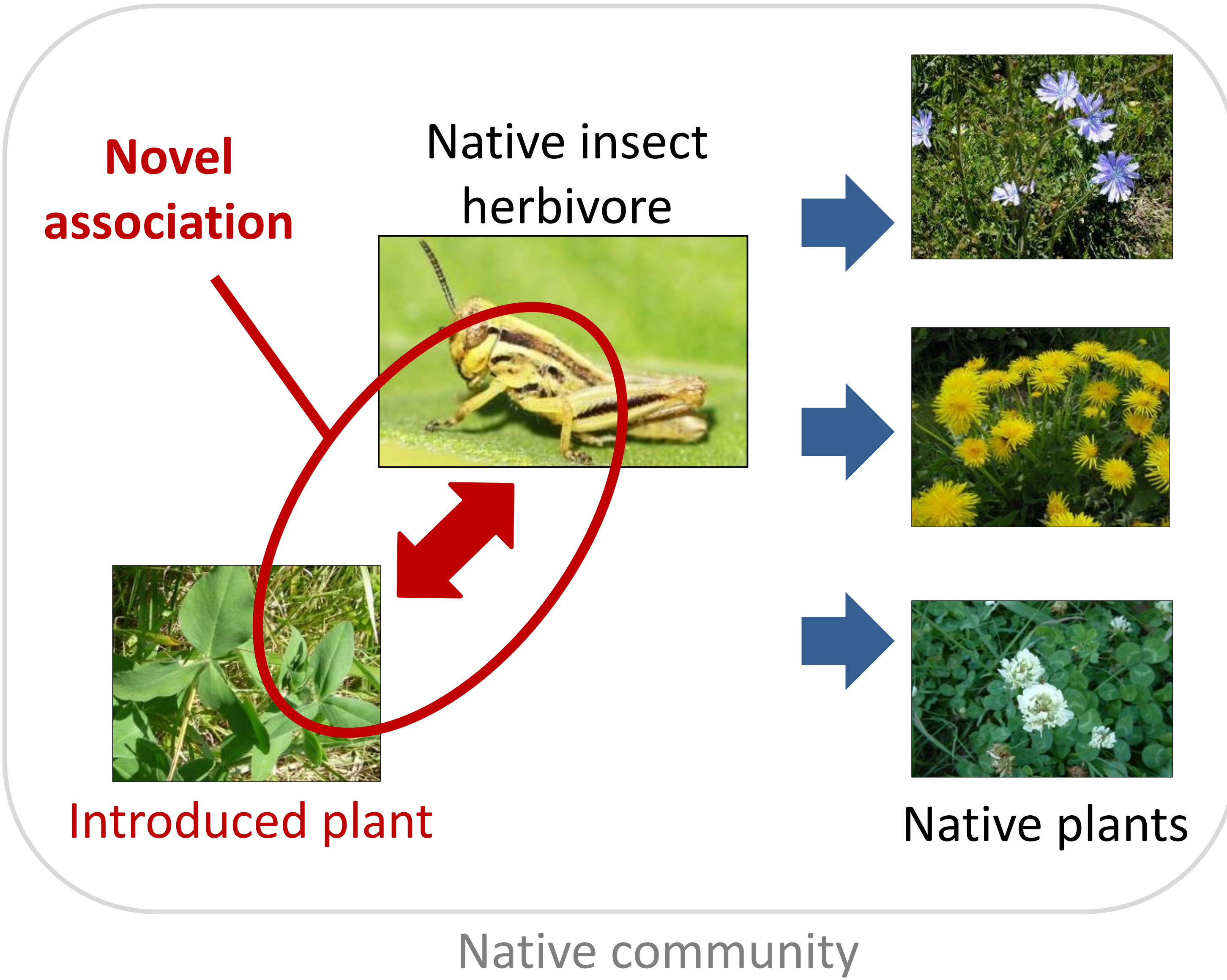
Novel Plant-Insect Associations: Implications of the Lack of Coevolution

Department of Entomology, University of Maryland
November 30, 2018

Novel Plant-Insect Associations



Novel Plant-Insect Associations

- a combination of resident (native) and non-resident (exotic) plant or insect species "in which at least one species has little or no experience with relevant ecological traits of its interaction counterpart" (Saul and Jeschke, 2015).

Introduced plant's native range

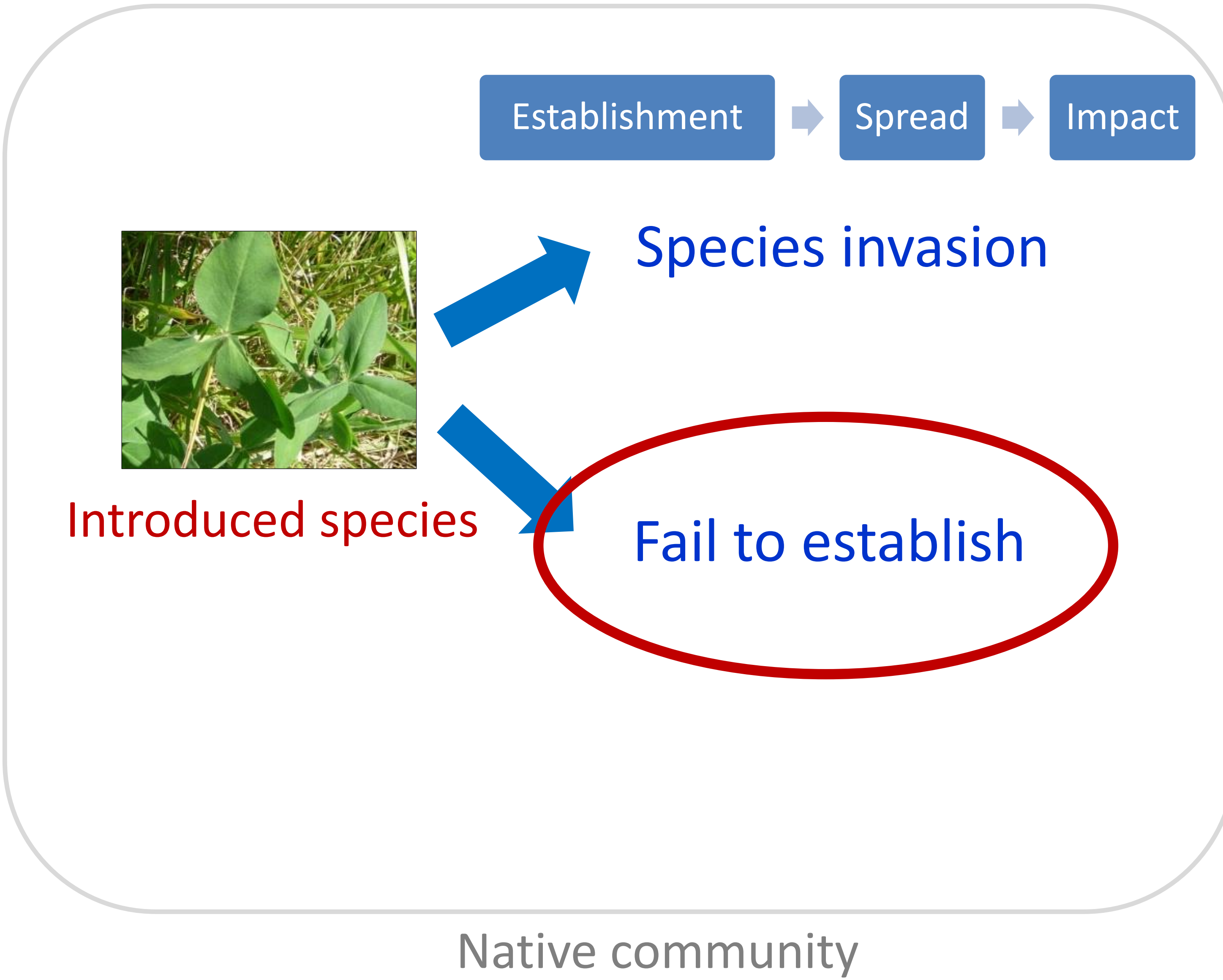
Lack of coevolution

Introduced plant

Native insect

Native community

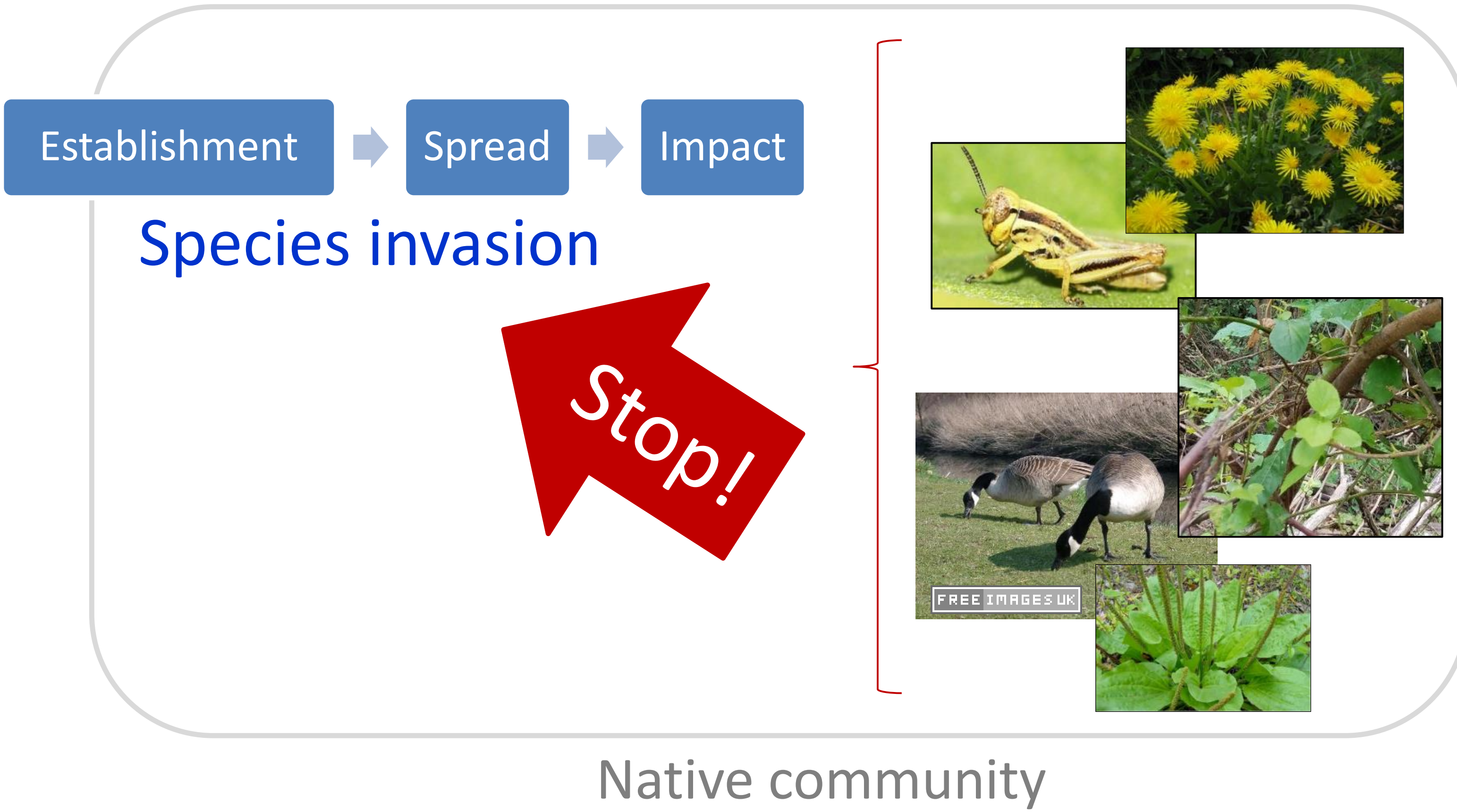
In the introduced range…



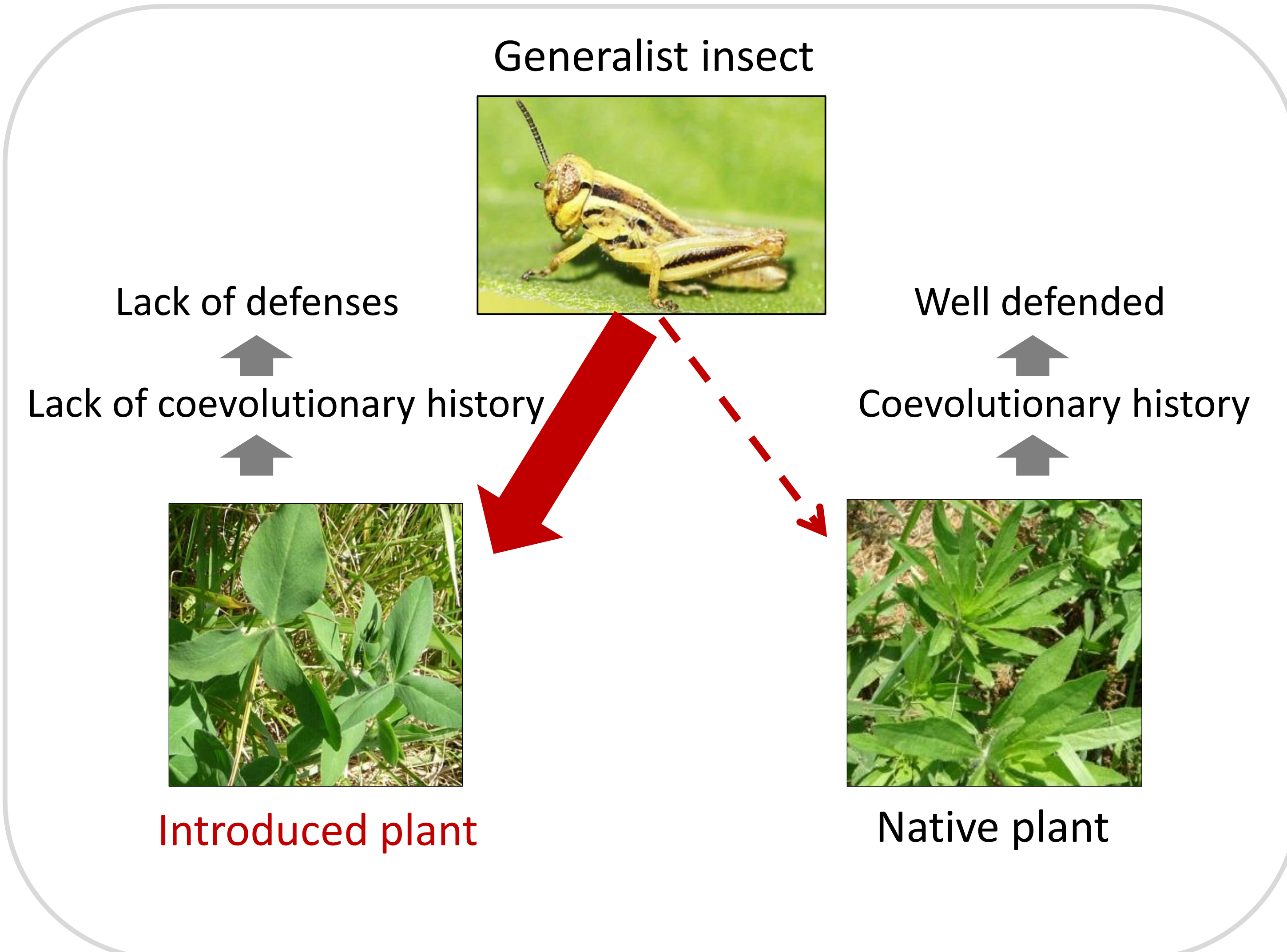
Why do introduced species fail to establish in a new range?

Biotic resistance

- "the ability of resident species in a community to reduce the success of exotic invasions" (Levine et al., 2004) – i.e. competition, parasitism, herbivory, or predation, etc.



Biotic Resistance Hypothesis

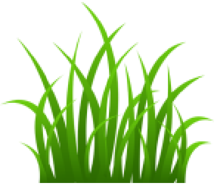


Native community

Why do introduced species fail to establish in a new range?

Novel species interactions

- How do insect herbivores respond to their novel host plants?



- How do plants respond to their novel insect herbivores?

Study system

Melanoplus grasshoppers
(Orthoptera: Acrididae)

Grasses (Poaceae)

Native

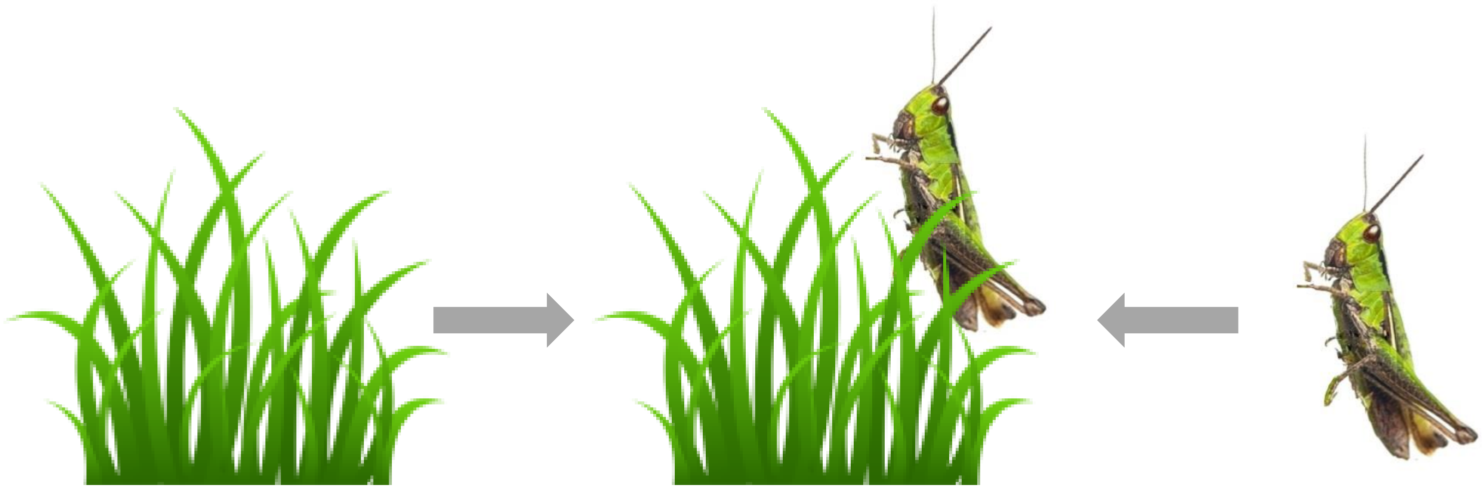
Native and Exotic

Outline

- **Ph.D. research:** *Melanoplus* grasshoppers on native vs. exotic grasses

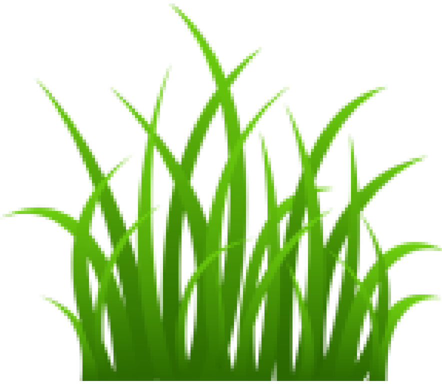
- **Review:** Acridid grasshoppers and their novel host plants
- **Current research:** *Melanoplus* grasshoppers and *Miscanthus sinensis* cultivars

Native versus Exotic Grasses: The Interaction between Generalist Insect Herbivores and Their Host Plants



Plant perspective

Insect perspective



- Do native and exotic grasses differ in their <u>resistance</u> to herbivory by *Melanoplus* grasshoppers?

- Do native and exotic grasses differ in their <u>tolerance</u> to herbivory by *Melanoplus* grasshoppers?

Do *Melanoplus* grasshoppers have feeding preferences for native and exotic grasses?

→ behavioral approach (feeding activity, consumption, assimilation)

→ molecular approach (DNA barcoding of ingested plant material)

Experimental Design

Plant responses, grasshopper feeding

Intact plants

Field

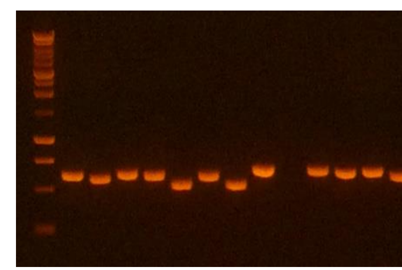
Greenhouse

Leaf segments

Molecular confirmation of diet

Protocol

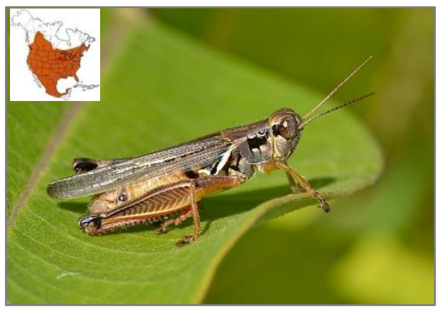
Ingested plants



Study Organisms

Melanoplus differentialis
Differential Grasshopper

Melanoplus femurrubrum
Red-legged grasshopper



Melanoplus spp.
*(*Orthoptera: Acrididae)
Grasshopper nymph

Andropogon gerardii
Big Bluestem

Bouteloua curtipendula
Side oats Grama

Native grasses

Miscanthus sinensis
Chinese Silver Grass

Bothriochloa ischaemum
Yellow Bluestem

Exotic grasses

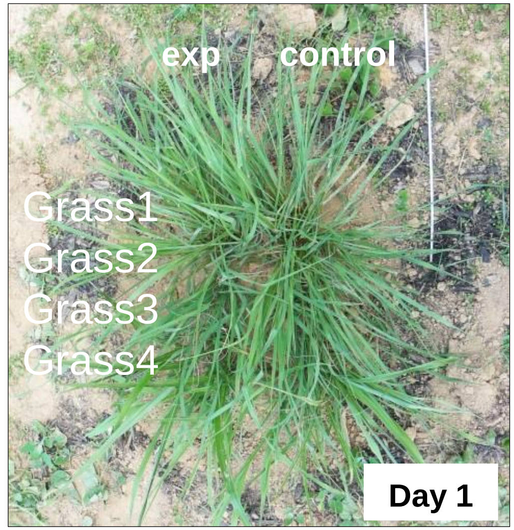
Study Sites

University of Cincinnati
Center for Field Studies
(UCCFS)

Western Maryland
Research and Education Center
(WMREC)

University of Cincinnati Greenhouse

Feeding Trials: Field

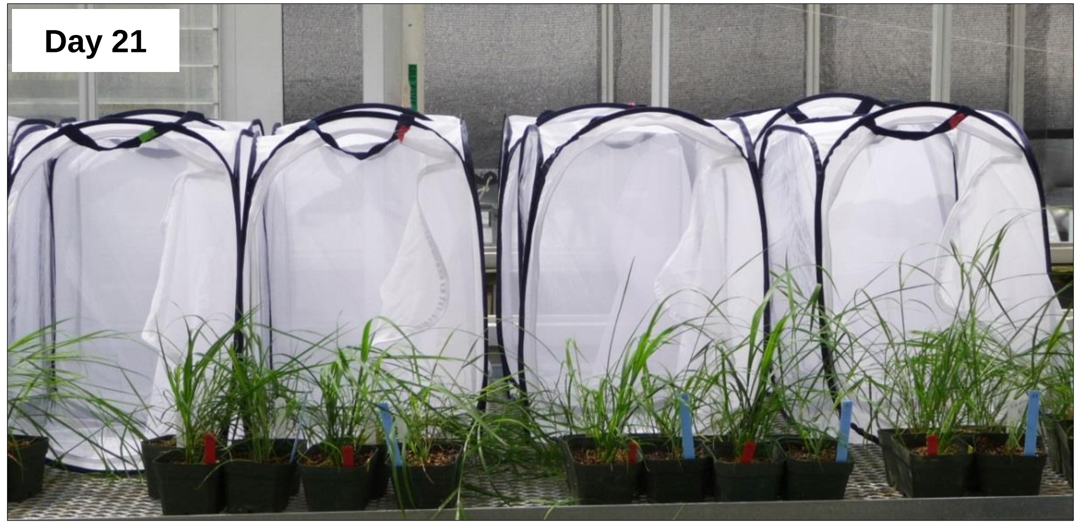


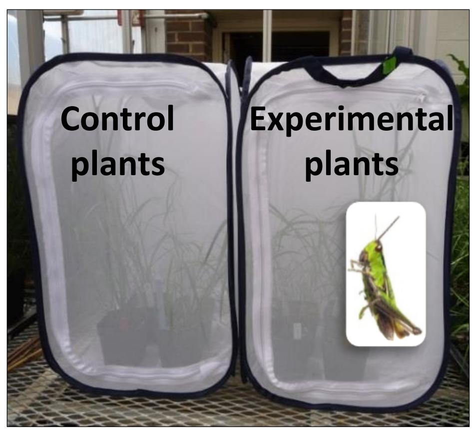
Plant growth / Grasshopper feeding

Plant regrowth

Avanesyan and Culley (2017), *J. Torrey Soc.*

Feeding Trials: UC Greenhouse





Plant Resistance

- **The ability of a plant to decrease herbivore damage**

  Price et al., 2011

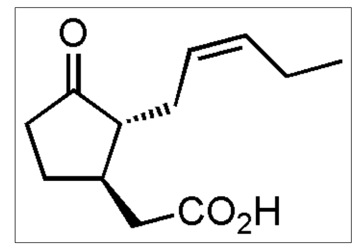
- "A resistance trait is any plant character that influences the amount of damage a plant suffers"

  Rausher, 1992

Wax

Spines

Trichomes



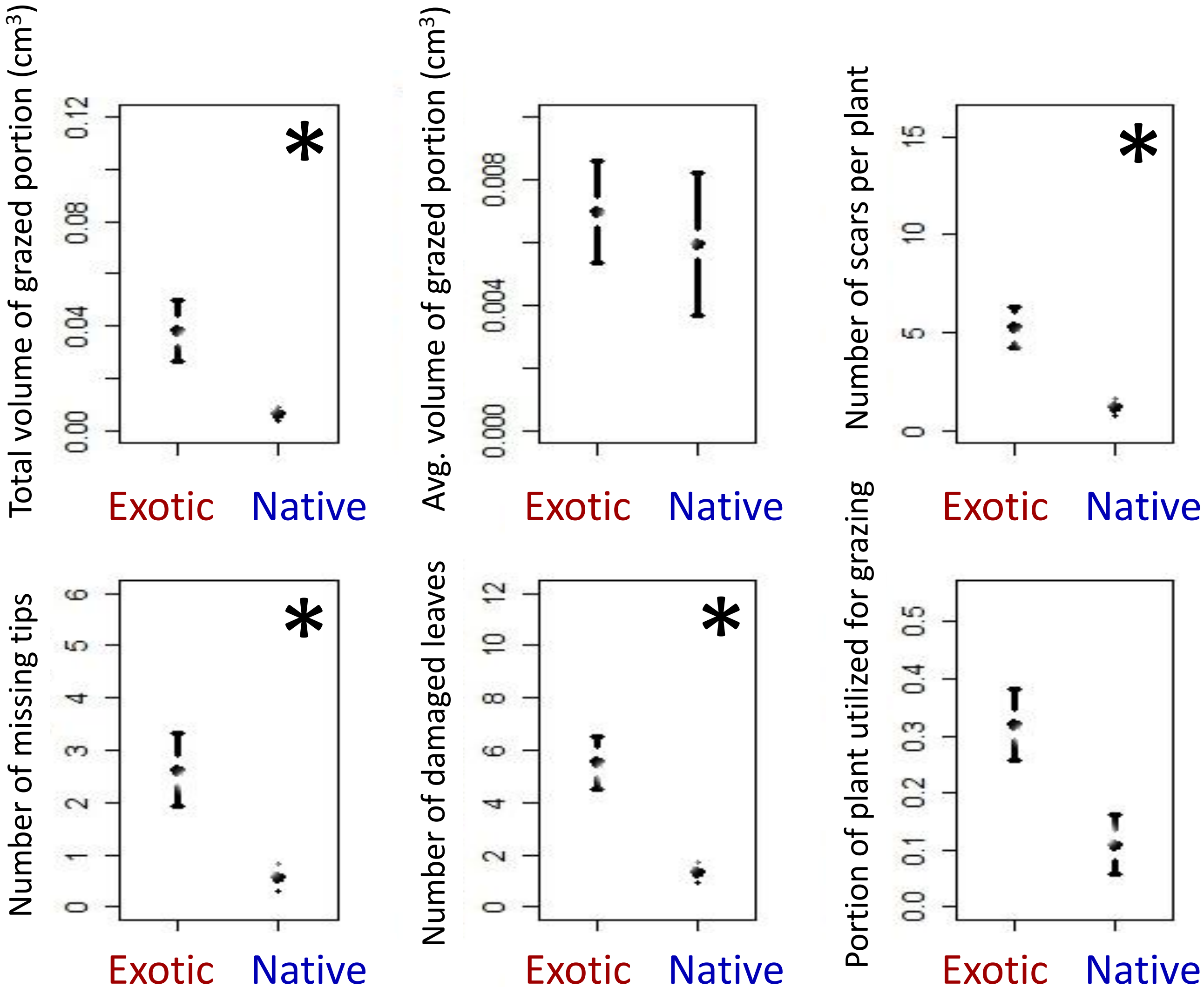
Jasmonic acid

- **Leaf damage** is one of the commonly used measurements for plant resistance

- Plants with more damage from herbivores are generally considered to have a lower level of resistance to herbivory

  Mauricio 2000, Zou et al. 2008

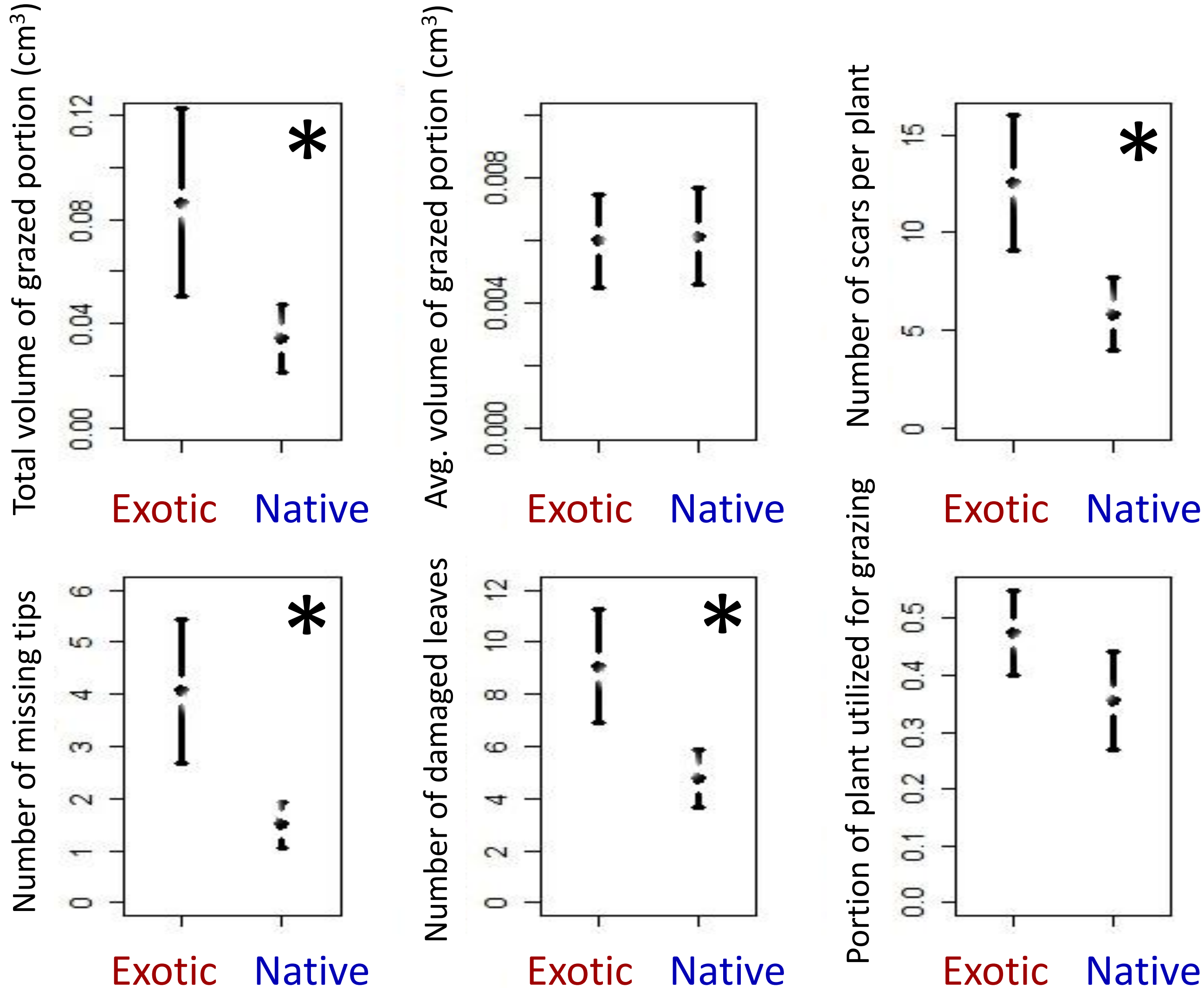
Results: Field



- Most measures of leaf damage were greater in exotic grasses at both field sites (MD and OH); mean ± CI ; * $p_{adj} < 0.001$

Avanesyan and Culley (2015), *Plant Ecology*

Results: Greenhouse



- Most measures of leaf damage were greater in exotic grasses; mean ± CI ; * $p_{adj} < 0.001$

Avanesyan and Culley (2015), *Plant Ecology*

Plant Tolerance

- **The ability of a plant to maintain fitness while sustaining herbivore damage**
  Price et al., 2011

- Physiological components of plant tolerance:
  growth rate, storage capacity, photosynthetic rates, nutrient uptake etc.
  Rosenthal & Kotanen 1994

- **Plant compensatory growth in terms of aboveground plant biomass** is one of the fundamental and commonly used measurements for plant tolerance to herbivory, especially in grasslands
  Rosenthal & Kotanen 1994; Atwood & Meyerson 2011;
  Leis & Morrison 2011

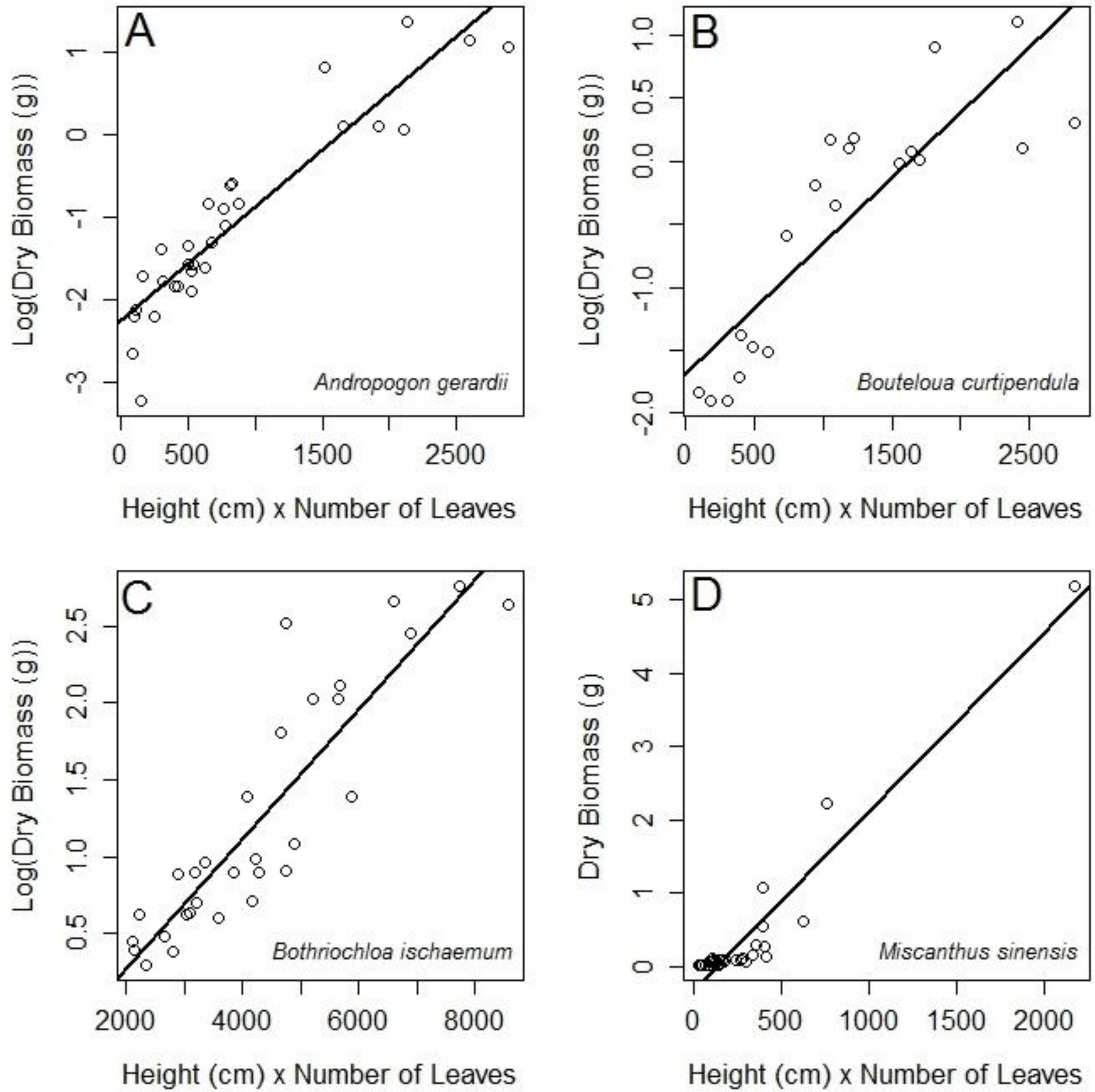
- Estimating biomass should be **non-destructive**, accurate, and easy to implement
  Redjadj et al. 2012

R^2=0.84

R^2=0.72

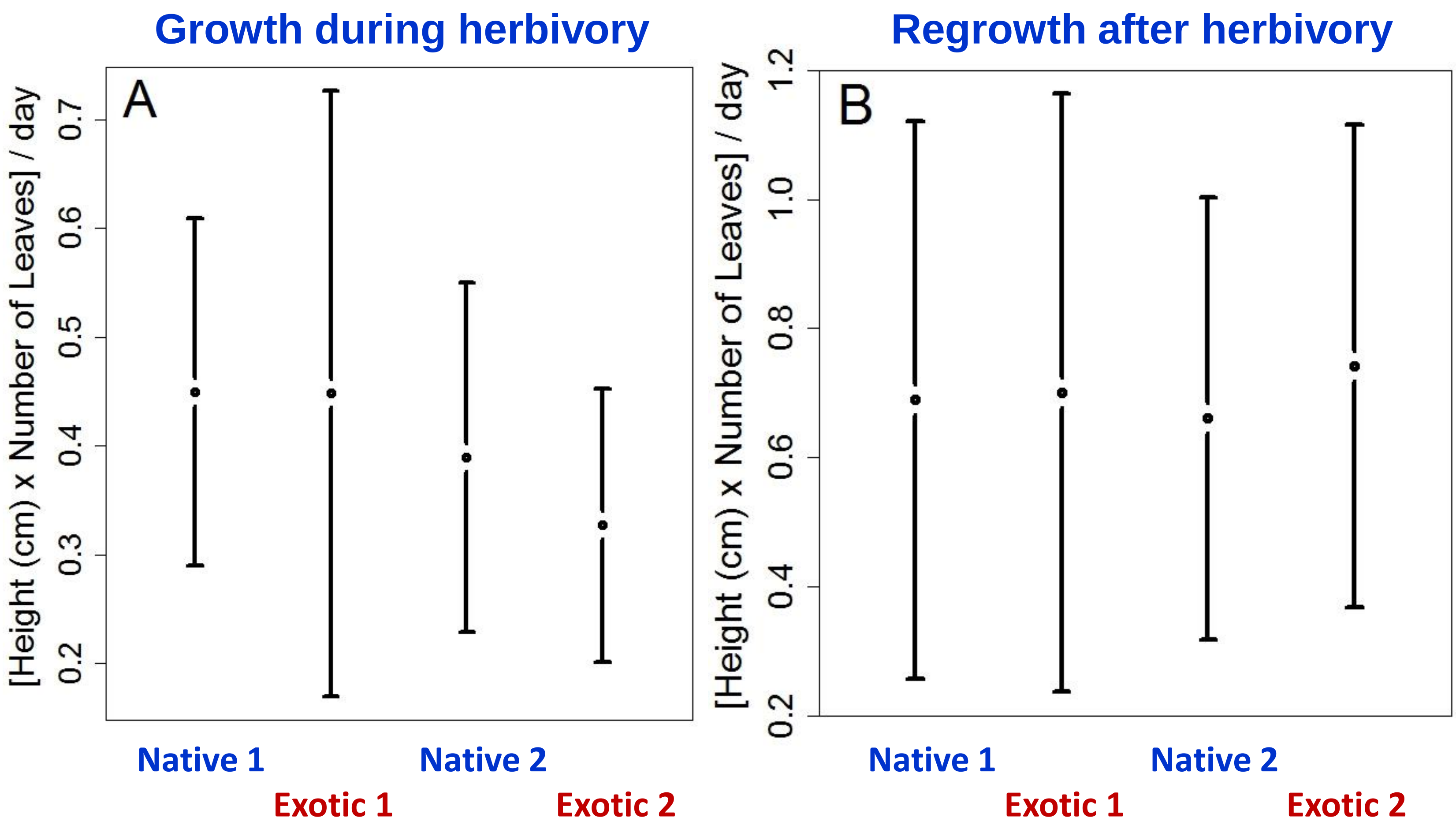
R^2=0.80

R^2=0.92

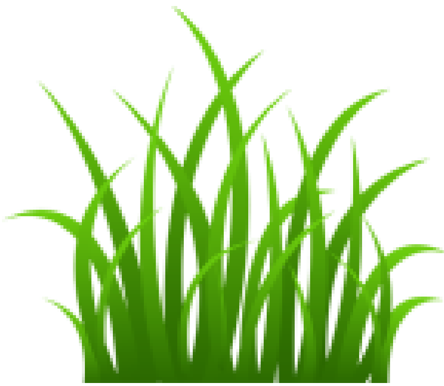


Avanesyan and Culley (2017), *J. Torrey Soc.*

Plant Tolerance



Avanesyan and Culley (2017), *J. Torrey Soc.*



Do native and exotic grasses differ in their resistance to herbivory by *Melanoplus* grasshoppers?

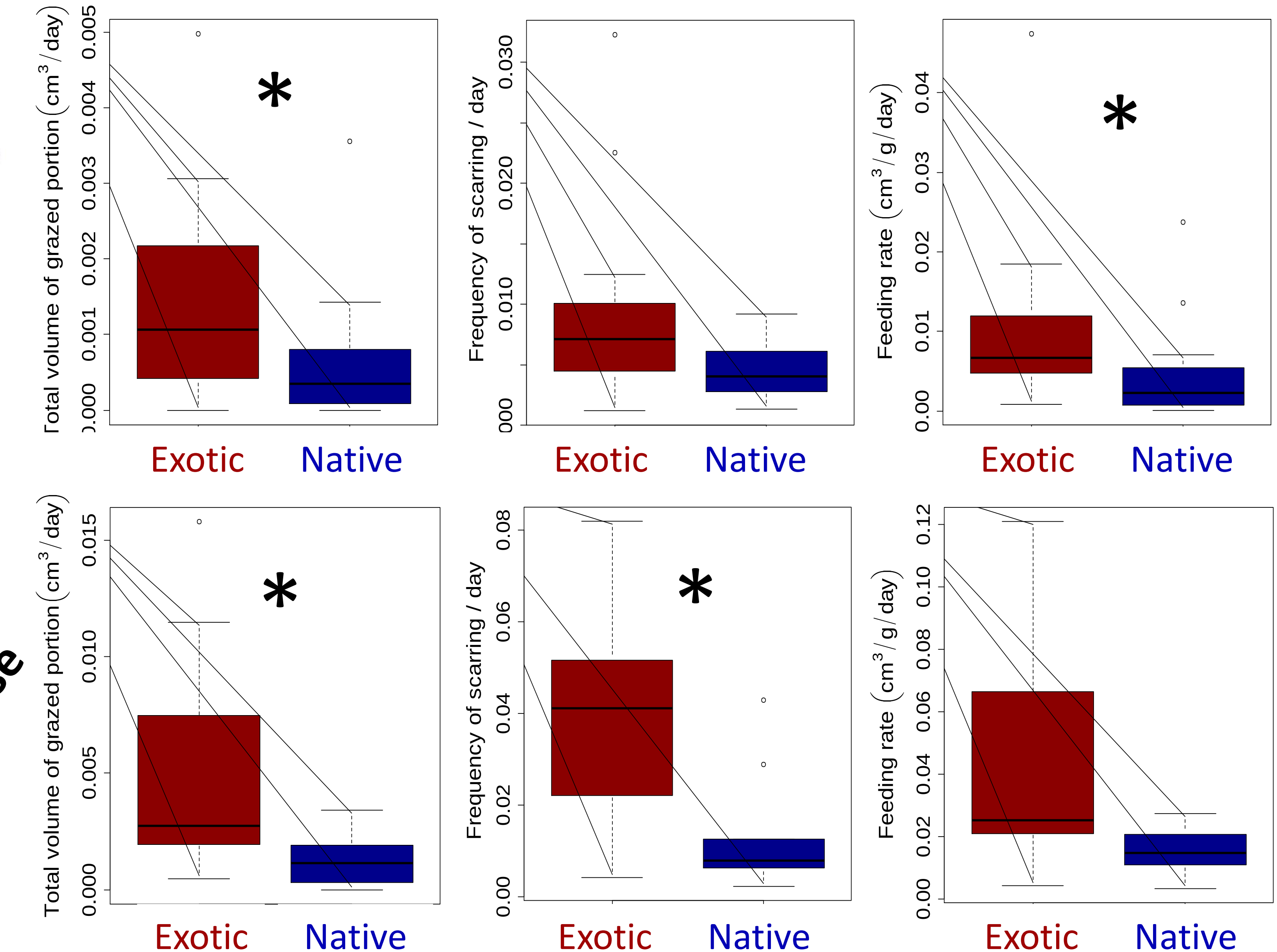
Exotic < Native

Do native and exotic grasses differ in their tolerance to herbivory by *Melanoplus* grasshoppers?

Exotic = Native

Do *Melanoplus* grasshoppers have feeding preferences for native and exotic grasses?

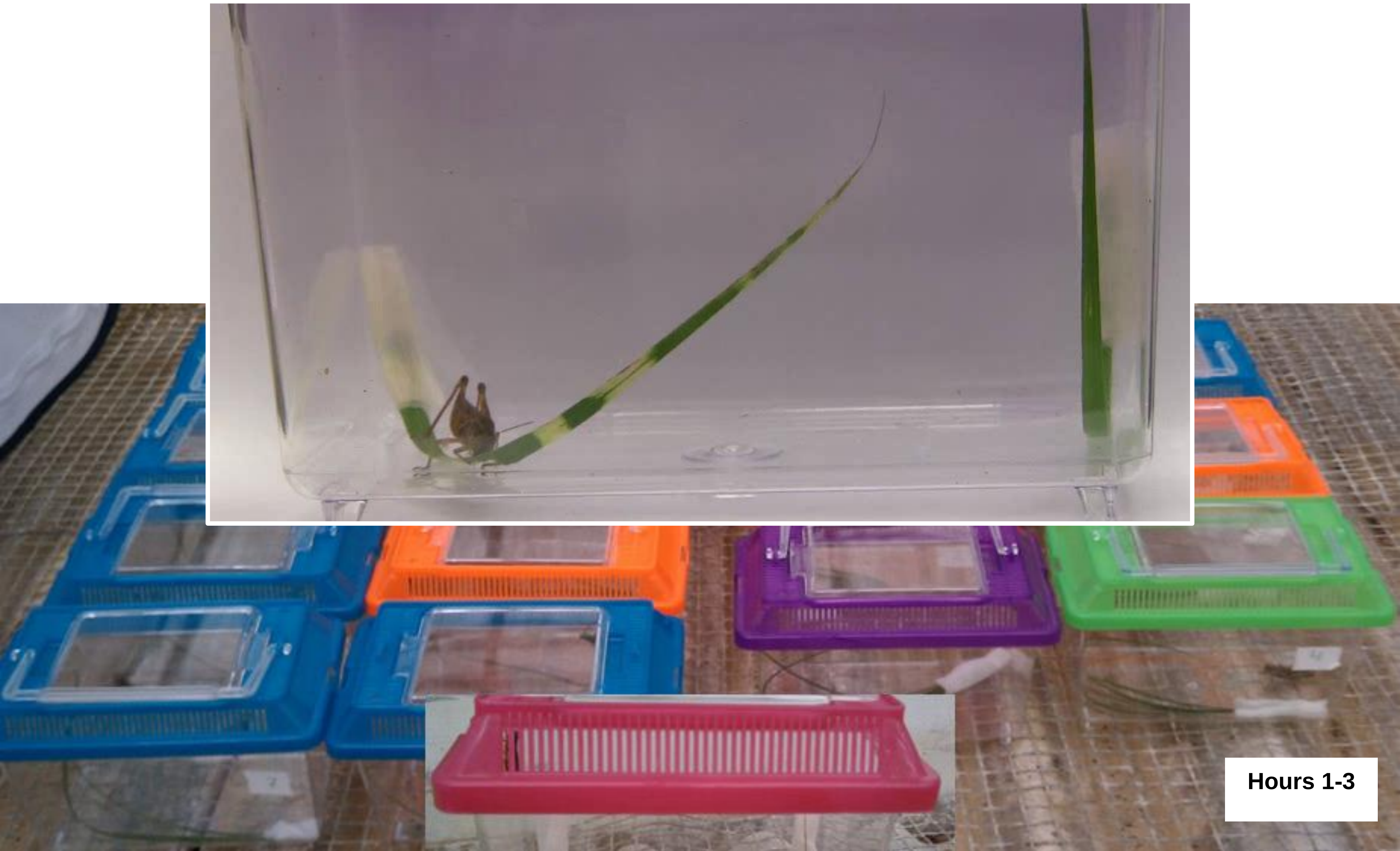
→ behavioral approach



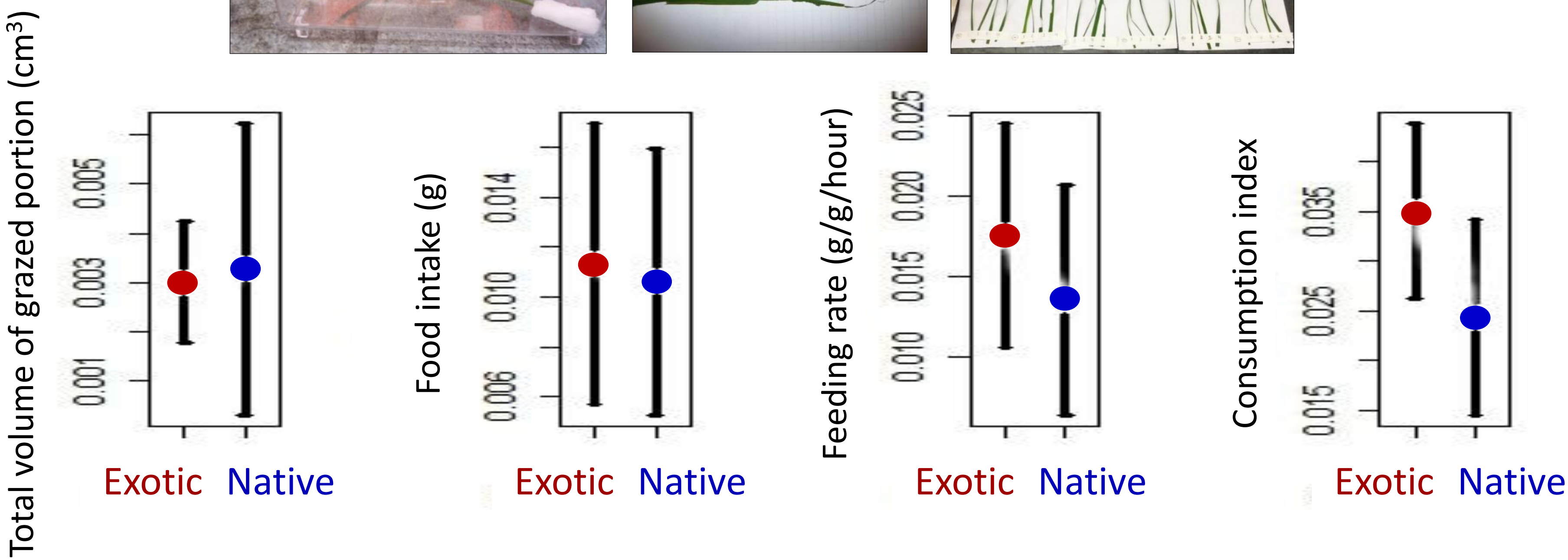
- Grasshopper food consumption and feeding activity were greater on exotic grasses;
  * p < 0.05

Avanesyan and Culley (2015), *Entom. Exp. Appl.*

Lab Assays (Leaves)



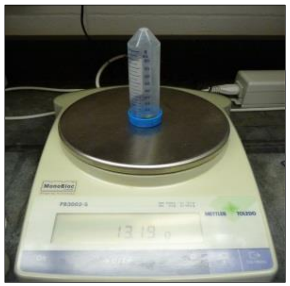
Lab Assays: Food Consumption

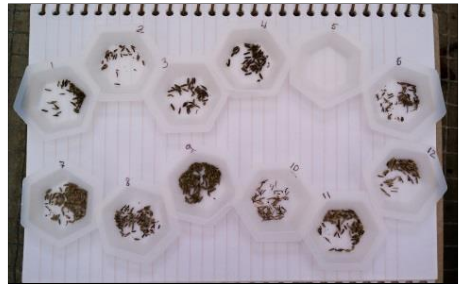


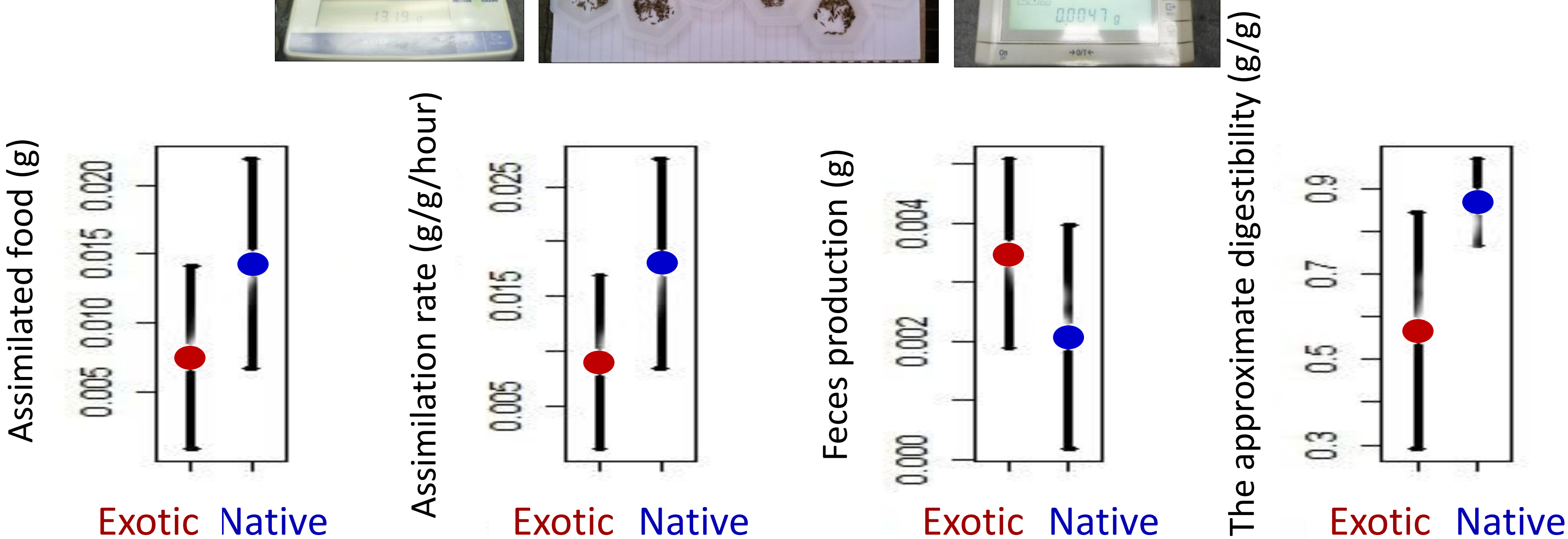
- Grasshopper food consumption did not differ on the leaves clipped from native and exotic grasses ($p > 0.05$)

Avanesyan and Culley (2015), *Entom. Exp. Appl.*

Lab Assays: Food Assimilation







- Grasshopper food assimilation did not differ on the leaves clipped from native and exotic grasses ($p > 0.05$)

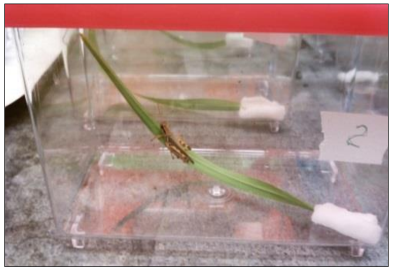
Avanesyan and Culley (2015), *Entom. Exp. Appl.*

Do *Melanoplus* grasshoppers have feeding preferences for native and exotic grasses?

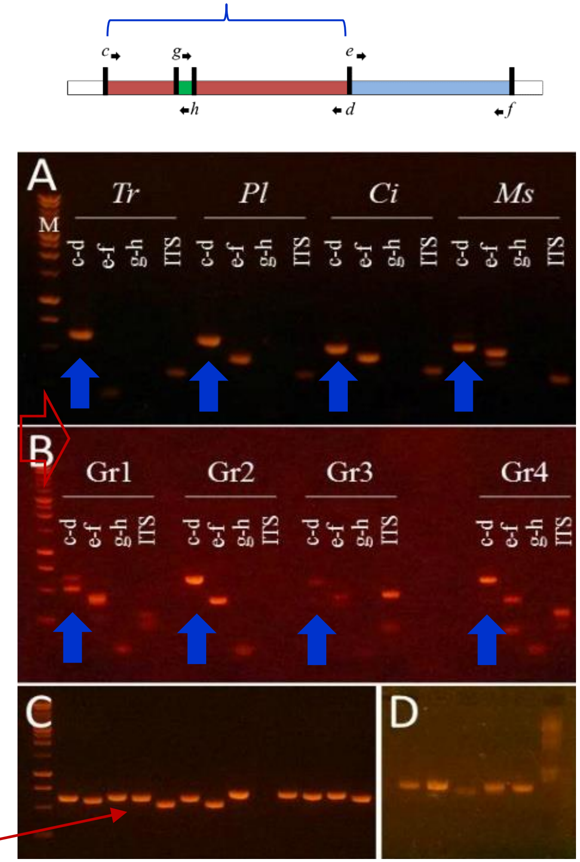
behavioral approach (feeding activity, consumption, assimilation)

Exotic ≥ Native

Molecular Confirmation of Diet



Chloroplast *trn*L (UAA) intron
~ 550 bp



Avanesyan 2014, *Application in Plant Sciences*

Testing the Protocol

Grasshoppers of different sizes

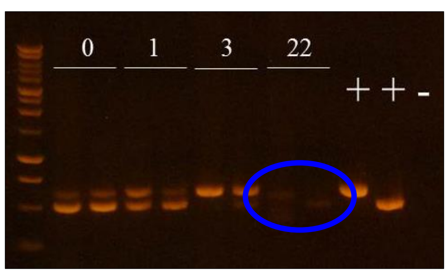
Melanoplus spp. nymph

12 h PI: choice, two plants

M. femurrubrum

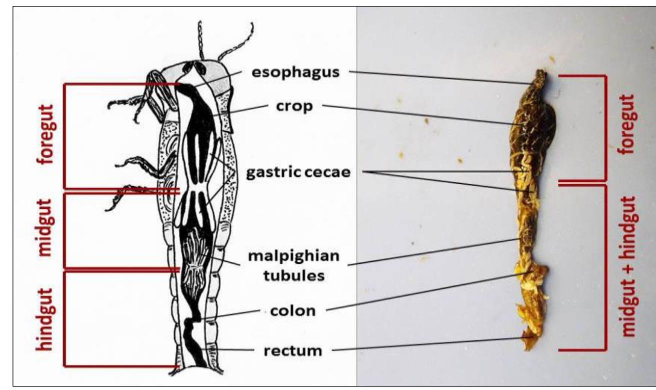
12 h PI: no choice, single plant

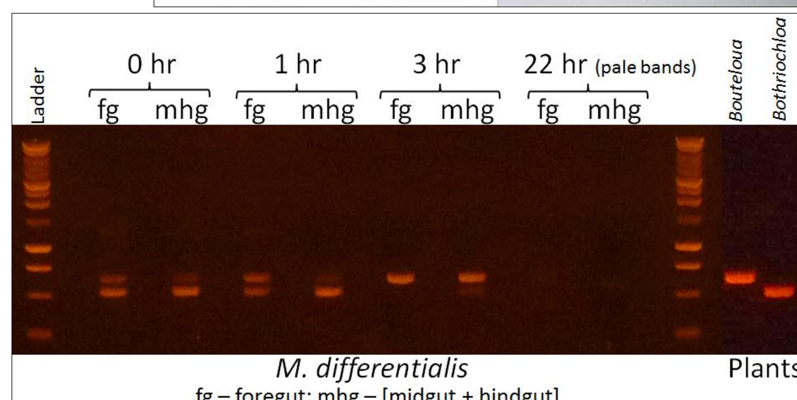
M. differentialis



22 h PI: choice, two plants

Different parts of grasshopper digestive system





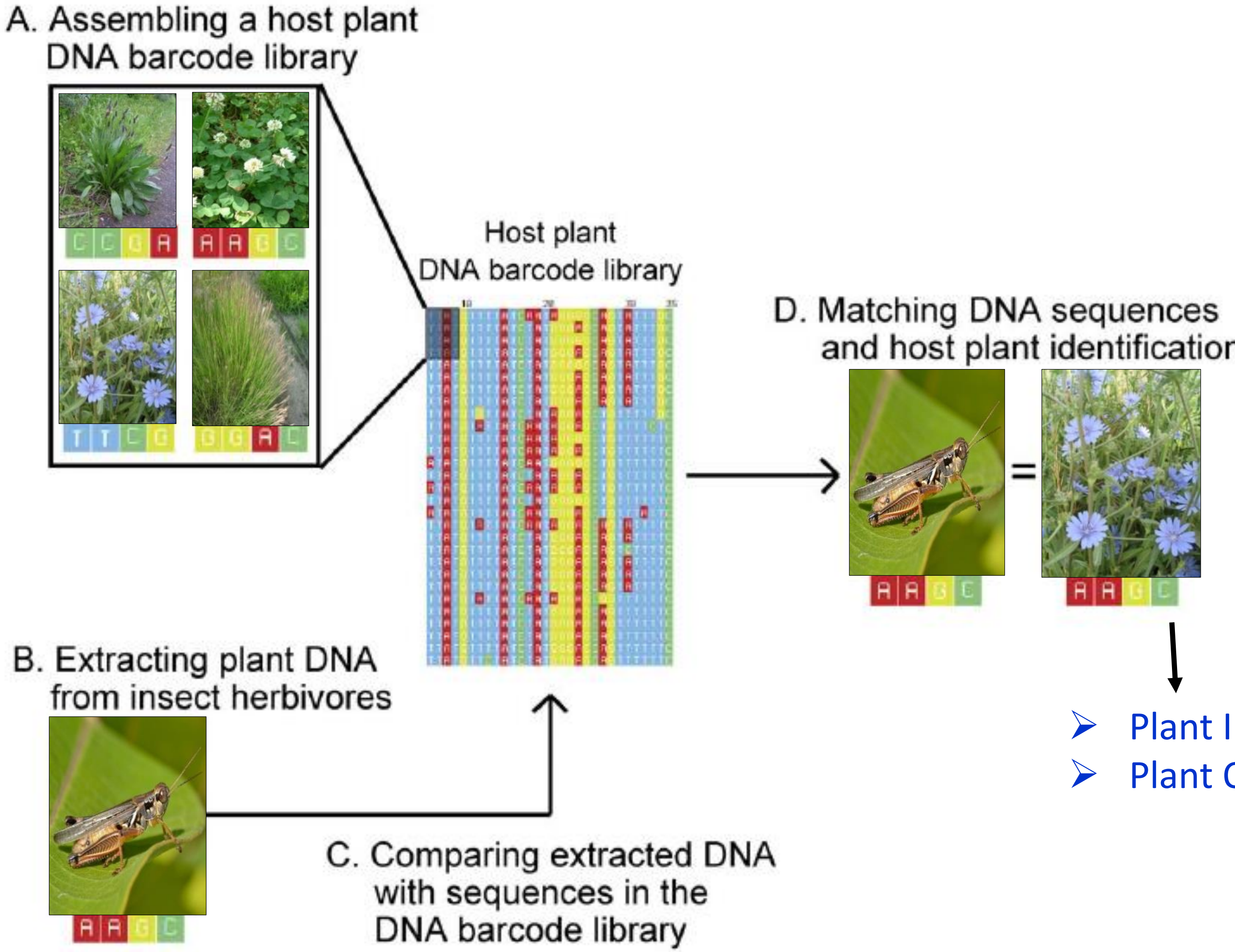
Avanesyan 2014, *Application in Plant Sciences*

Applying the Protocol

Cincinnati Center
for Field Studies (OH)

Western Maryland
Research and Education Center (MD)

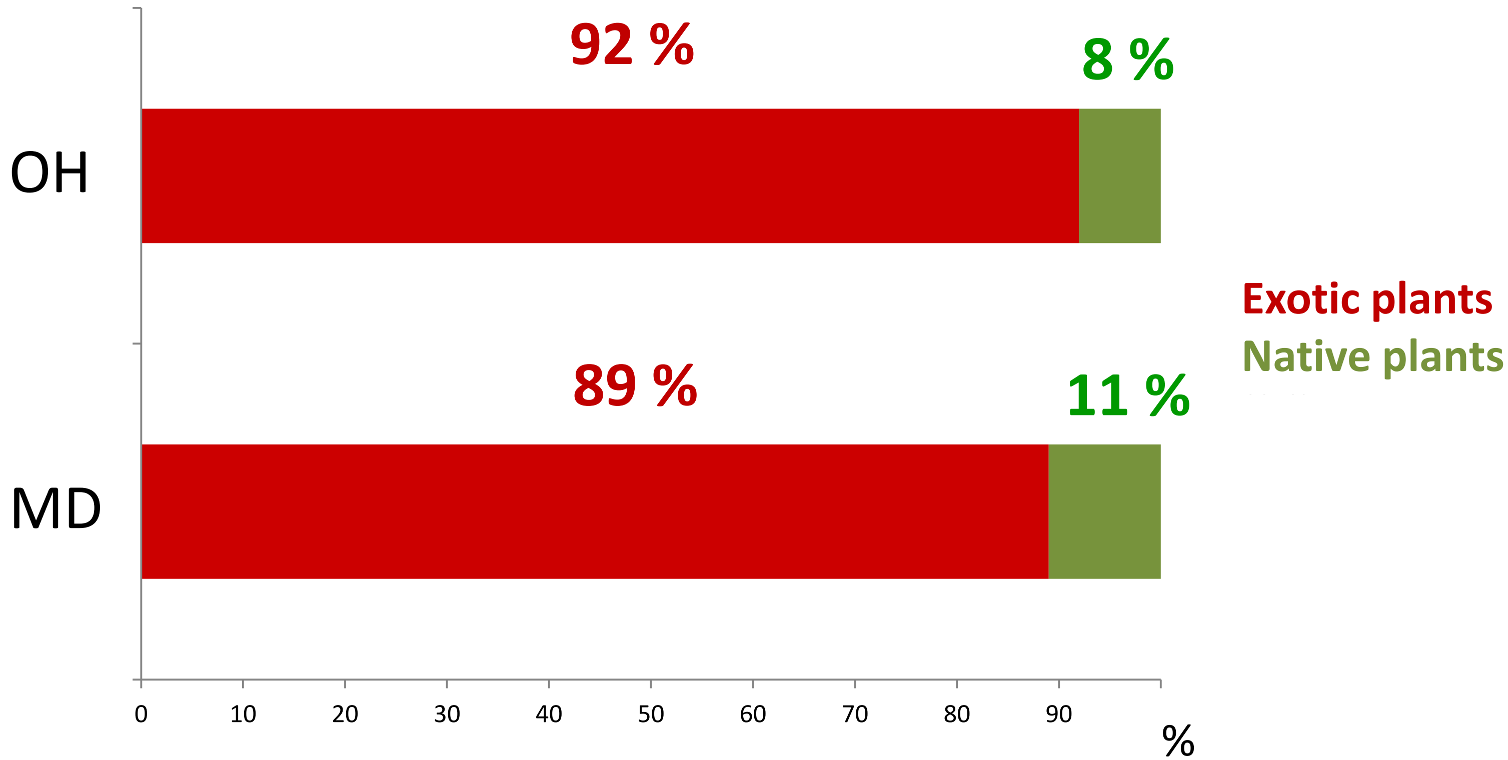
Host Plant Identification



- Plant ID
- Plant Origin

Modified from García-Robledo et al. (2013)

Proportions of Ingested Plants



- Grasshopper gut contents contained greater numbers of exotic plant species at both field sites ($p < 0.0001$, Binomial test)

Avanesyan and Culley (2015) *Entomologia Experimentalis et Applicata*

Do *Melanoplus* grasshoppers have feeding preferences for native and exotic grasses?

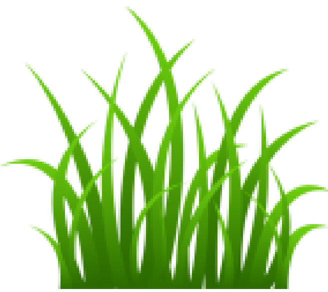
→ behavioral approach (feeding activity, consumption, assimilation)

Exotic ≥ Native

→ molecular approach (DNA barcoding of ingested plant material)

Exotic > Native

Main Conclusions



Overall, exotic grasses demonstrated lower resistance to grasshopper herbivory than native grasses in most experiments, while they tolerated the herbivory similar to native grasses

Exotic ≤ Native

Grasshoppers did not avoid feeding on exotic grasses and even preferred them to native plants in most experiments.

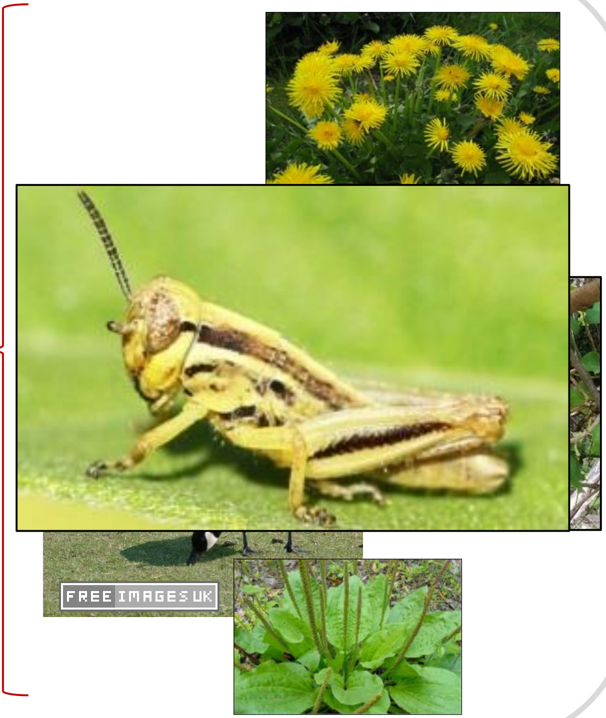
Exotic ≥ Native

Application to Biotic Resistance

Establishment → Spread → Impact

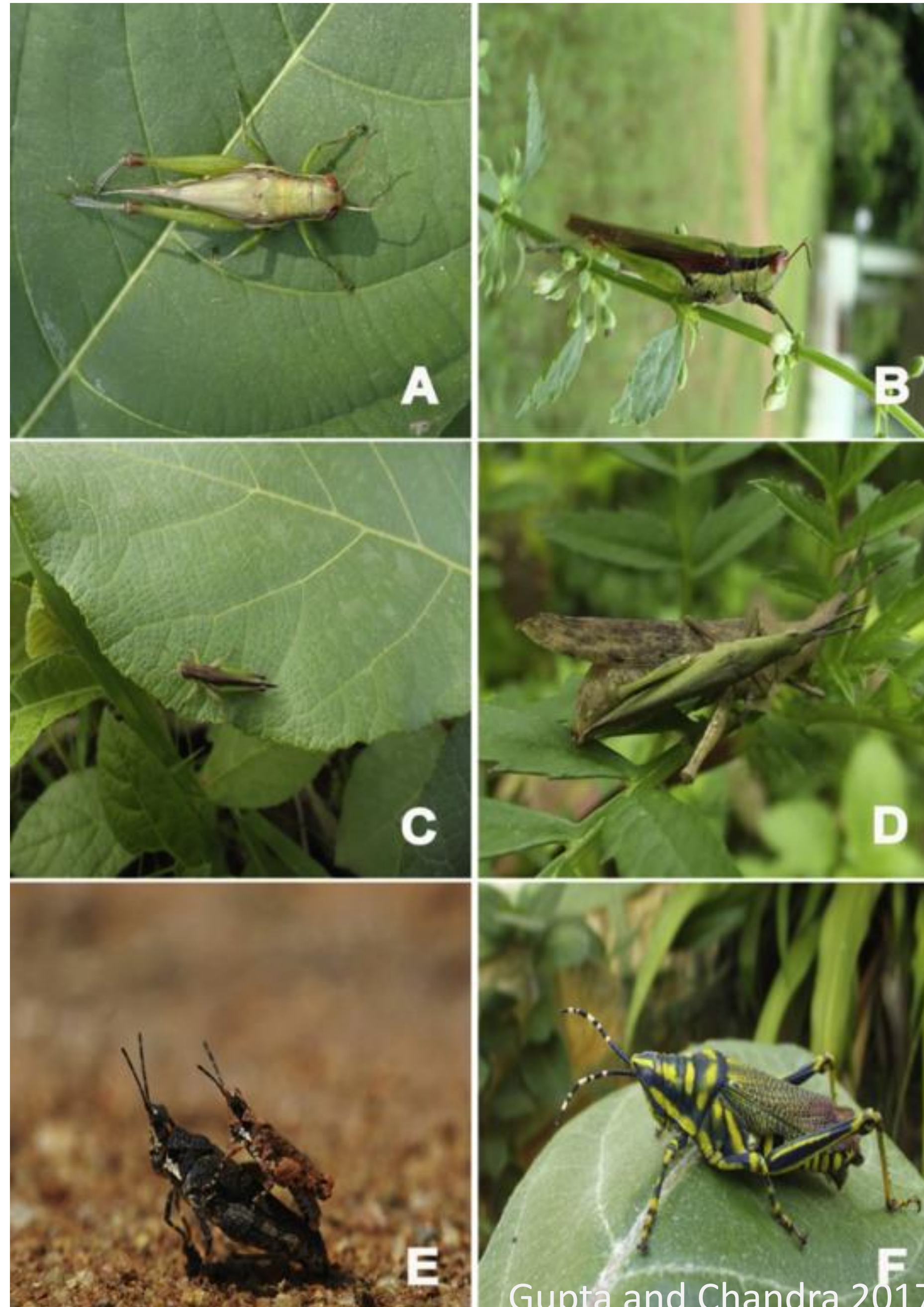
Plant invasion

Stop!



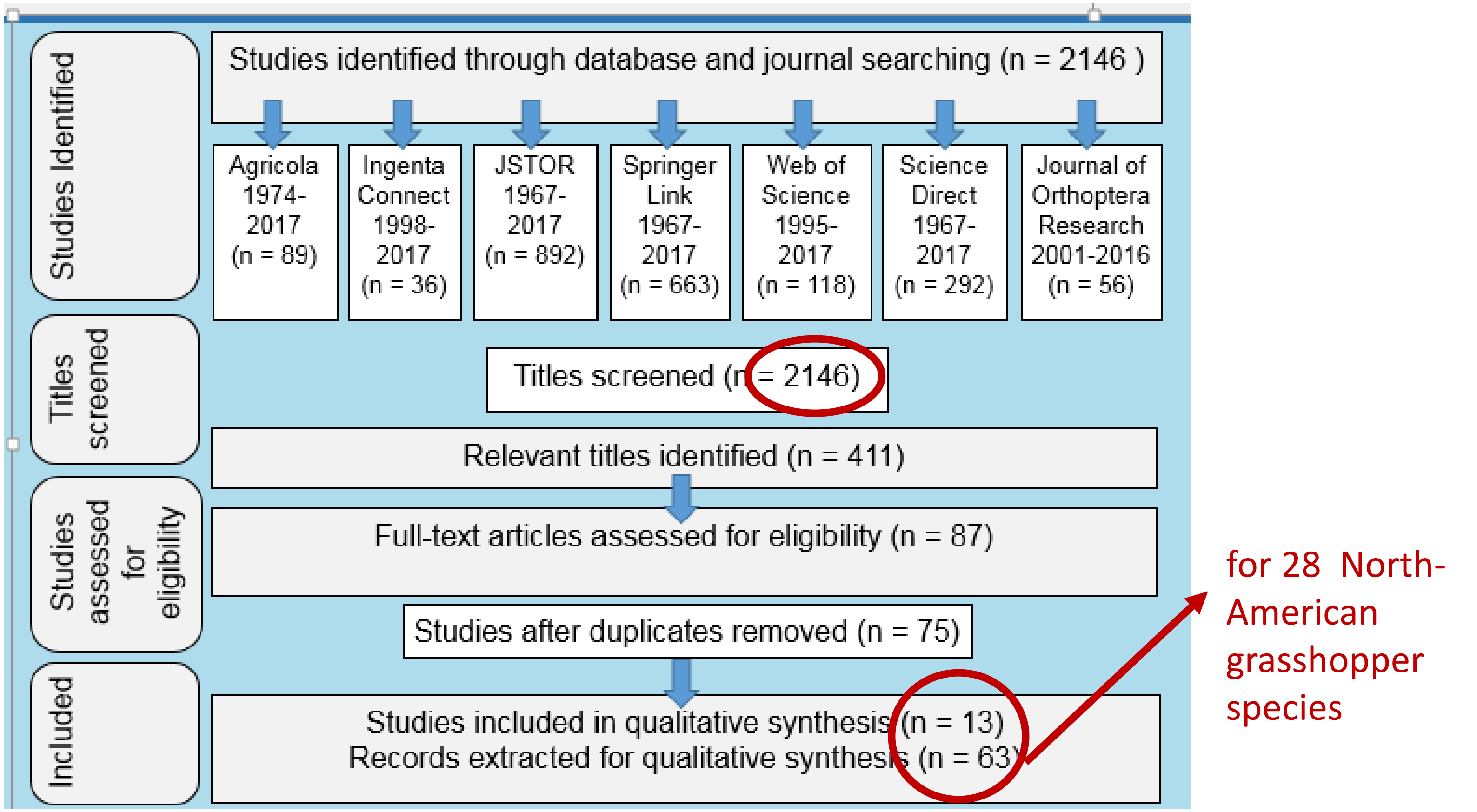
Native community

Do all the grasshoppers prefer to feed on exotic plants?



Gupta and Chandra 2017

Should I Eat or Should I Go? Acridid Grasshoppers and Their Novel Host Plants: Implications for Biotic Resistance



Avanesyan 2018, *Plants*

Systematic Review and Meta-analysis

Plant Ecol (2015) 216:451–464
DOI 10.1007/s11258-015-0449-9

Herbivory of native and exotic North-American prairie grasses by nymph *Melanoplus* grasshoppers

Alina Avanesyan · Theresa M. Culley

Received: 4 July 2014 / Accepted: 12 January 2015 / Published online: 15 January 2015
© Springer Science+Business Media Dordrecht 2015

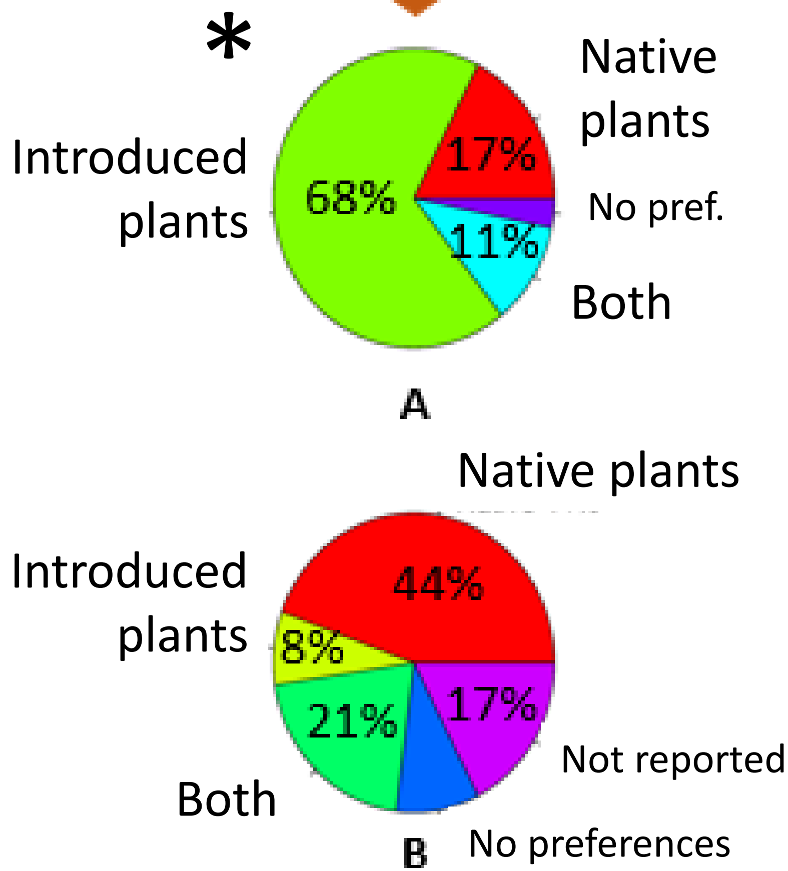
Abstract Although the general interaction between native and exotic plants and specialist insect herbivores has received considerable attention in ecological studies, plant responses to herbivory by generalist insects, as well as feeding preferences of generalist insects, are still poorly understood. Experimental studies comparing leaf damage of native and exotic plants to generalist insects have provided inconsistent results due to irregularities in methodology such as

exotic grasses. Using a combination of
choice feeding experiments with intact
clipped leaves under different (field and
conditions, we found that overall both
grasshopper performance (body length)
on the exotic grasses compared to native
results suggest that exotic grasses which
coevolutionary history with native
plus grasshoppers might have lower

The authors used a very wide range of experimental conditions and measurements to assess grasshopper preferences

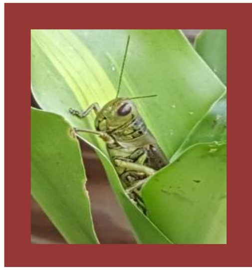
- **4 experimental environments**: common garden, greenhouse, lab (leaves), lab (stems)
- **3 types of feeding trials**: no-choice, choice (2 plants), choice (plant mixture)
- **2 types of plant material**: intact plants, clipped plant parts
- **Different stages**: adults, nymphs, mix
- **35 measurements** of feeding preferences!

Acridid grasshoppers prefer to feed on introduced plants

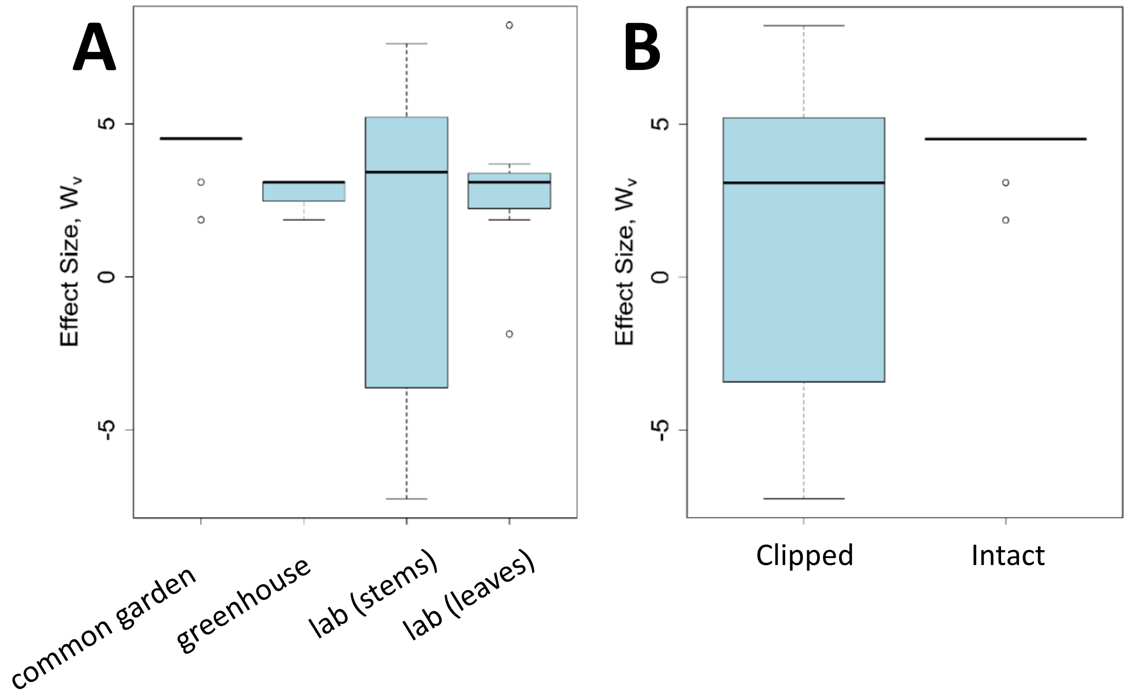


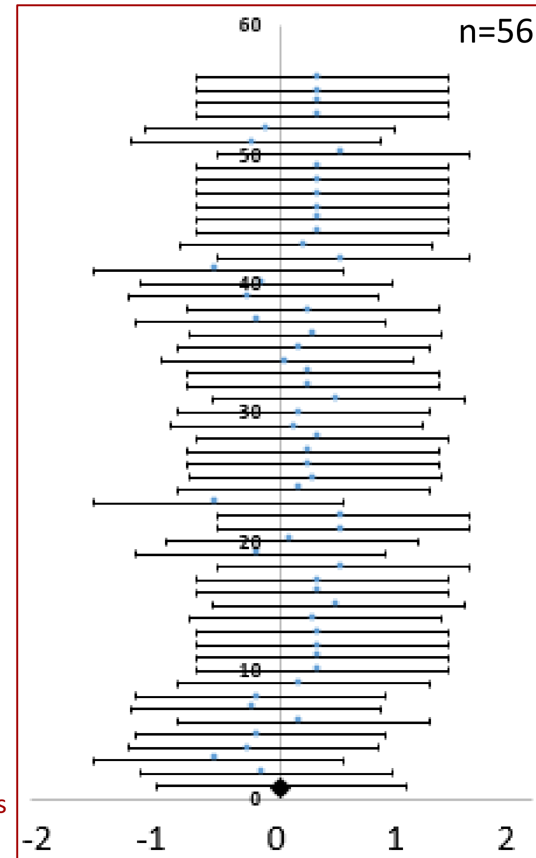
- Most preferred plants
- Least preferred plants

Avanesyan 2018, *Plants*



Acridid grasshoppers prefer to feed on introduced plants regardless the experimental conditions or plant material offered





Preference Metric $= \dfrac{n_{\text{most preferred exotic plant species}} - n_{\text{most preferred native plant species}}}{n_{\text{total plant species offered}}}$

Avanesyan 2018, *Plants*

Most of the preferred plants are highly invasive

- 20 introduced plant species (out of 22) were reported as “the most preferred”
- 12 species showed high or middle invasive rank
- *Bromus inermis* (smooth brome) and *Schedonorus arundinaceus* (tall fescue) are among the most preferred (for 50% grasshopper species)

Avanesyan 2018, *Plants*

Application to Biotic Resistance

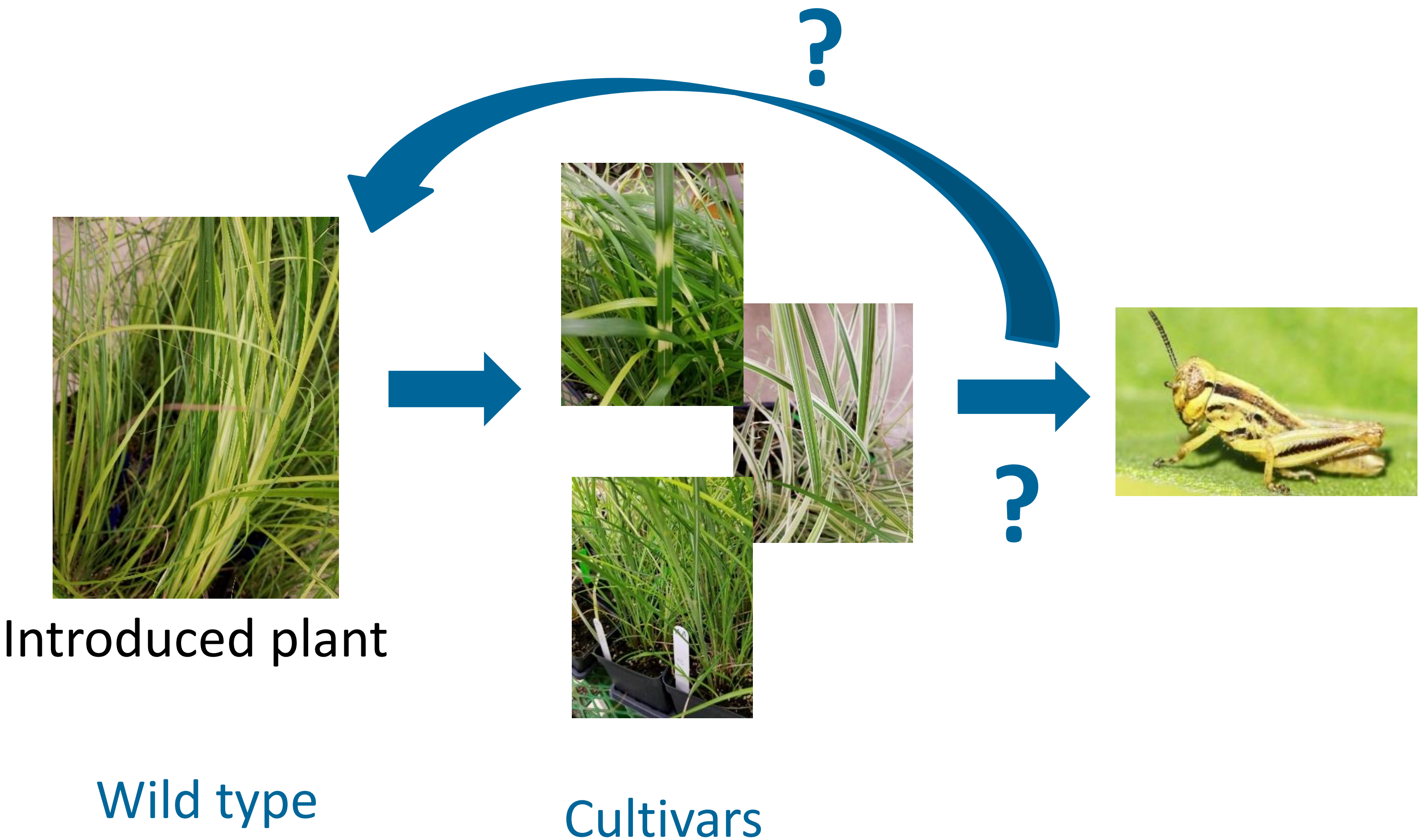
Establishment → Spread → Impact

Plant invasion

Stop!

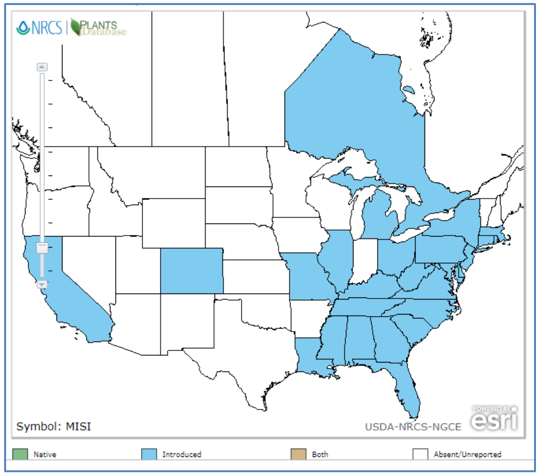
Native community

Grasshoppers and Introduced Plants



Interactions between *Melanoplus* grasshoppers and *Miscanthus sinensis* varieties

Miscanthus sinensis Andersson
Chinese silvergrass



- Native to Japan
- 1893: introduced to Asheville NC; 1894: Washington DC
- 1940: naturalized populations in New York, Washington DC, Florida, West Virginia
- 2018: reported in 27 states
- disturbed areas, open fields, forest understories (in Maryland)

Miscanthus sinensis varieties

- one of the most popular ornamental plants
- > 100 cultivated varieties

- Striped pattern
- Less vigorous, less invasive

- 'all-green' plants
- More aggressive

Miscanthus sinensis varieties

M. sinensis 'Zebrinus' (ZE)

M. sinensis 'Dixieland' (DI)

M. sinensis 'Autumn Anthem' (AA)

M. sinensis 'Gracillimus' (GR)

M. sinensis 'Morning Light' (ML)

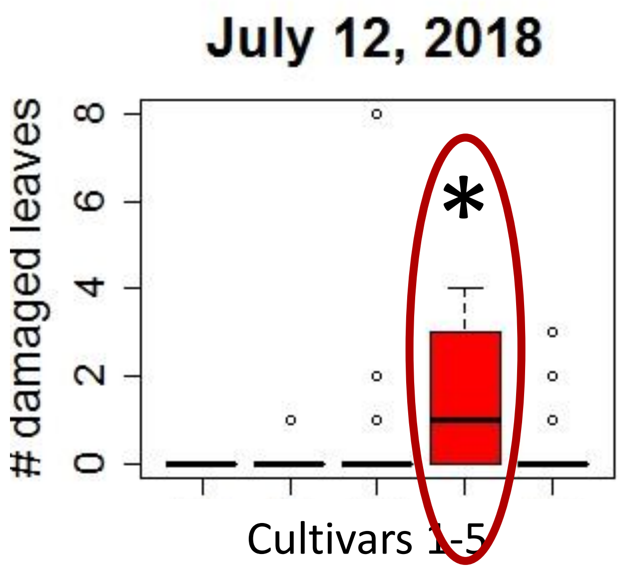
Research Questions

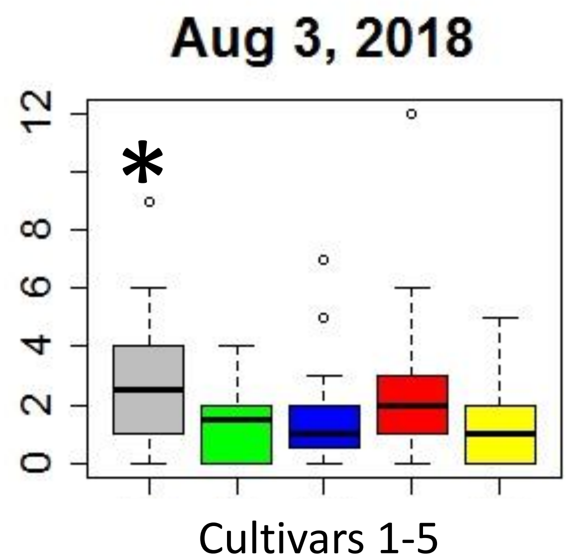
- Do Miscanthus sinensis cultivars differ in their resistance and tolerance to grasshopper herbivory?

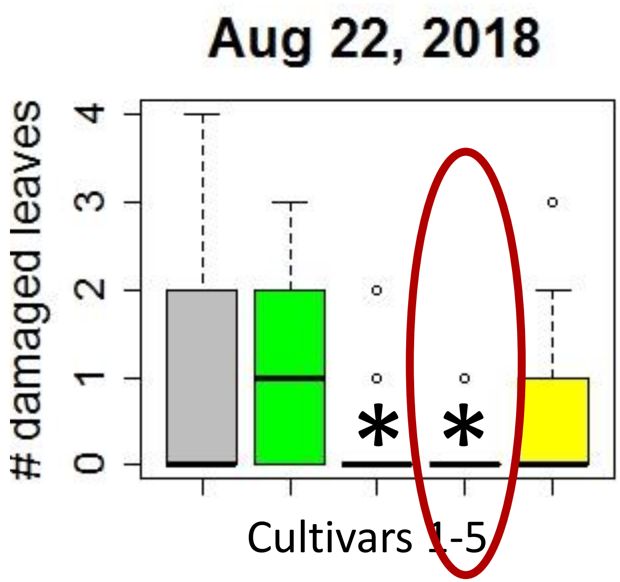
- Do the plant responses to herbivory in *M. sinensis* cultivars differ from the plant responses in *M. sinensis* wild type?

Field Experiments

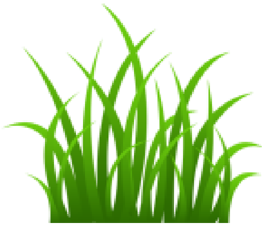
- 5 cultivars
- 30 plants/cultivar
- measured plant growth and leaf damage at 4 time points

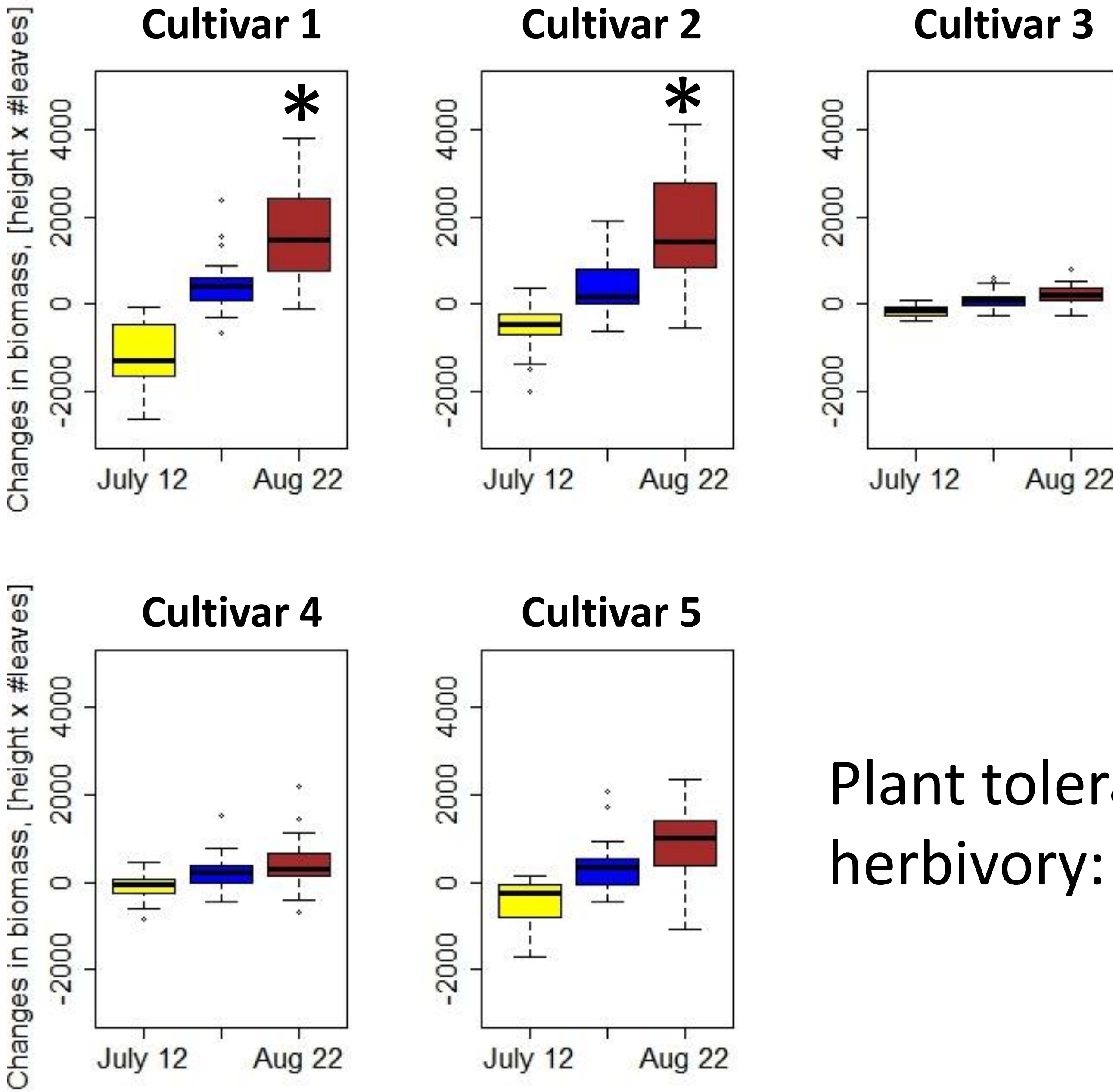






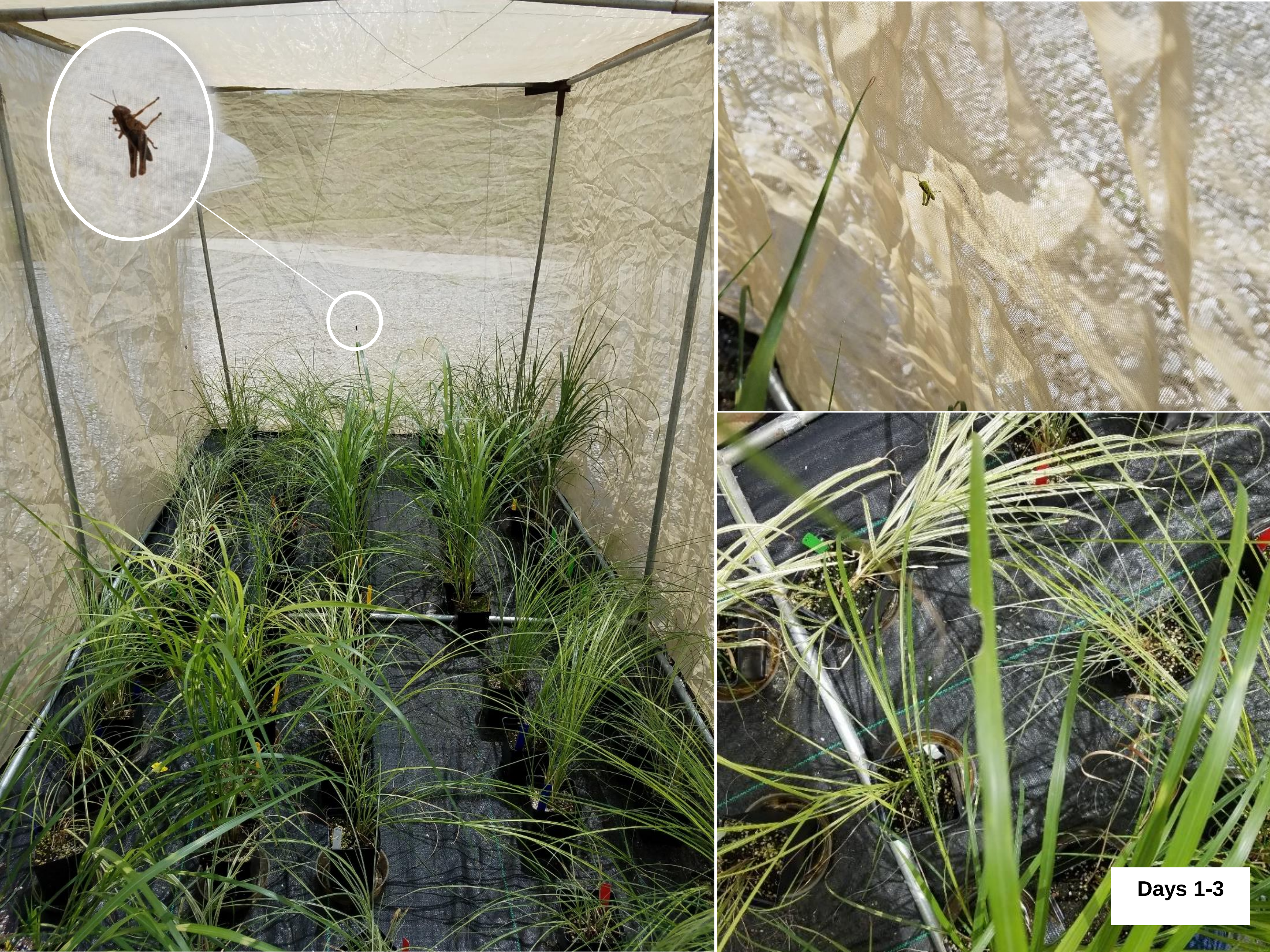
Plant resistance to herbivory: field



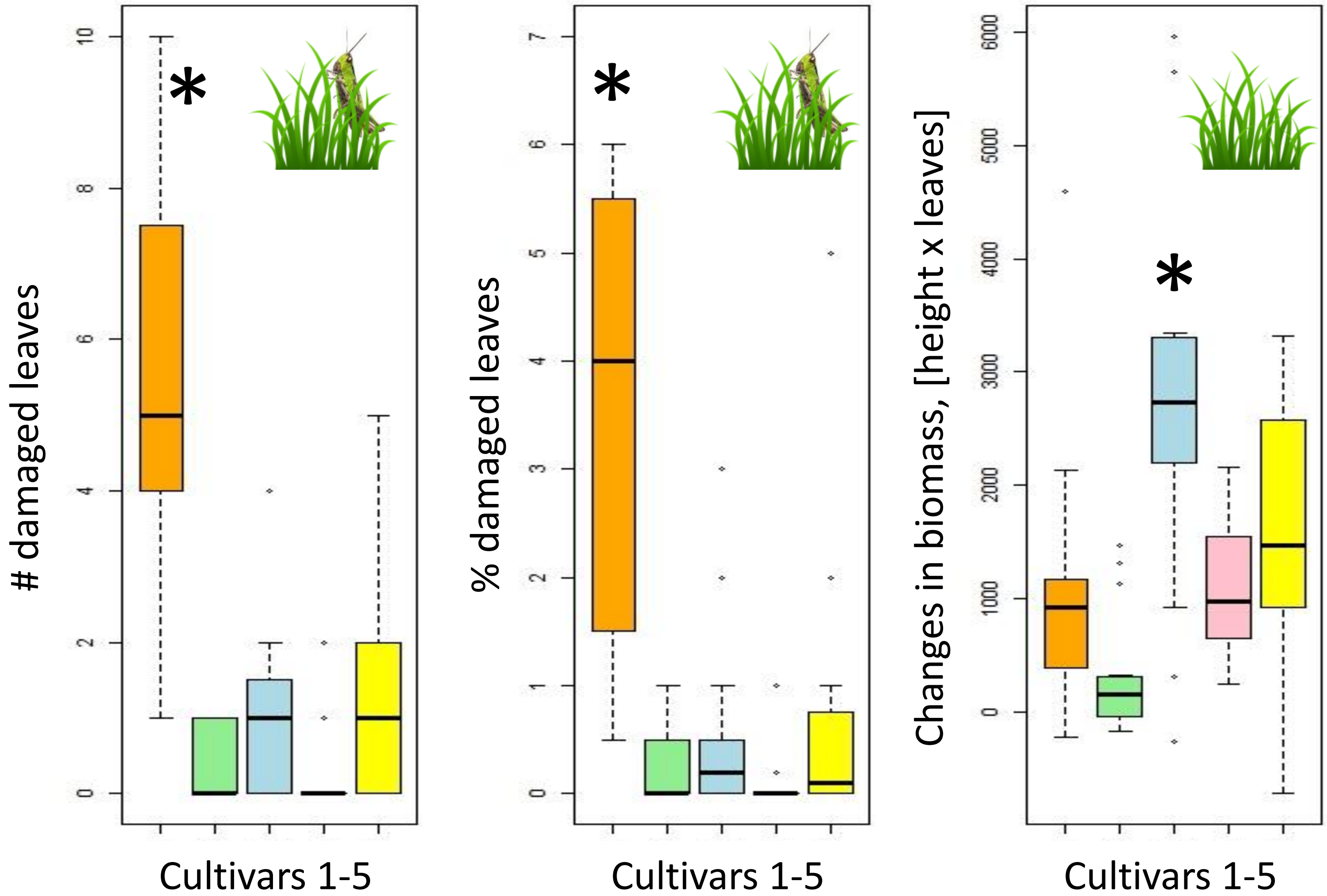


Plant tolerance to herbivory: field

Greenhouse experiments


Days 1-3

Plant Resistance and Plant Tolerance to Herbivory: Greenhouse



Preliminary Conclusions



- Grasshoppers feed on all the cultivars
- Plant responses differ among the cultivars

Field:

- plant resistance to herbivory in ‘Gracillimus’ and ‘Morning Light’ (‘all-green’ cultivars) is significantly lower than that in other cultivars in the beginning of the season, but it is significantly higher at the end of the season
- plant tolerance in ‘Gracillimus’ and ‘Autumn Anthem’ (‘all-green’ cultivars) is significantly higher than that in other cultivars

Greenhouse:

- plant resistance in ‘Autumn Anthem’ (‘all-green’ cultivar) is significantly lower than that in other cultivars
- plant tolerance in ‘Gracillimus’ (‘all-green’ cultivar) is significantly higher than that in other cultivars

Next step..

- Do Miscanthus sinensis cultivars differ in their resistance and tolerance to grasshopper herbivory?

- Do the plant responses to herbivory in *M. sinensis* cultivars differ from the plant responses in *M. sinensis* wild type?

Plant morphology

Plant population genetics

Summary

Why do introduced species fail to establish in a new range?

Native insect herbivore

- Behavioral mechanisms
- Morphological adaptations

- Plant chemistry
- Insect seasonal phenology

Introduced plant

- Phylogenetic relatedness

Native plant

- ....many other mechanisms

Native community

Many thanks!!

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