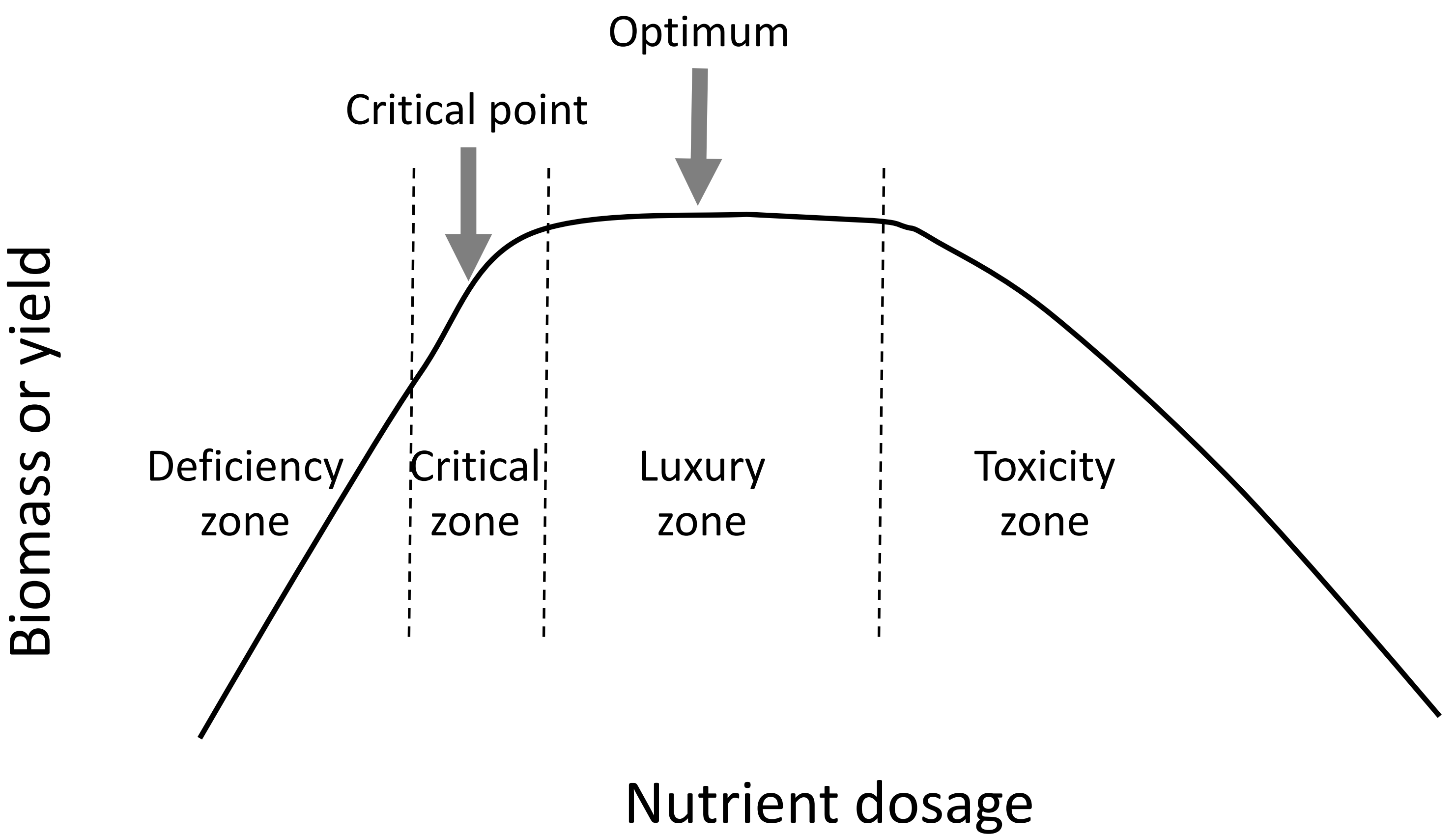
How much biochar is necessary?

Thomas lab field trial locations



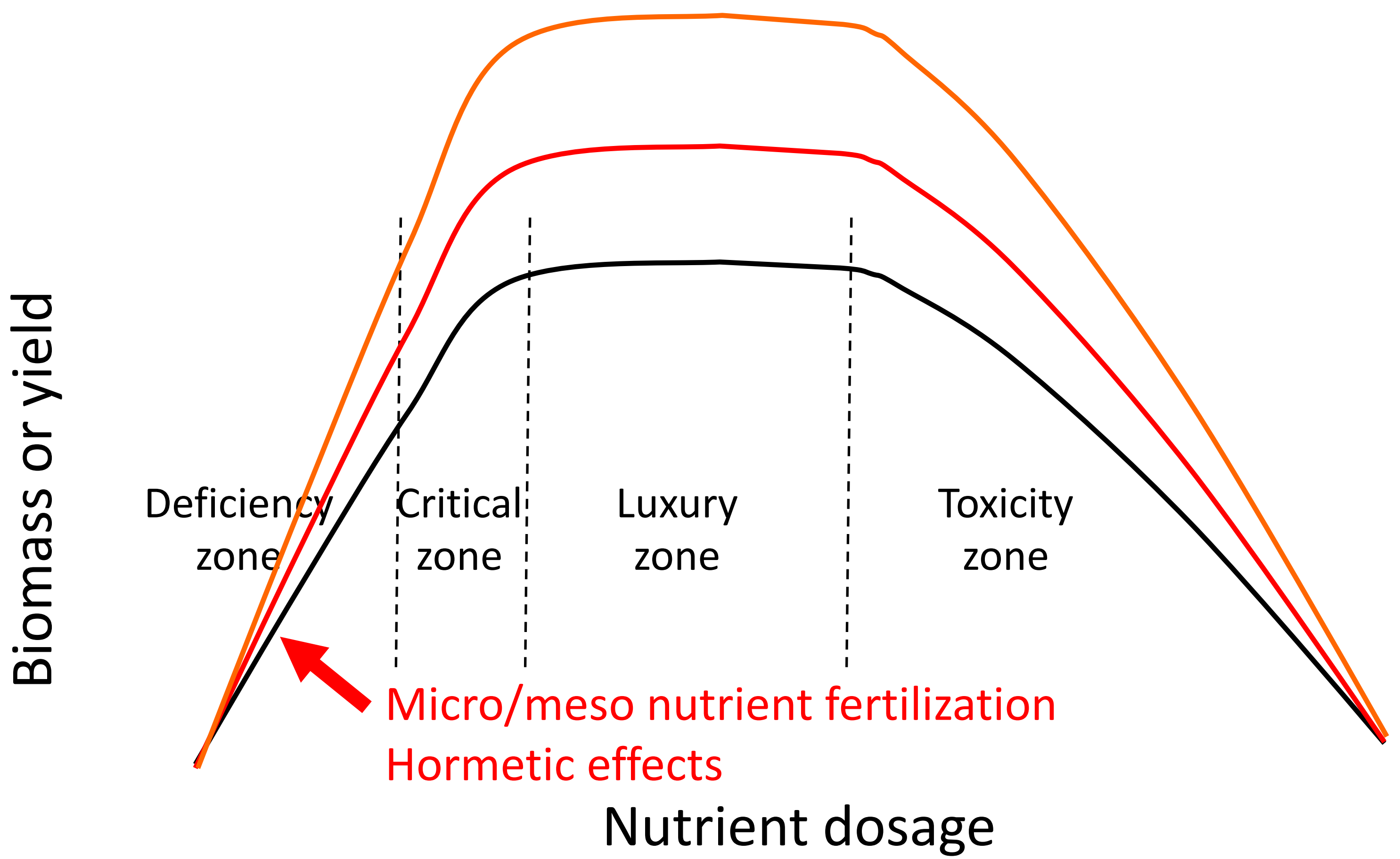
(1) Toronto, (2) Haliburton Forest, (3) Porcupine Mine ON, (4) Musselwhite Mine ON, (5) Kakabeka Falls ON, (6) Sylhet, Bangladesh, (7) Black River Gorges NP, Mauritius, (8) Pastaza, Ecuador

Dose-response relationship and soil amendment optimization

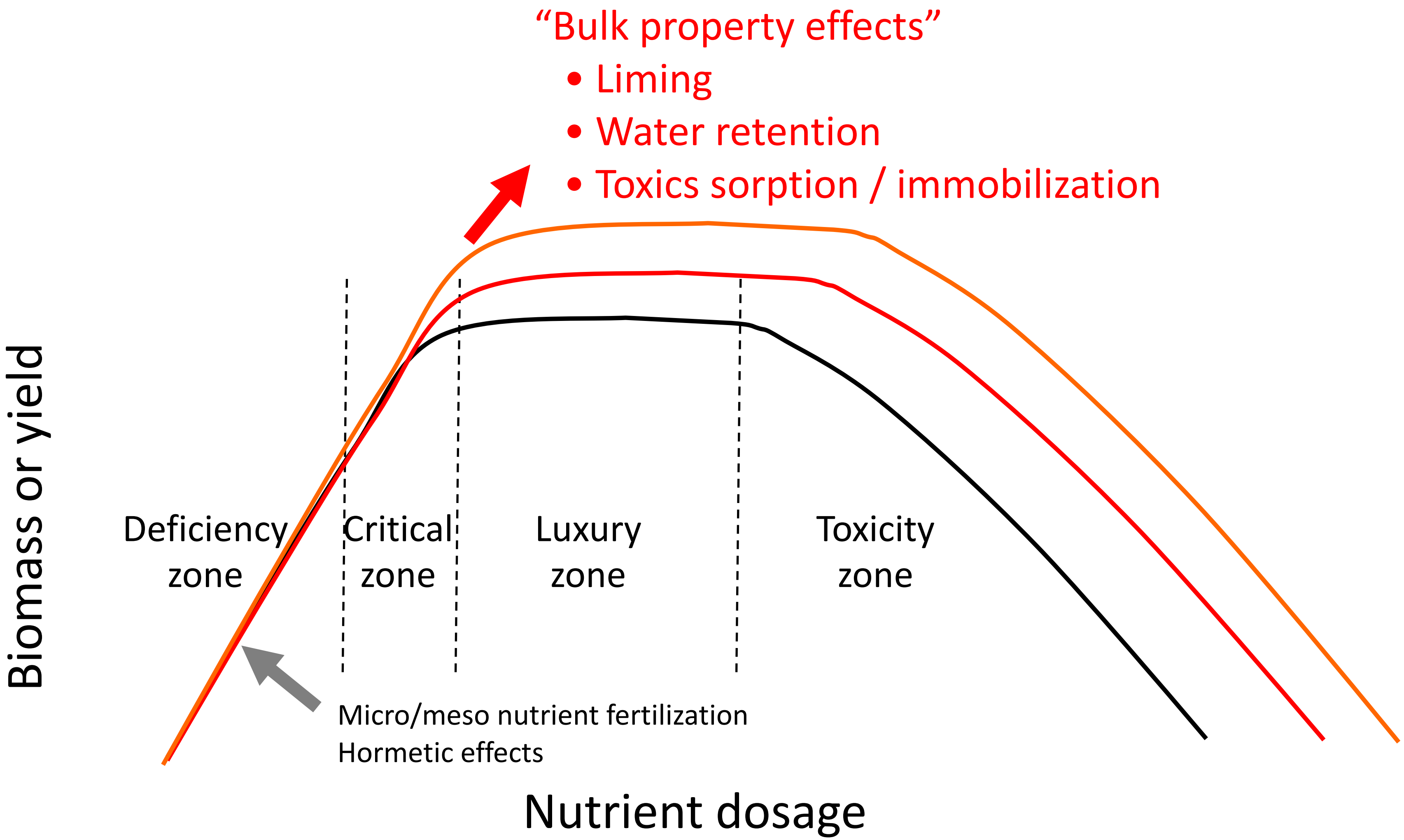


Relationship to mechanisms?

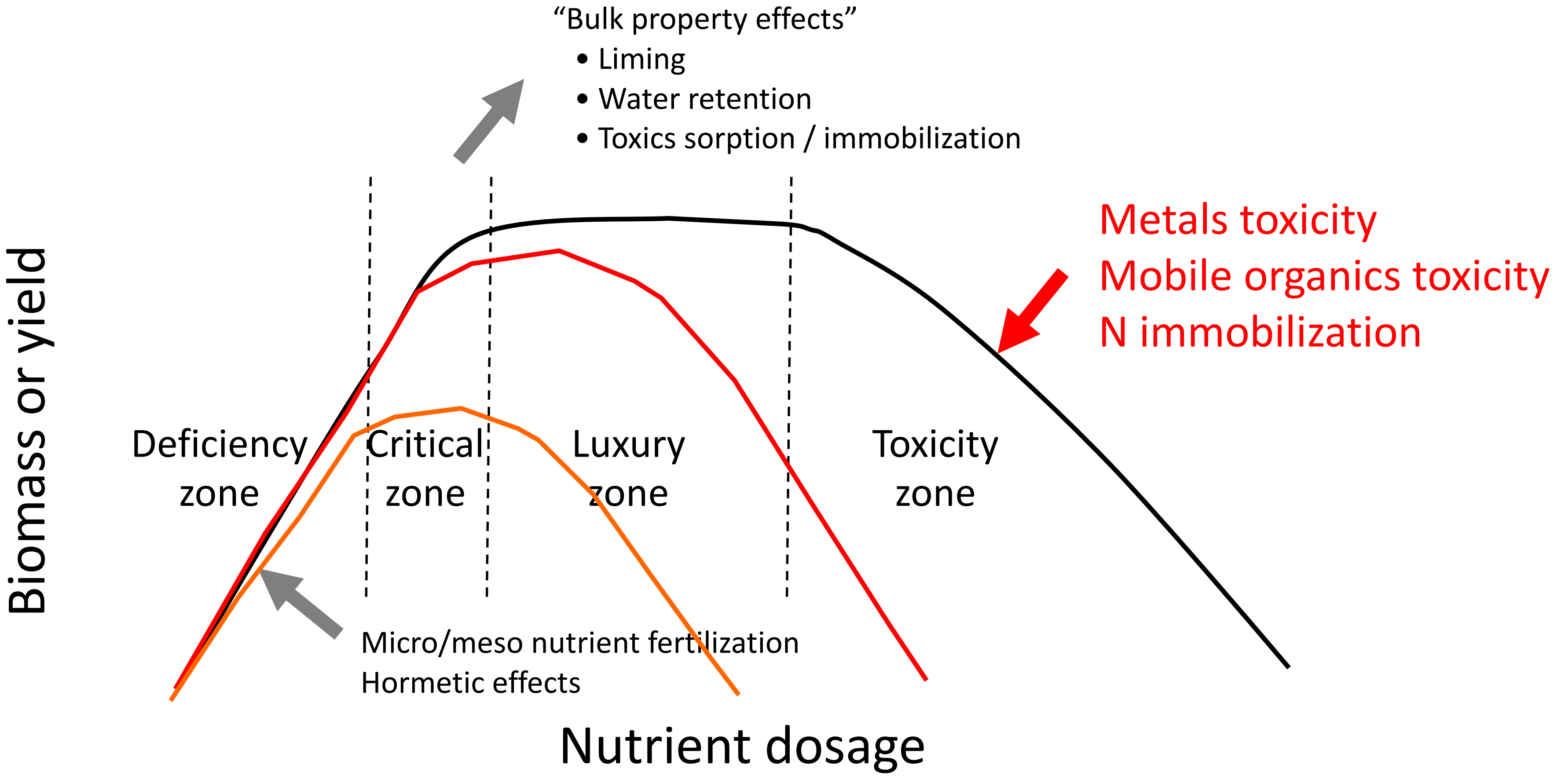
Nutrient supply – in particular micro-nutrients / hormetic effects



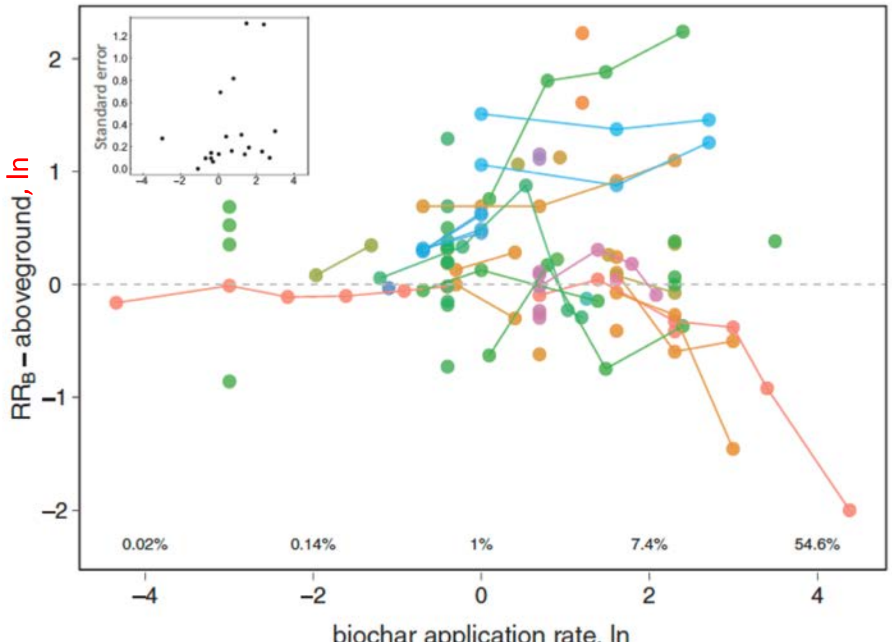
Bulk property effects



Toxicity effects

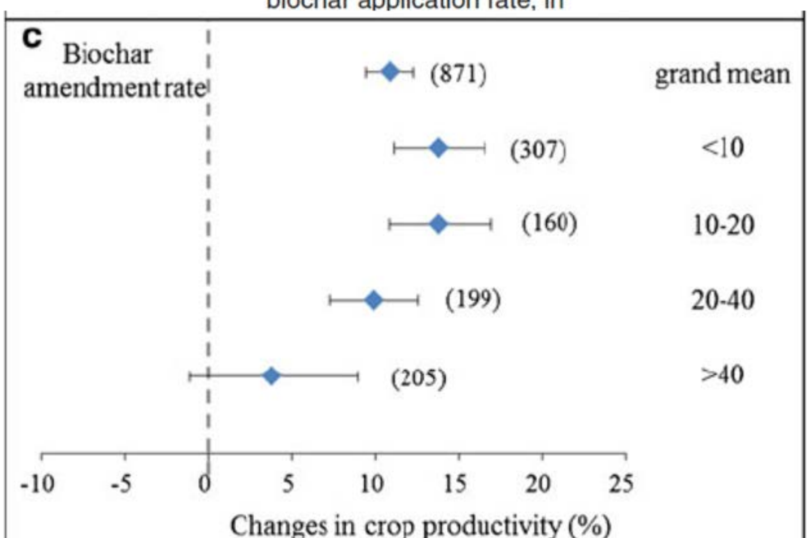


Valiant but disappointing attempts at meta-analysis



Biederman and Harpole 2013 (GCB Bioenergy

- About half of response values are negative
- Suggestive of peak, but no significant relationship found

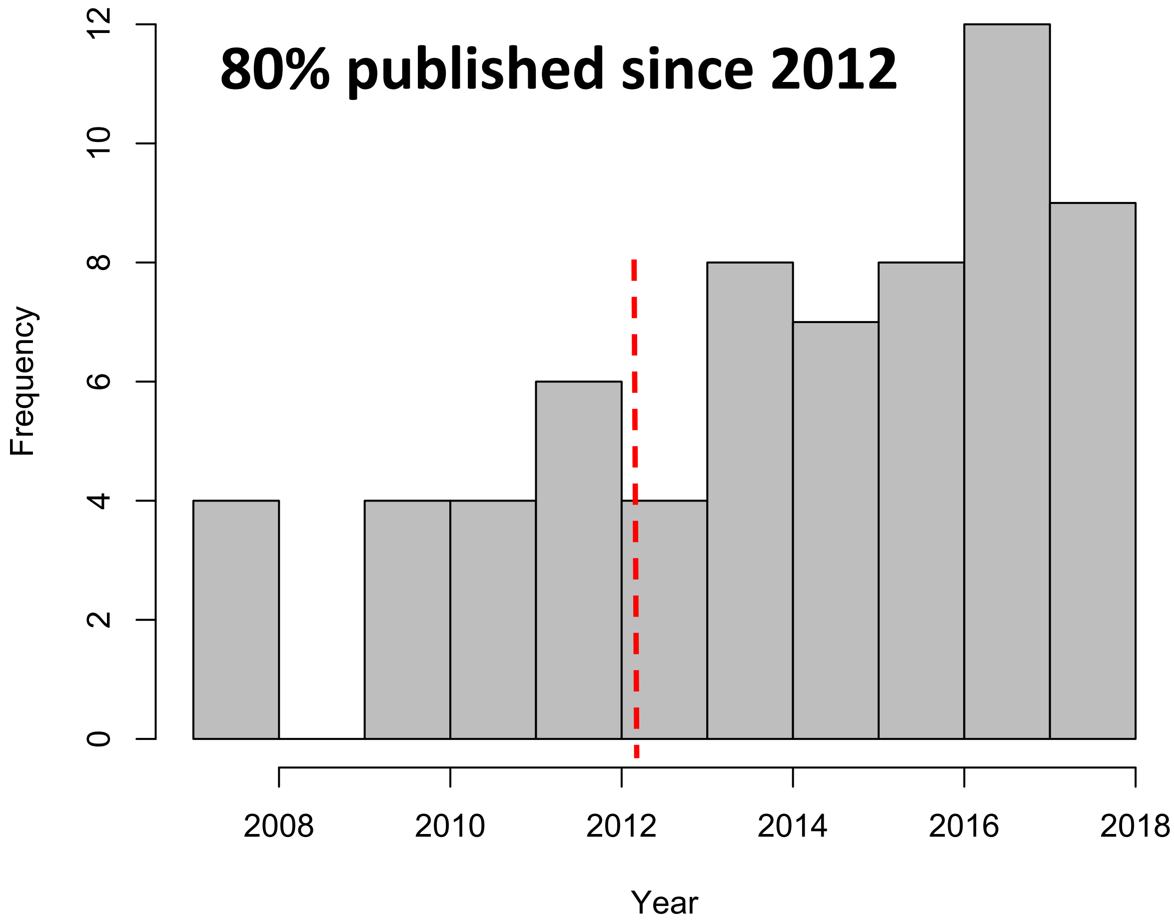


Liu et al. 2013 (Plant & Soil 373:583–594)

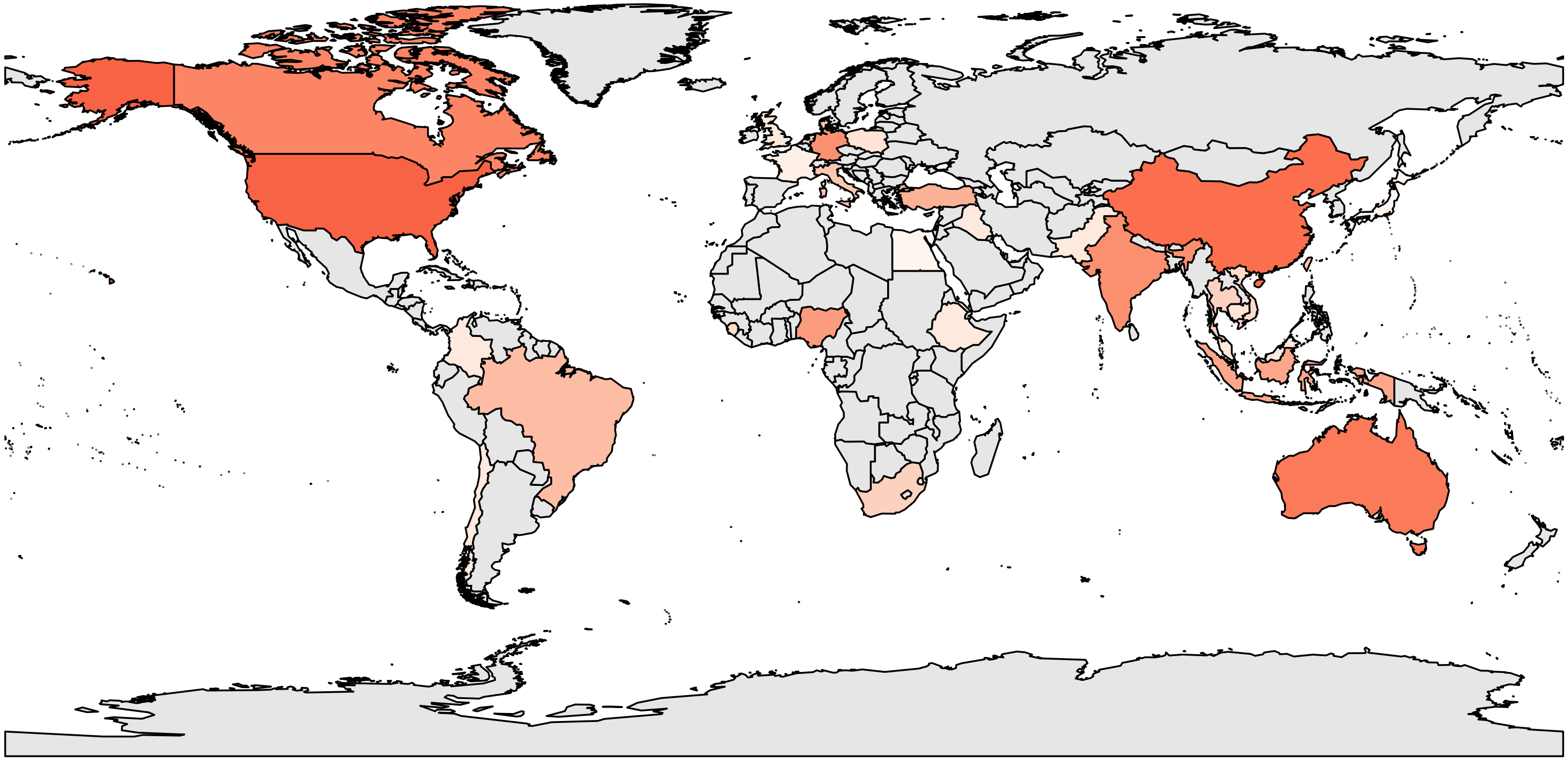
- Peak at lowest dosages?

Neither paper examines possible functional relationships or estimates an optimal dosage or critical point.

Studies presenting biochar dose-response data (3+ doses)

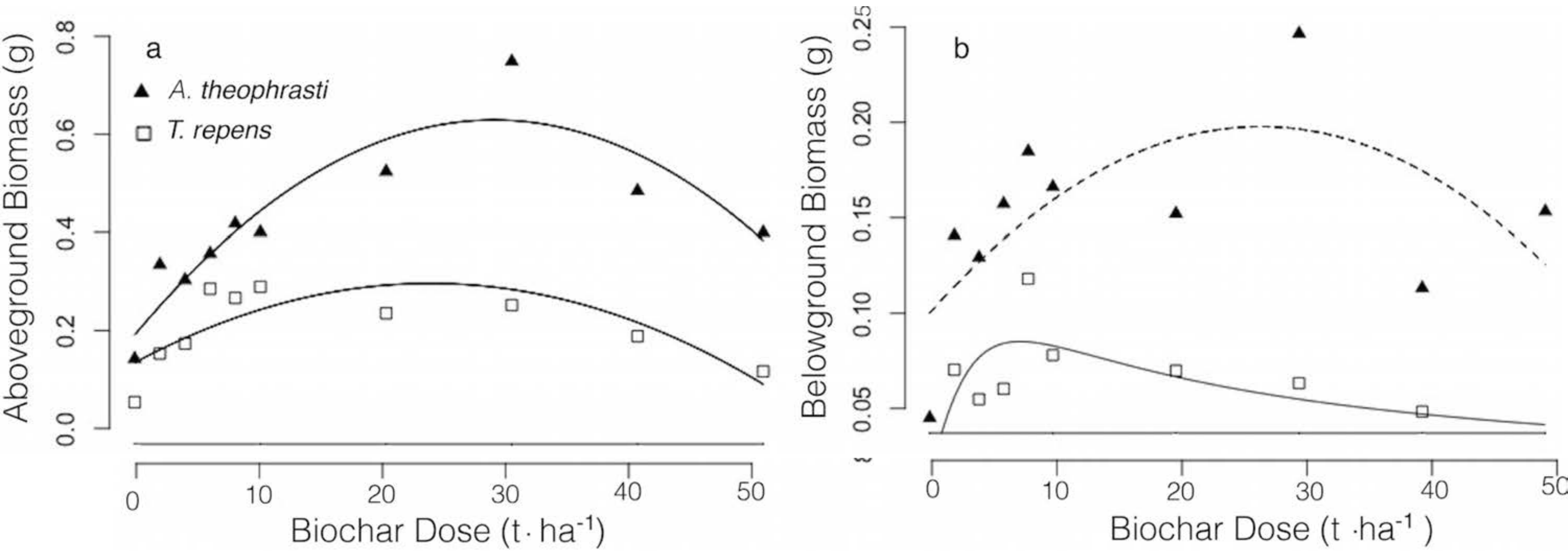


Global data representation



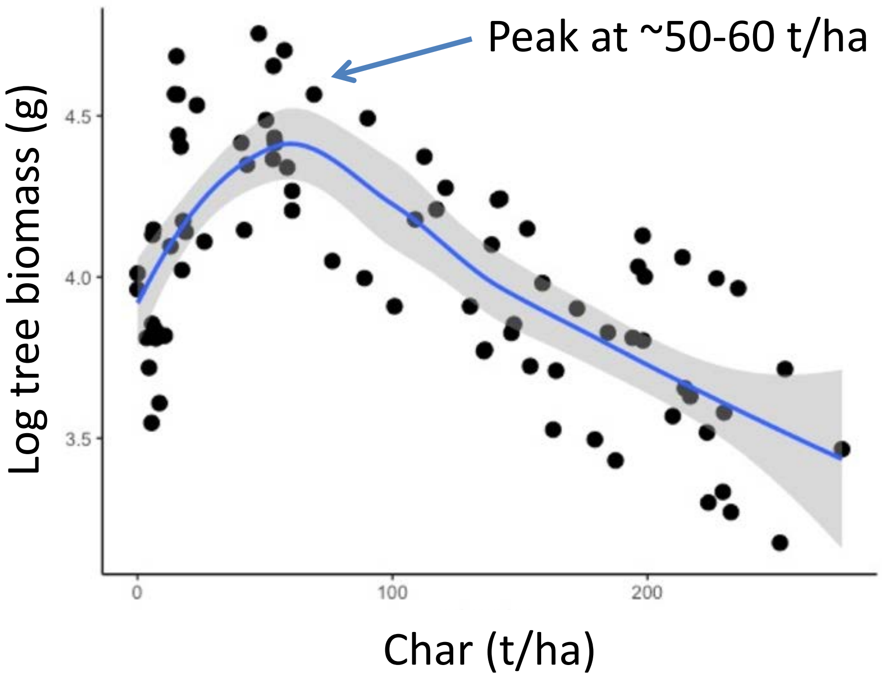
219 dose-response relationships from 66 publications; 30 countries
Data compiled through Jul. 15, 2018

New data: some well-resolved dose-response curves



(Nigel Gale PhD work: Gale and Thomas, ms. in review, *Sci. Tot. Environ.*)

Natural chars and tree growth: "natural" experiment at Musselwhite, ON



- High natural variability in post-fire char deposition
- Peak growth at intermediate levels of naturally occurring chars

(Gale and Thomas, ms in prep.)

Meta-regression results

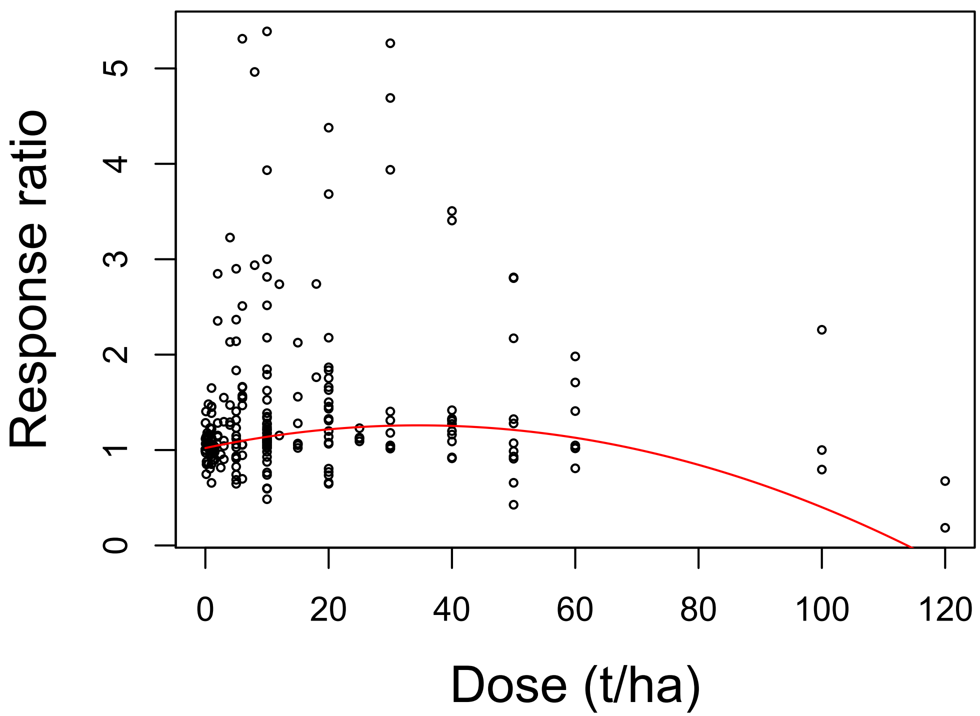
Analysis restricted to studies quantifying aboveground biomass, using dosage units of t/ha, and reporting standard errors (scaled relative to mean response)

Results:

Study term: $P < 0.0001$

Dose term: $P = 0.0001$

Quadratic term: $P < 0.0001$



Dosage units note: conversion factors used to convert from %m/m units to t/ha vary by *6-fold*; studies reporting in %m/m units only were excluded.
Mean conversion factor: **1% (m/m) = 15 t/ha**

Dose-reponse functions

- **Polynomials** have been fit in prior biochar studies (if any explicit function)

  $y = 1 + ax - bx^2$

- **Piecewise functions** have most commonly been used in agricultural studies (especially economic analyses)

  $y = 1 + ax; k > x_t$

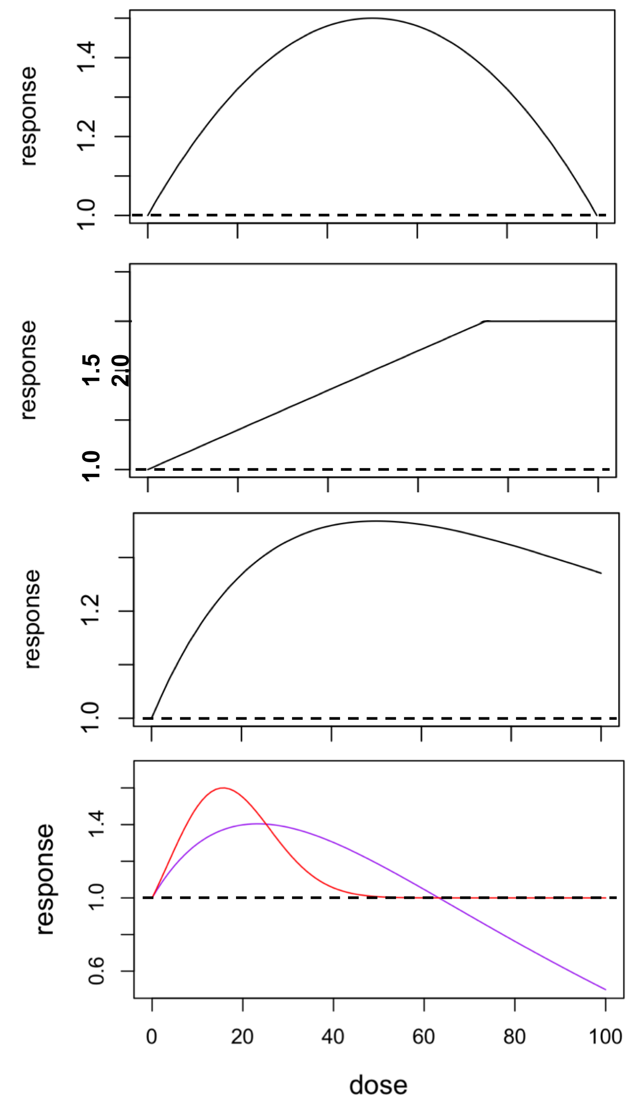
- **Mitscherlich function** (Mitscherlich 1909)

  $y = 1 + ax \cdot \exp(-bx)$

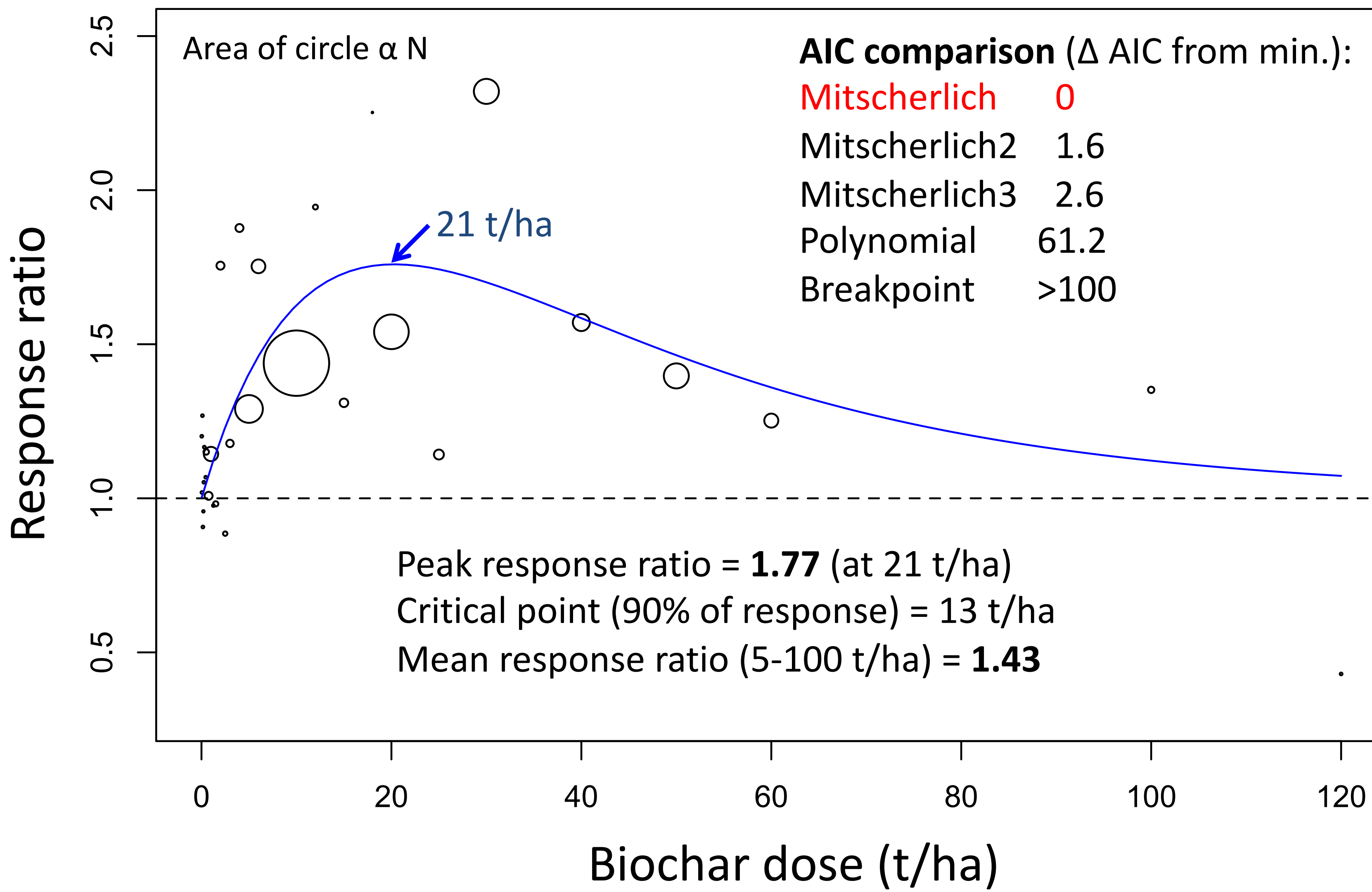
- **Modified Mitscherlich** forms

  Mitscherlich2 $y = 1 + ax \cdot \exp(bx - cx^2)$

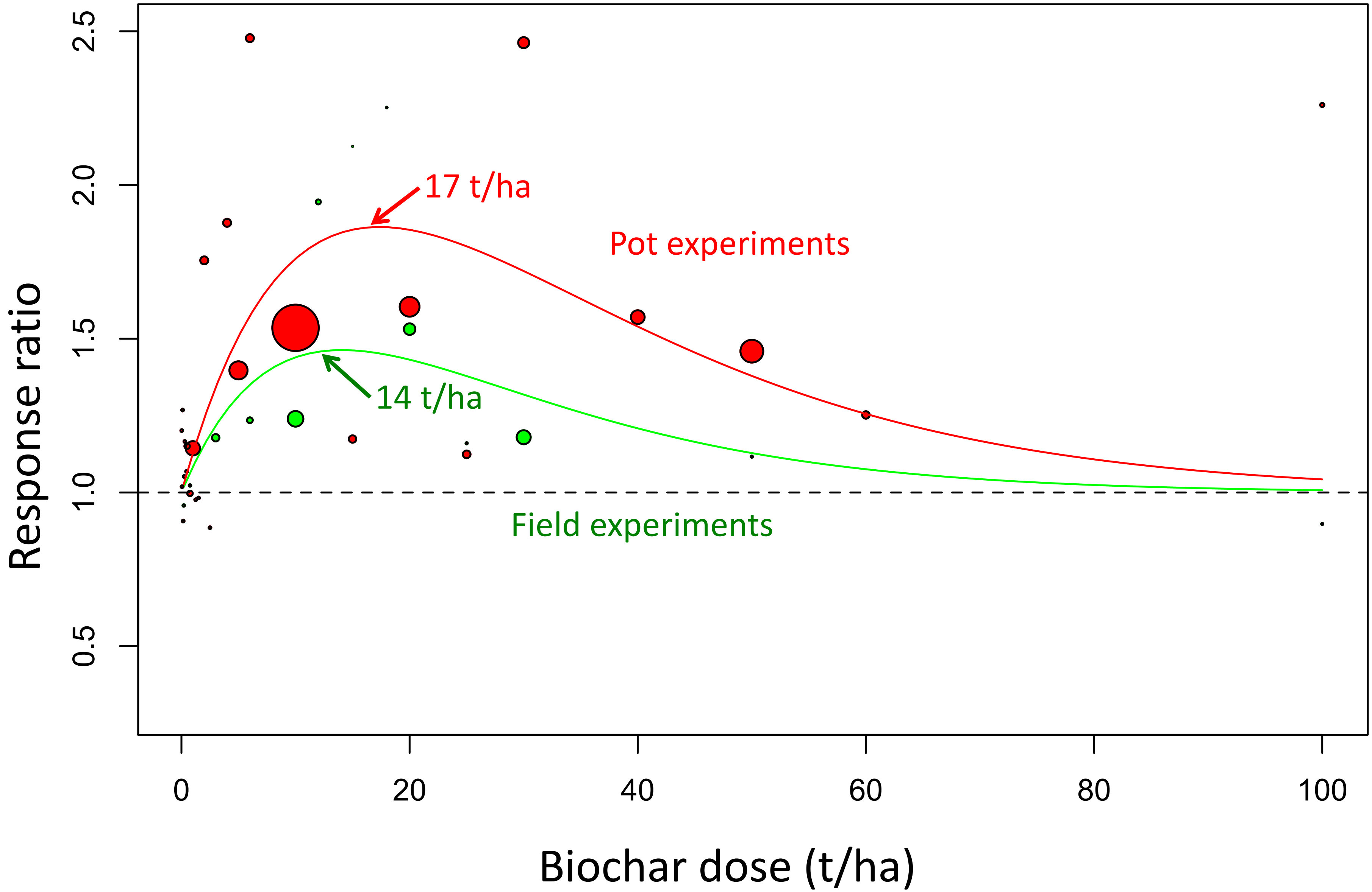
  Mitscherlich3 $y = 1 + ax \cdot \exp(-bx) - cx$



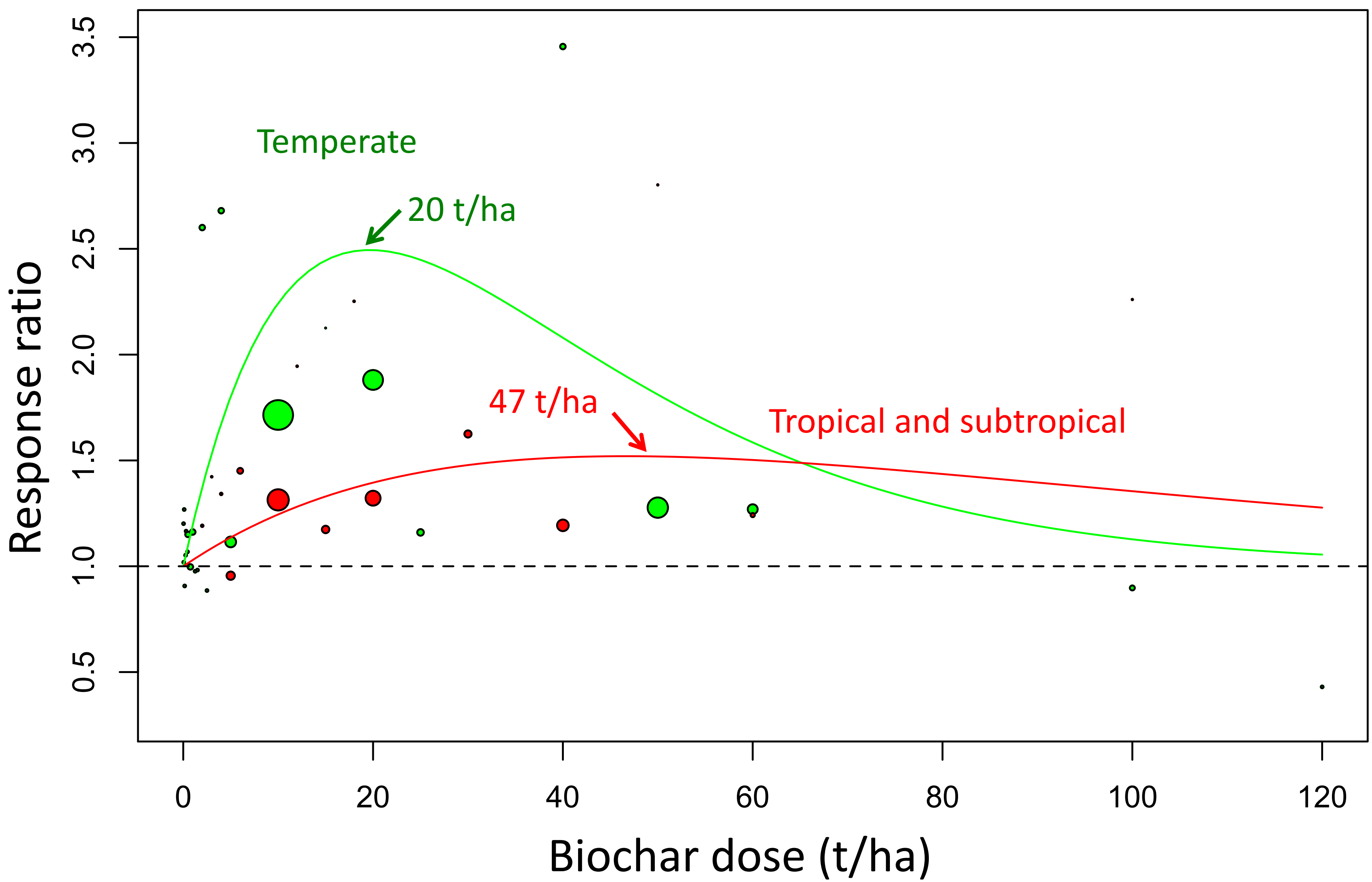
Composite pooled relationship



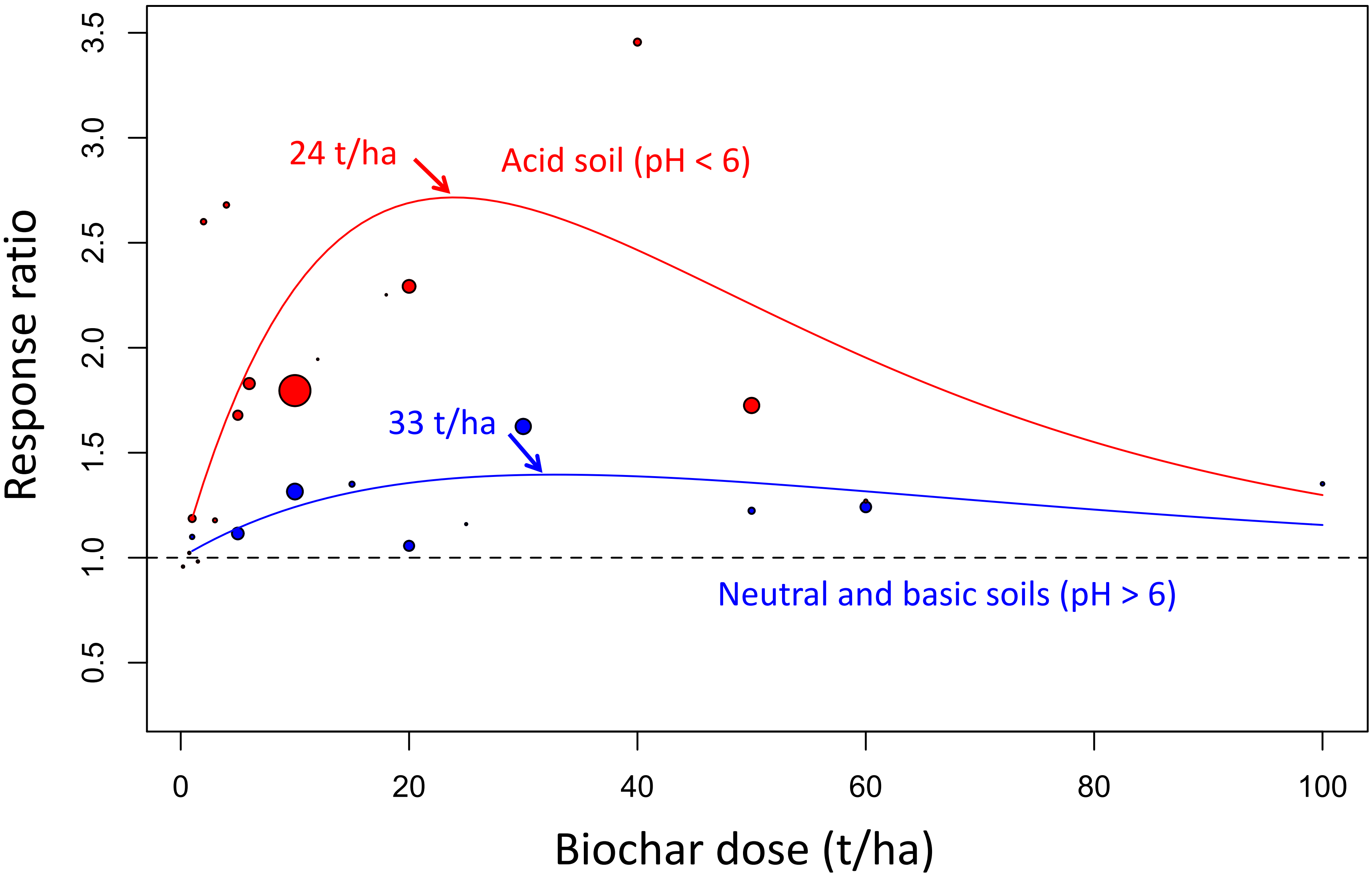
Field vs. pot experiments



Biogeographic zone

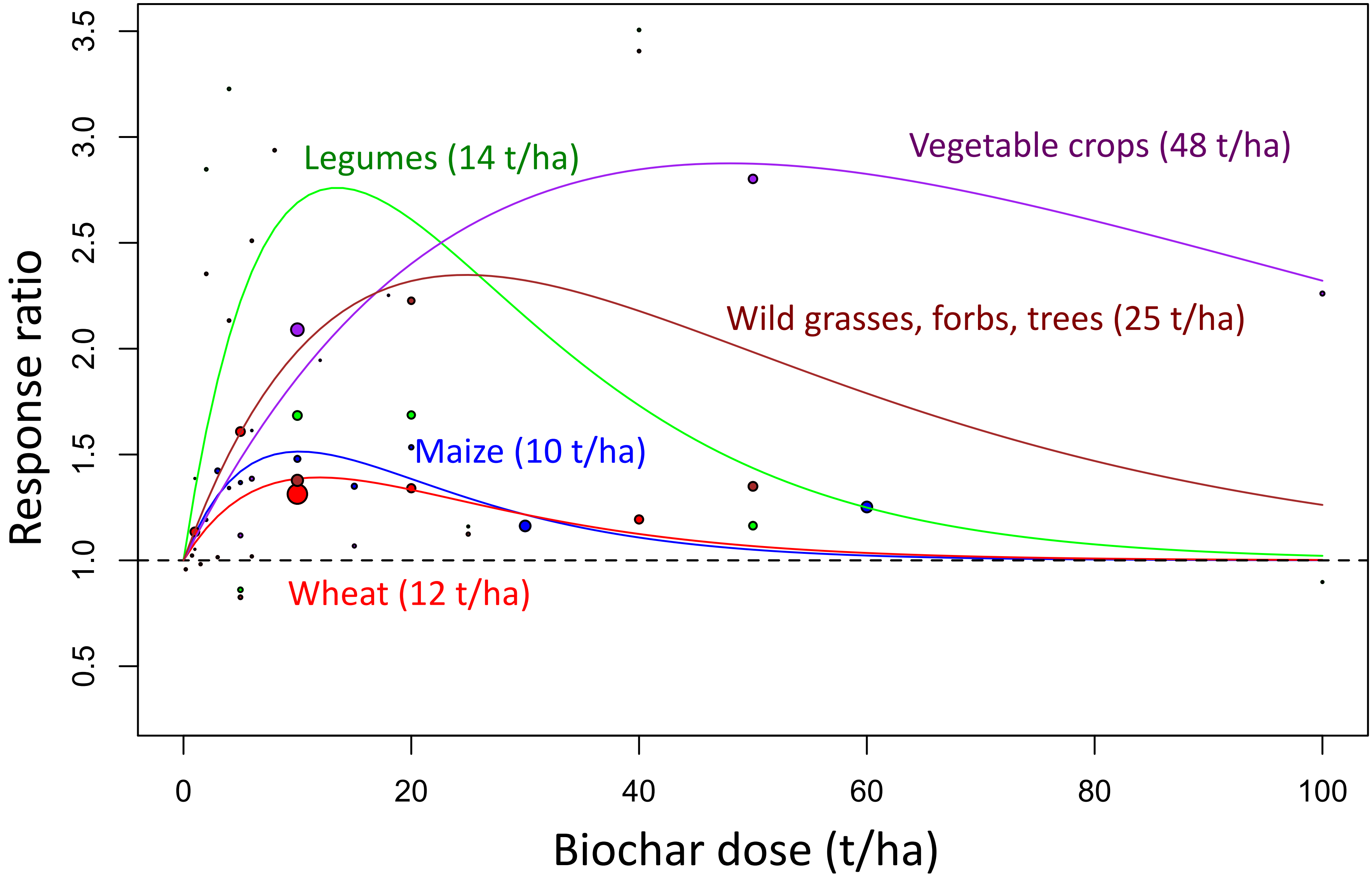


Soil pH



24 t/ha
Acid soil (pH < 6)
33 t/ha
Neutral and basic soils (pH > 6)
Response ratio
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
20
40
60
80
100
Biochar dose (t/ha)

Crop / species groups

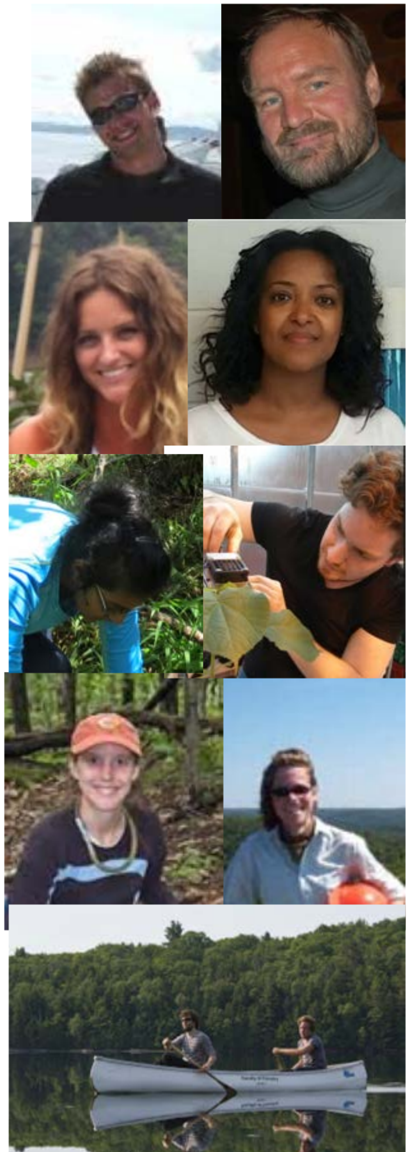


Take-home points

- Biochar dose-response relationships are asymmetrically hump-shaped
- The *Mitscherlich equation* provides the best description for pooled patterns among functional forms examined
- The pooled optimum point is ~20 t/ha (with different crop groups ranging from 10-50 t/ha)
- Adjusting dosages to approximate optima has large potential effects on crop performance
- Analyses provide evidence that optima and “critical points” for biochar dosage vary with climate and soil conditions, and most strongly among crops
- Results are consistent with conclusion that strongest biochar responses are found with legumes, vegetable crops, and natural vegetation including woody plants

Eilhard A. Mitscherlich
(1874-1956)

Acknowledgments



Industrial Partners: Haliburton Forest and Wildlife Reserve, Ltd. (Peter Schleifenbaum Manager and CEO), Ontario Mining Association

Collaborators: Nathan Basiliko, John Caspersen, Roberta Fulthorpe, Mohini Sain, Myrna Simpson, Sandy Smith, Trevor Jones

Post-docs, visiting scholars, students, and technicians: **Jillian Bieser, Nigel Gale**, **Sossina Gezahegn**, **Jon Schurman**, **Tara Sackett**, **Genevieve Noyce**, Mark Horsburgh, Aruna Kumari, Mohammed Halim, Emma Horrigan, Carolyn Winsborough, Jona Kowalik, Christine Leduc, Janise Herridge, Caroline Cornu, Guo Xiaorong, Chihiro Ikeda

GOLDCORP

OMA
ONTARIO MINING ASSOCIATION

NSERC
CRSNG

Haliburton Forest
& WILD LIFE RESERVE LTD