# Exploring Oat and Pea Varieties for Intercropping as Forage

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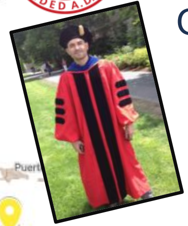
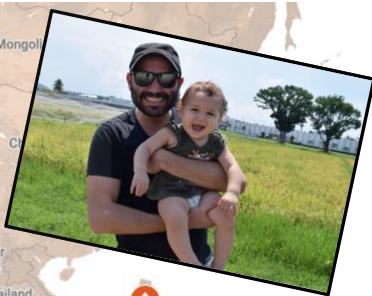


- PhD at Cornell in Plant Breeding & Genetics



- Scientist at IRRI - Philippines working in **rice breeding**

- Originally from Colombia!
- BS in Biology
- Worked at CIAT in **rice genetics**

- Passionate about **International Agriculture**

- Love diving!

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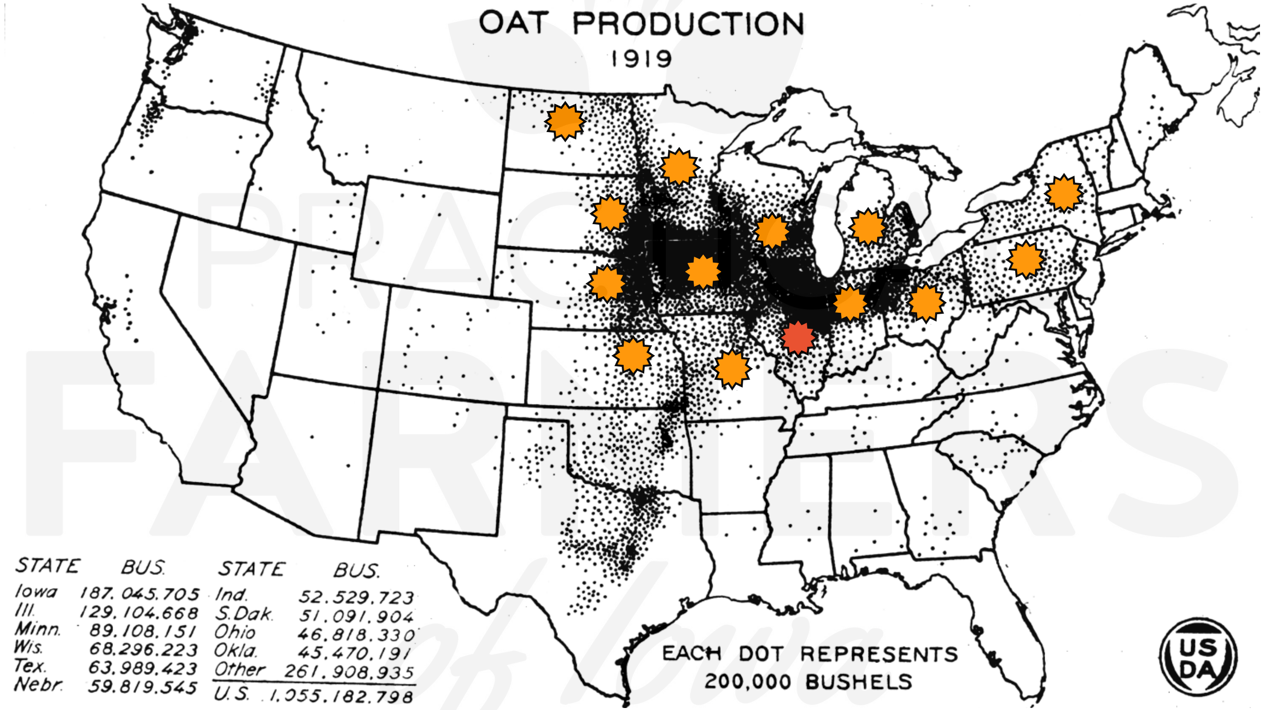
https://smallgrains.web.illinois.edu/wp/

# U.S. oat production before

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Source: United States Census Bureau (https://www.census.gov/).

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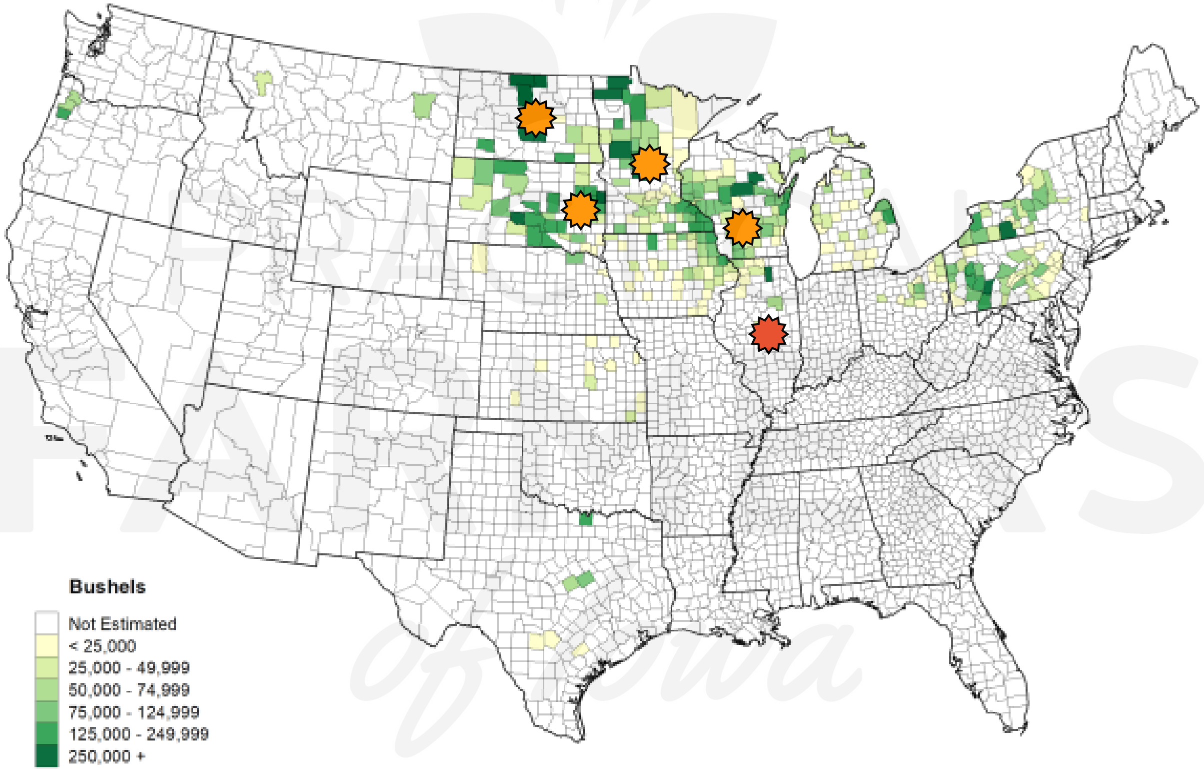
# U.S. oat production now




Source: USDA NASS (https://www.nass.usda.gov/).

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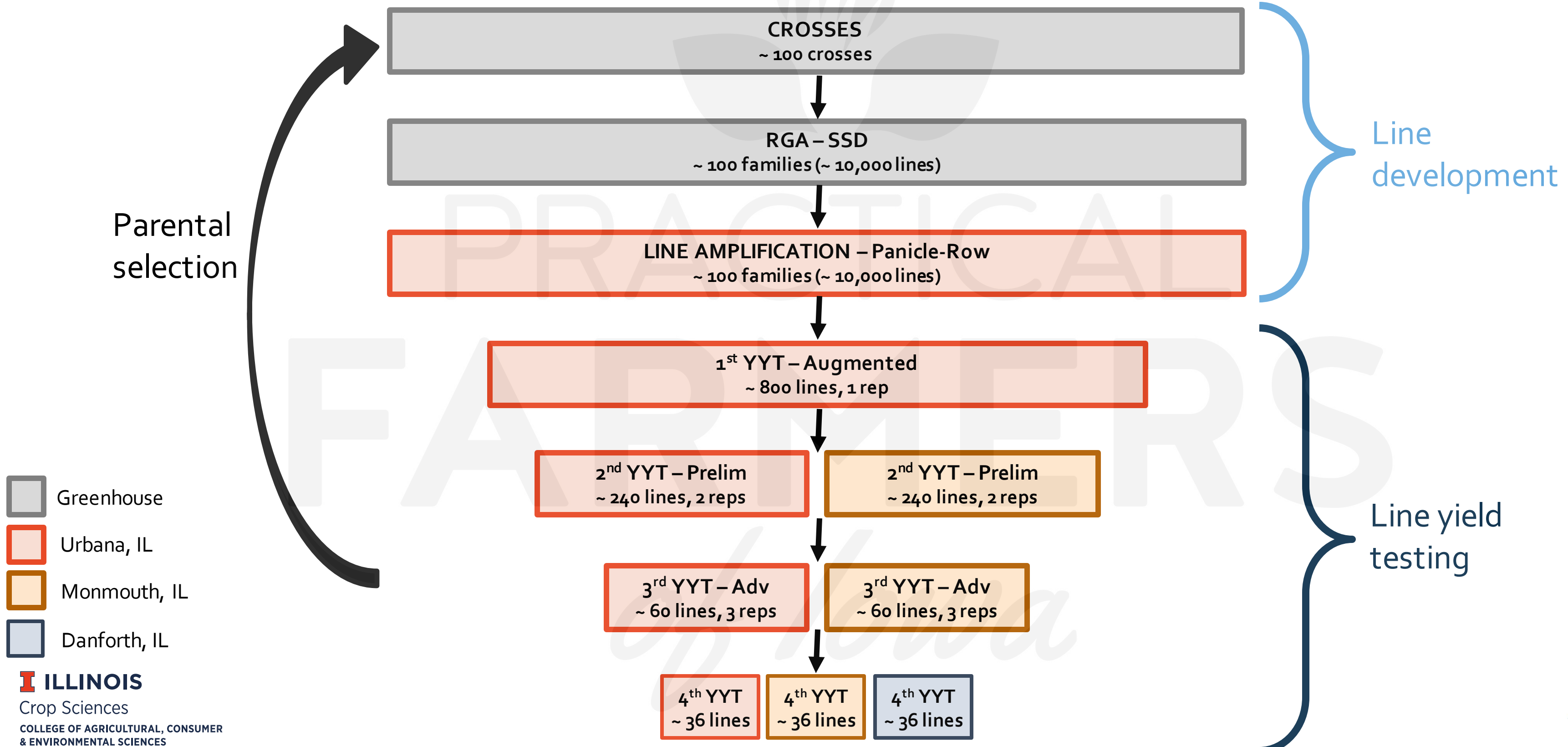
# Importance of oat

- It is a good source of dietary fiber, protein, fat, and minerals.
- Help treatment of diabetes and cardiovascular diseases.
- Oat included in crop rotations can help break diseases and weed cycles, as well as herbicide use.
- Diversify cropping systems.

# Let's keep breeding oats – UIUC program

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Source: The author.

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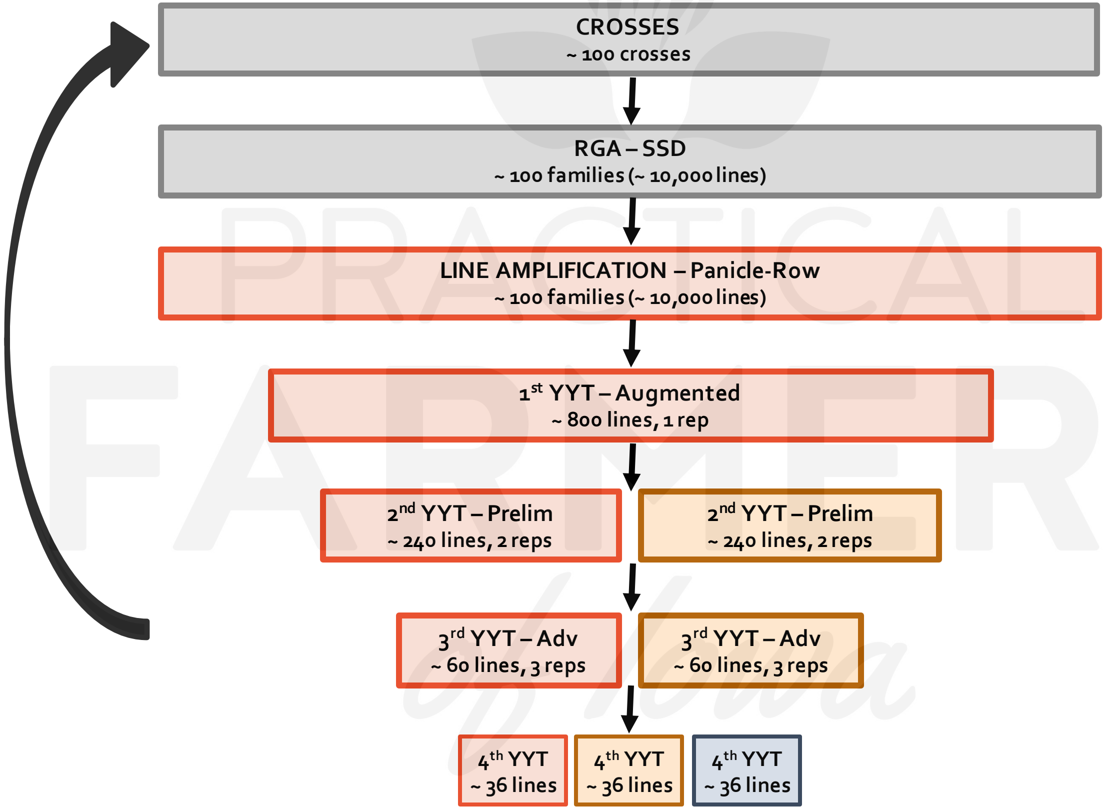
# Let's keep breeding oats – UIUC program

**ΔG:** the amount of increase in performance that is achieved through genetic improvement




$$\Delta G = i r \sigma_A / L$$

$\Delta G$ rate of genetic gain

$i$ selection intensity

$r$ selection accuracy

$\sigma_A$ additive genetic standard deviation

$L$ generation interval

$ / cycle

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Source: The author.

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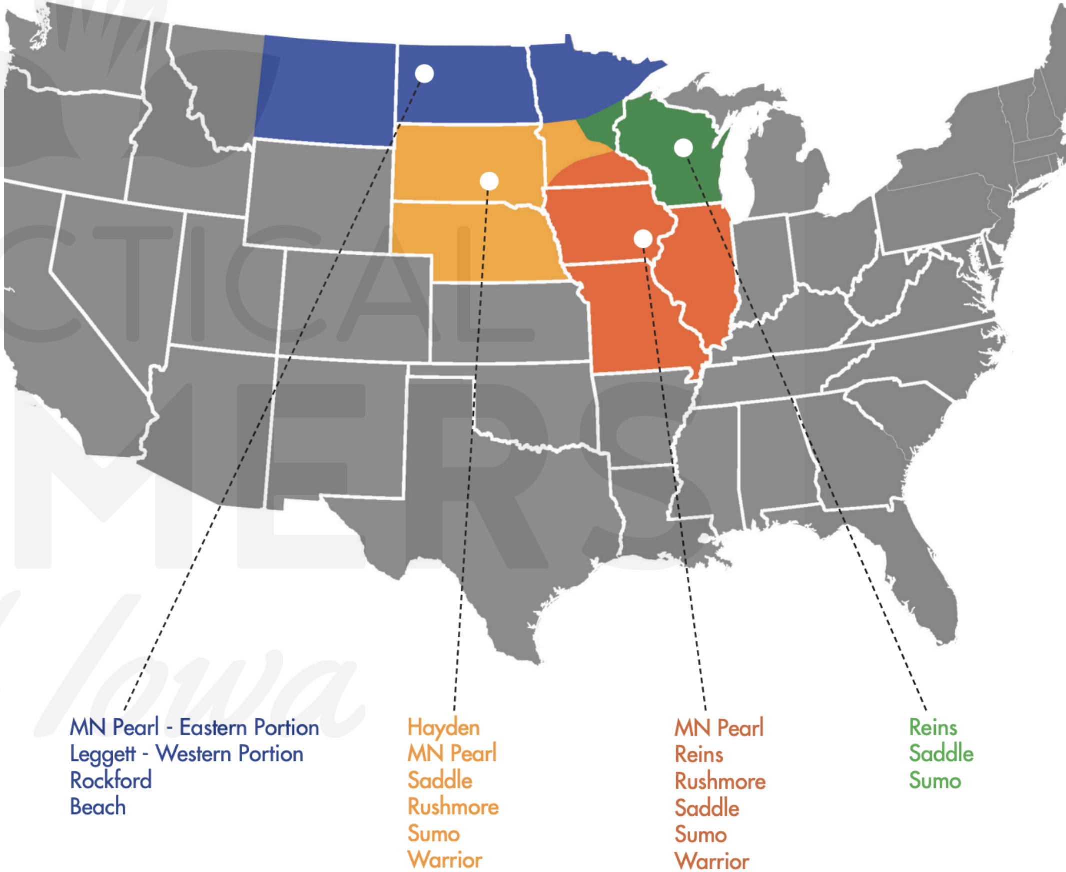
# Variety development – Reins

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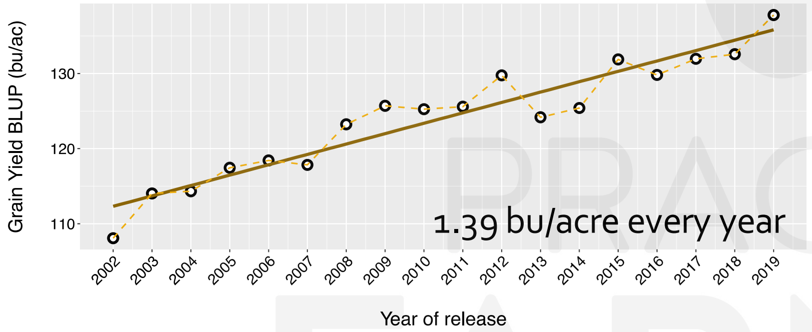
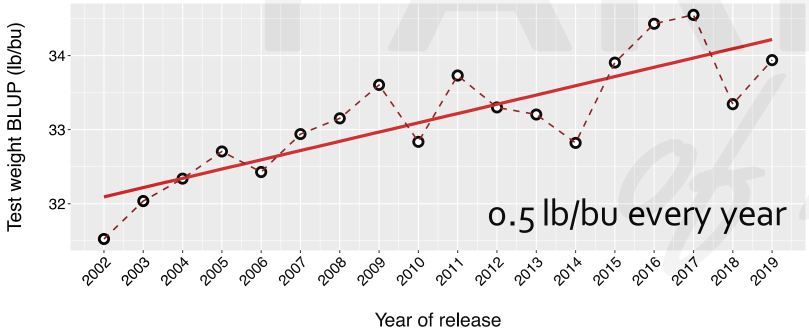
Source: Grain Millers. https://www.grainmillers.com

# UIUC oat genetic gain: productivity

## Grain yield bu/ac

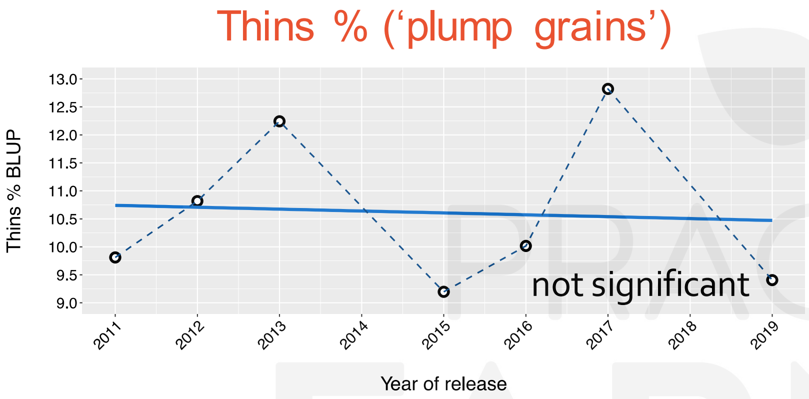


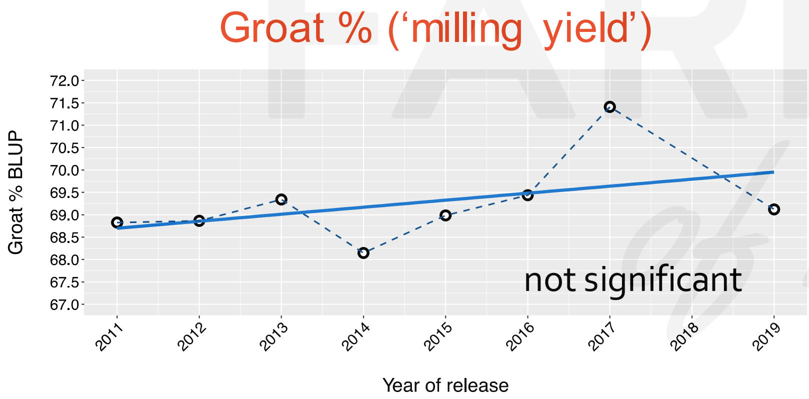

## Test weight lb/bu

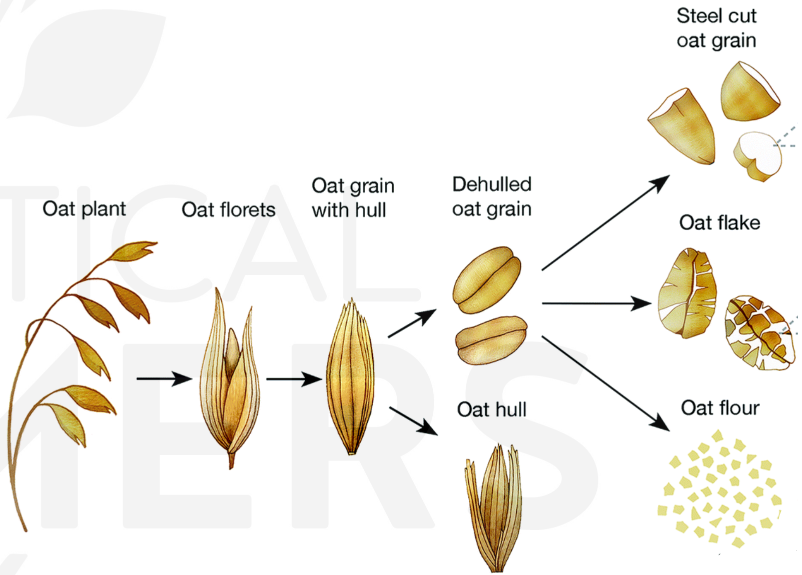



Source: Scheffel et al. (in preparation)

# UIUC oat genetic gain: milling quality



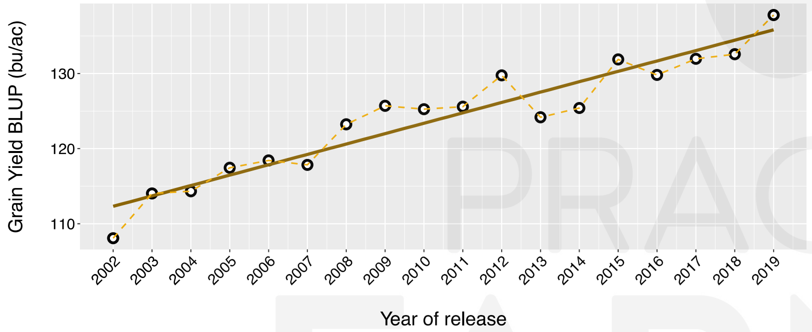

**Quality Standards**

| | Spec | Min/Max |
|---|---|---|
| Test Weight | 38 | 36 |
| Moisture | 13.5% | 10-14% |
| Thins | 12% | 20% |
| De-Hulled | 8% | 12% |

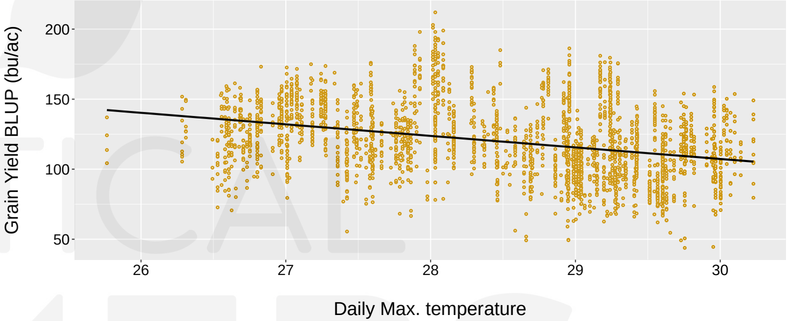
Source: Grundy et al. 2019, & Grain Millers (https://www.grainmillers.com/)

# Effects of temperatures on oat

## Grain yield bu/ac




## Temperature Grain yield bu/ac

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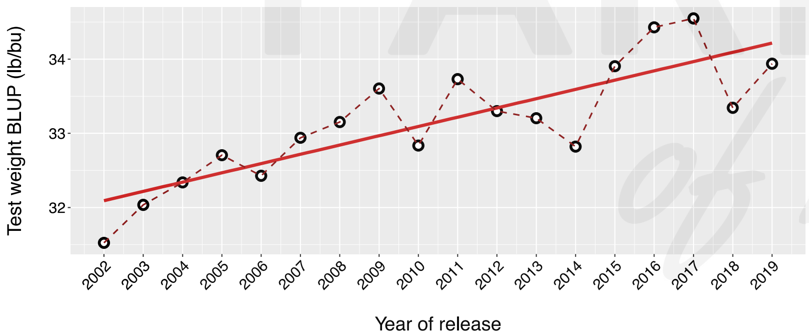


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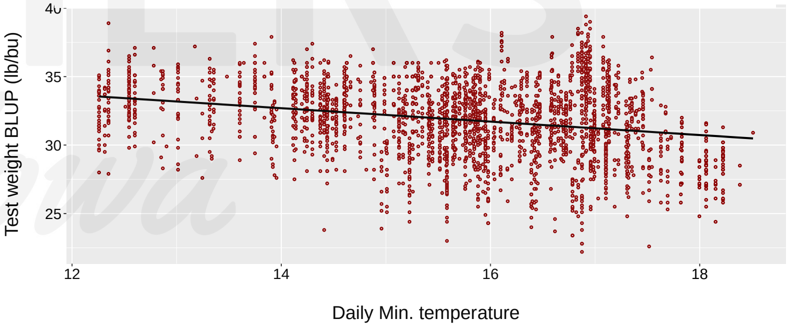
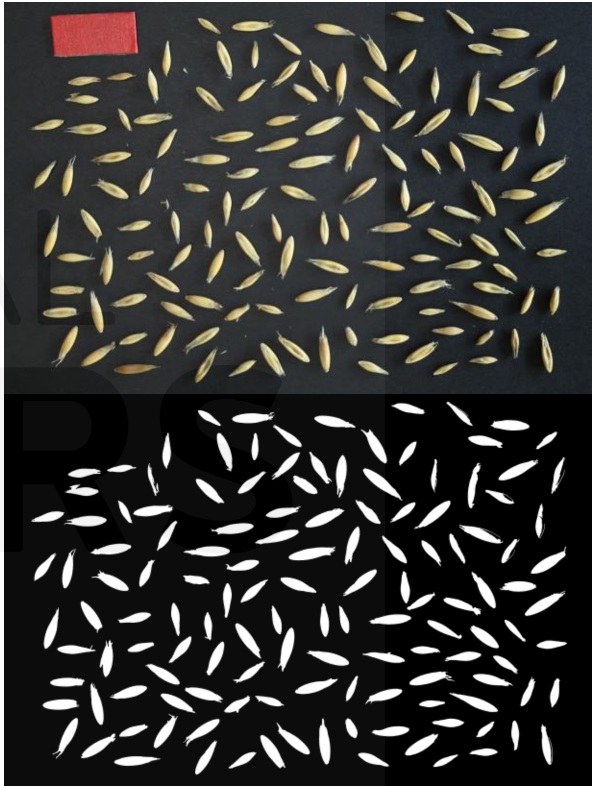



Source: Scheffel et al. (in preparation)

# Mission

- Develop new breeding tools, methods, & strategies to:
    - Improve the quality and nutritional value of crops.
    - Ameliorate the effects of climate change on agriculture.
    - **Increase crop diversity & sustainability.**

# Improve quality & nutritional value

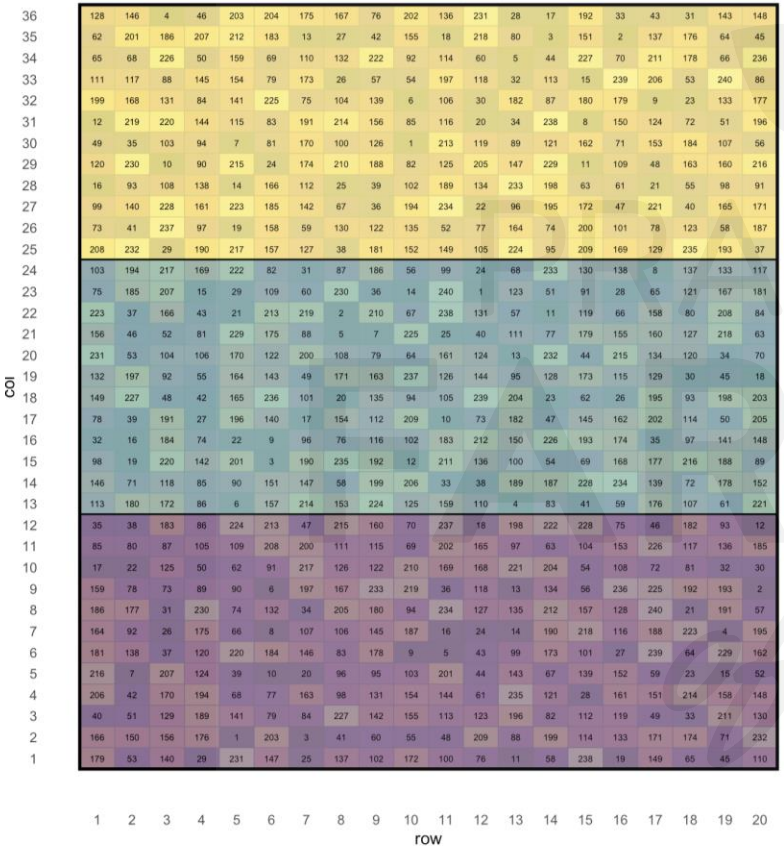






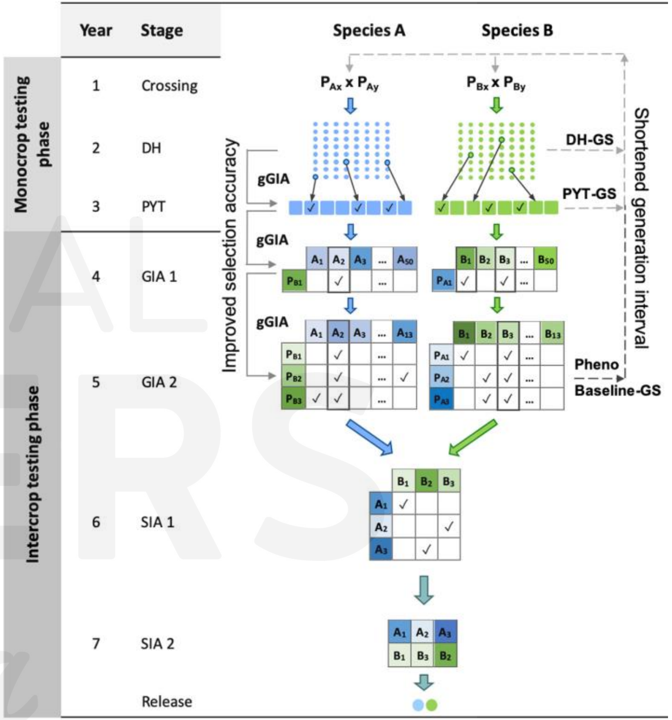
Source: Dakhal et al. (in preparation)

# Ameliorate the effects of climate change




Source: Scheffel et al. (in preparation)

# Increase crop diversity - Intercropping





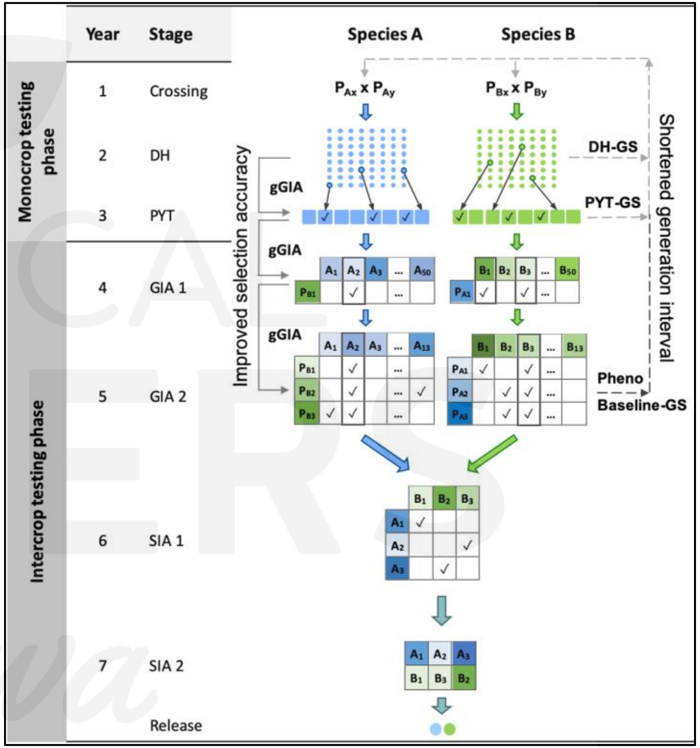

Source: GRA Milcah Kigoni, and Bancic et al. 2021

# Why intercropping matters

- Mixed intercropping is a crop diversification approach in which two or more crops are grown together in no specific arrangement:
  - Improve ecosystem services.
  - Financial profit.
  - Production efficiency.
  - Social wellness.

# Intercropping breeding challenges

- Major global crop species are grown as monocrop, with breeding programs tailored for them.
- Intercrop breeding is more complex since it requires the optimization of two or more crops simultaneously.

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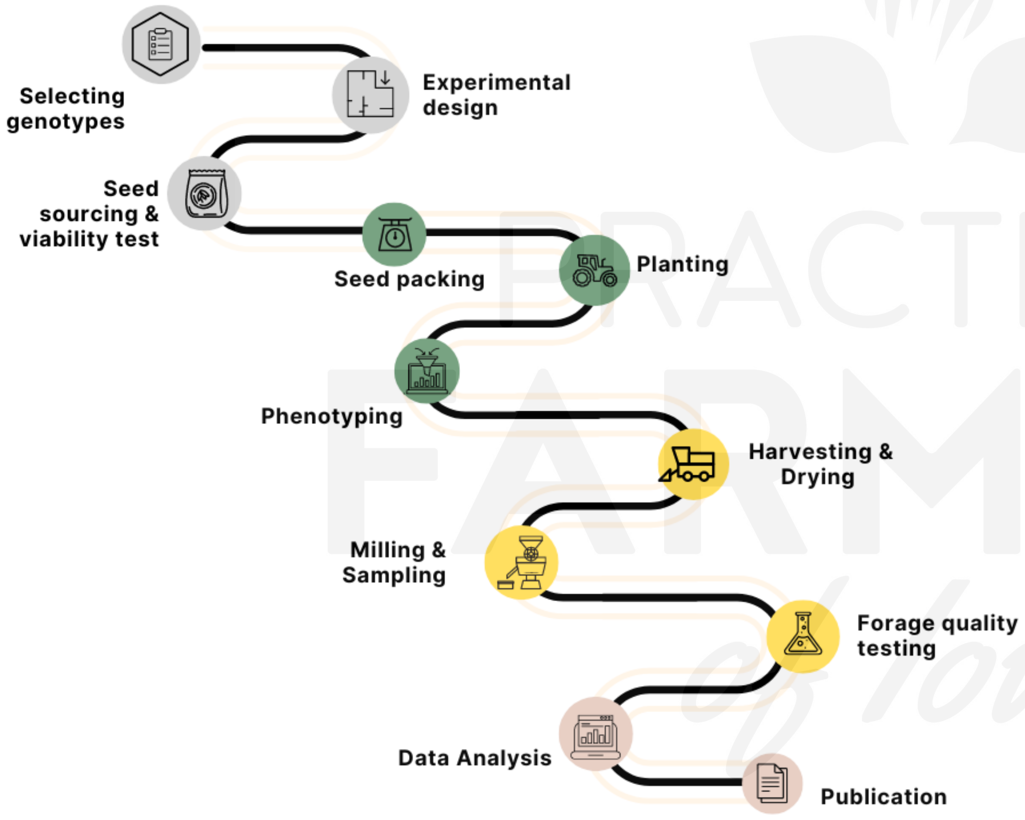
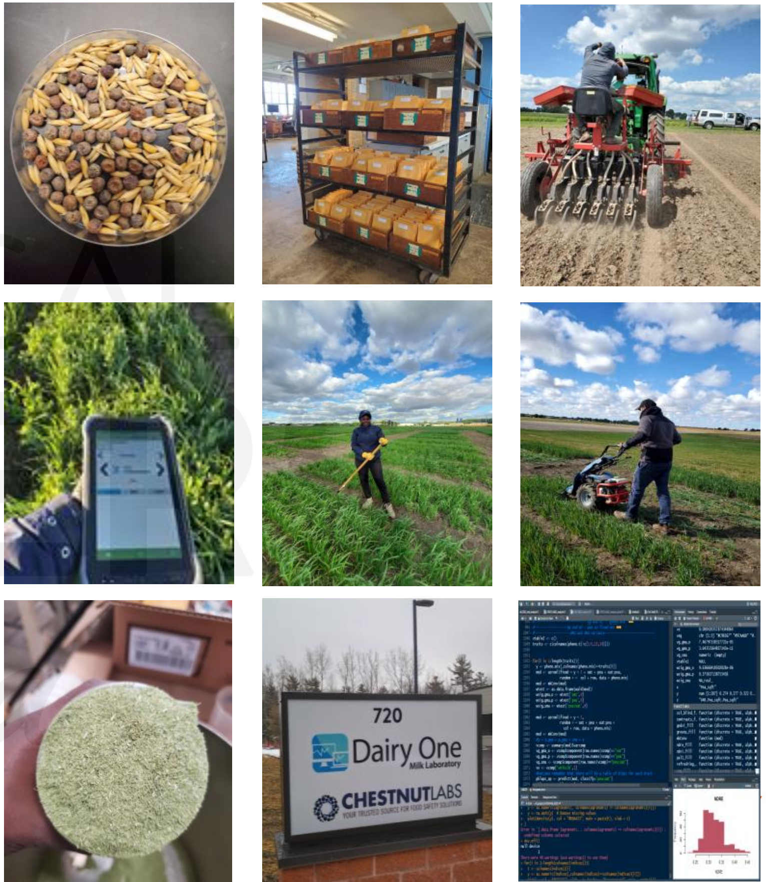
# Objectives

I. Assess genetic variability and genetic correlation of forage yield and quality traits in UIUC oat germplasm under oat-pea intercrop conditions.
II. Evaluate the general mixing ability (GMA) and specific mixing ability (SMA) of UIUC oat germplasm in oat-pea mixtures.
III. Evaluate high-throughput phenotyping (UAV-sensors) methods to improve cost and efficiency in oat-pea intercrop biomass estimation.

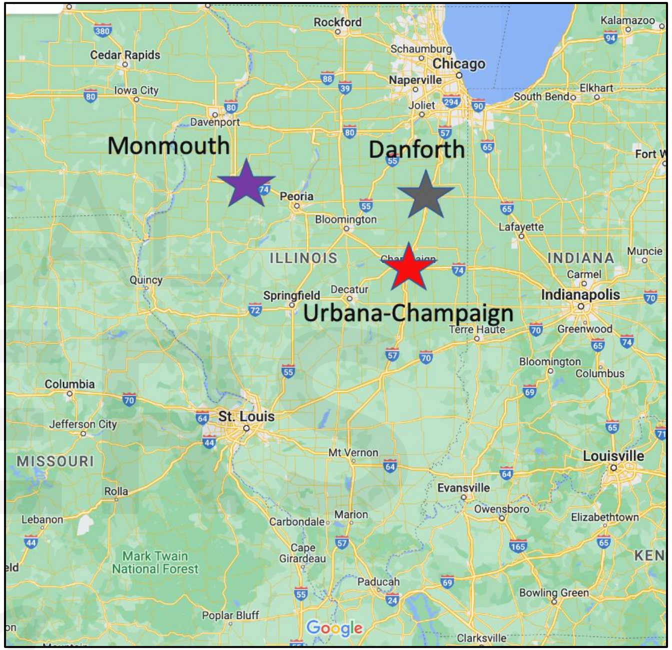
# Methodology workflow



# Experiment location

| | |
|---|---|
| Site Name | South Farm |
| Location | Urbana, IL |
| Elevation (m) | 219.7 |
| Hardiness zone | 5b (-15 to -10 °F/-26.1 to -23.3 °C) |
| Soil type | Silt Loam |
| Estimate plot area (m²) | 9.3 |
| Planting seasons | **Fall 2022** (August - October), **Spring 2023** (April – July), and **Fall 2023** (August - October) |

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# Experimental design

**Mixed Design:**

- Full factorial: 24 Oats X 4 Pea, 3 reps
- Mixed plots/rep: 24 oats X 4 peas = 96
- Mono plots/rep: 24 oats + 4 peas = 28
- Total plots per rep: 124
- Total plots: 372
- Plot size: 20 x 4.5 ft

| | O-1 | O-2 | O-3 | O-4 | O-5 | O-6 | O-7 | O-8 | O-9 | O-10 | O-11 | O-12 | O-13 | O-14 | O-15 | O-16 | O-17 | O-18 | O-19 | O-20 | O-21 | O-22 | O-23 | O-24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P-1 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-2 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-3 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-4 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-1 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-2 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-3 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-4 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-1 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-2 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-3 | | | | | | | | | | | | | | | | | | | | | | | | |
| P-4 | | | | | | | | | | | | | | | | | | | | | | | | |

**Planting:**

- Planting depth:

~1 inch

- Seeding ratio:

Oat : Pea (40:60)

- Seeding rate:

Oat (mono = 27 (~1M/ac), mix = 12 plants sqft).

Pea (mono = 13 (~400K/ac), mix = 8 plants sqft).

- Pea inoculation:

Rhizobium Powder.

- Harvest stage:

Oat boot – early heading stage

# Germplasm

| Germplasm | Origin | Year Released | Max PH (cm) | Tannin free |
|---|---|---|---|---|
| **Austrian** | Landrace | NA | 121.9 | No |
| **FrostMaster** | NA | NA | 121.9 | Yes |
| **Windham** | NDSU & USDA-ARS | 2007 | 73.7 | Yes |
| **Whistler** | Progene Research of Washington | 2005 | 81.3 | Yes |
| **Arvika 4010 - Spring** | Canada | | | |

**4 Winter Pea (*Pisum sativa*)**

**Selection Criteria: Varieties, Maturity, Plant height, Winter hardiness, Forage.**

| Germplasm | Origin | YOR | Maturity | Plant Height (cm) |
|---|---|---|---|---|
| **Baker** | Iowa State University | 2007 | Early | 95.1 |
| **Buckskin** | UIUC | 2008 | Early | 89.8 |
| **Colt** | SDSU | 2009 | Early | 91.8 |
| **Corral** | UIUC & Cornell University | 2010 | Early | 81 |
| **Deon** | University of Minnesota | 2013 | Late | 96.8 |
| **Esker** | University of Wisconsin | 2019 | Midseason | 90.6 |
| **Excel** | Purdue University | 2006 | Late | 91.9 |
| **Goliath** | SDSU | 2012 | Late | 110.2 |
| **Hayden** | SDSU | 2014 | Midseason | 91.7 |
| **Horsepower** | SDSU | 2011 | Midseason | 85.1 |
| **IL17-5238*** | UIUC | NA | Midseason | 85.9 |
| **IL17-7334*** | UIUC | NA | Midseason | 71.2 |
| **IL17-1253*** | UIUC | NA | Midseason | 83.3 |
| **IL17-7339*** | UIUC | NA | Midseason | 74.5 |
| **Leggett** | AAFC-Manitoba | 2004 | Late | 89.6 |
| **Natty** | SDSU | 2014 | Midseason | 97.2 |
| **Newburg** | North Dakota | 2011 | Late | 100.9 |
| **Ogle** | UIUC | 1981 | Midseason | 89.2 |
| **Reins** | UIUC | 2015 | Early | 79.8 |
| **Rushmore** | SDSU | 2019 | Midseason | 82 |
| **Saber** | UIUC | 2010 | Early | 82.2 |
| **Saddle** | SDSU | 2017 | Midseason | 82.2 |
| **Spurs** | UIUC | 2003 | Early | 89.7 |
| **Warrior** | SDSU | 2018 | Late | 83.4 |

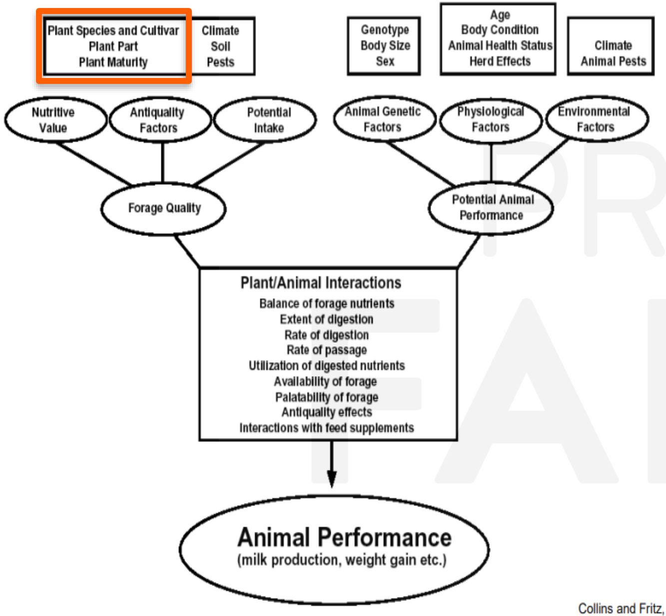
**24 Spring Oat (*Avena sativa*)**

**Selection Criteria: Varieties, Checks, Maturity, Plant height, Forage.**

# Phenotypes collected

| Trait | Category | Units | Variable Type | Crop Ontology |
|---|---|---|---|---|
| Seed germination | Agronomic | % | Continuous | CO_341:0000075 |
| oat plants per m2 | Agronomic | Count | Discrete | CO_356:2000103 |
| Pea plants per m2 | Agronomic | Count | Discrete | CO_356:2000103 |
| Plant height (crop height model) | Agronomic | cm | Continuous | CO_350:0000021 |
| Dry matter Yield (DMY) | Agronomic | Lb/ac | Continuous | CO_350:0000277 |
| Crude Protein (CP) | Forage Quality | % | Continuous | CO_345:0000016 |
| Acid detergent fiber (ADF) | Forage Quality | % | Continuous | CO_345:0000001 |
| Neutral detergent fiber (NDF) | Forage Quality | % | Continuous | CO_345:0000029 |
| Total Digestible Nutrients (TDN) | Forage Quality | % | Discrete | NS |
| Relative Feed Value (RFV) | Forage Quality | NS | Discrete | NS |
| Vegetation Indices | Other | NS | Continuous | CO_321:0000301 |

# Phenotypes collected




Collins and Fritz, 2003

- **DM Yield:** weight of harvested above-ground biomass after all water has been removed
- **Crude Protein (CP):** protein N and nonprotein N (total N x 6.25)
- **Fiber components:**
  - Neutral detergent fiber (NDF)
    - Hemicellulose, cellulose, and lignin
    - Inversely related to intake
    - Partially digestible
  - Acid detergent fiber (ADF):
    - Cellulose and lignin
    - Highly indigestible
- **Relative Feed Value (RFV)**
  - Index **used to compare similar forages**
  - Calculated based on Digestible dry matter (DDM) and animal dry matter intake DMI
- **Total Digestible Nutrients (TDN)**
  - Indicates relative energy value of forage to an animal
  - Calculated based on digestible crude protein, digestible crude fiber, digestible N-free extract and digestible crude fat

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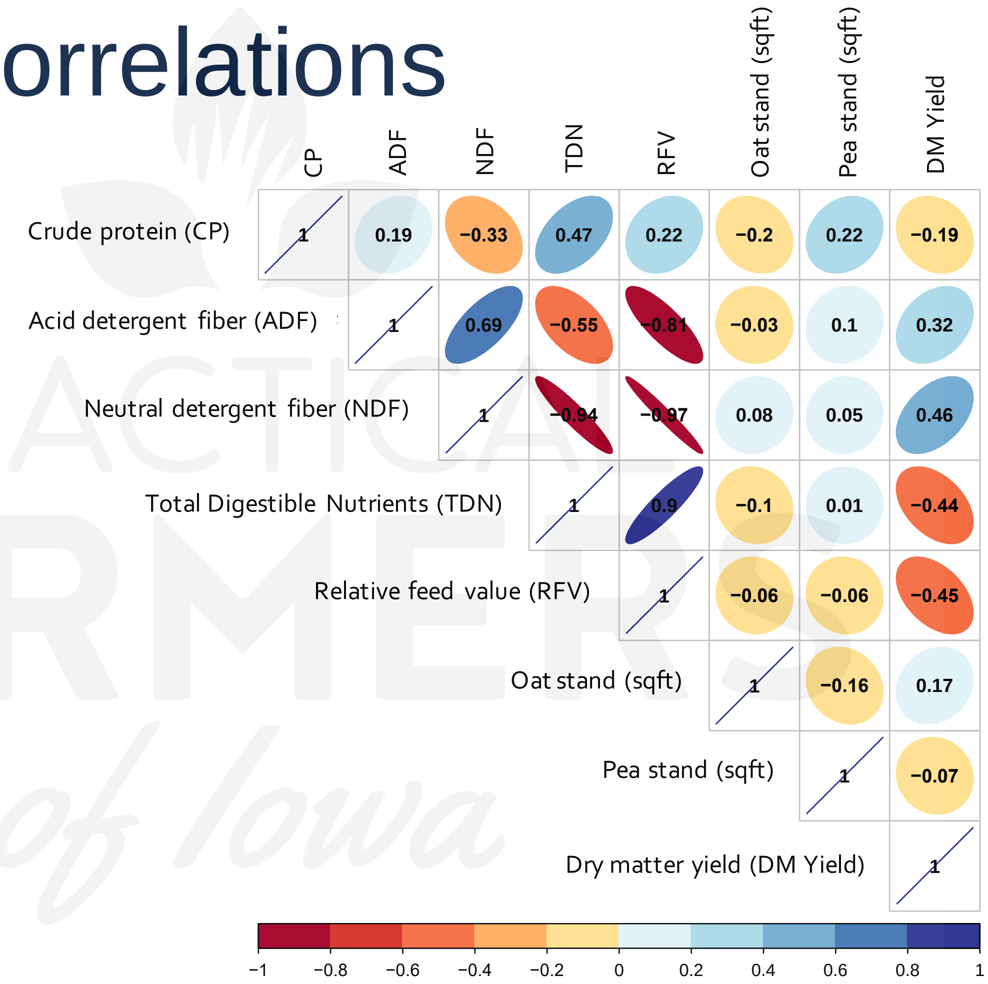
# Results

# Multi-season Yield Results

| Ranking Trait | Top 5 oat genotypes (GMA) | Top 4 pea genotypes (GMA) | Top 5 oat-pea combinations (SMA) |
|---|---|---|---|
| DM Yield Fall 22 | BUCKSKIN | WINDHAM | **SPURS** x WINDHAM - 794 |
| | ESKER | FROSTMASTERS | **BUCKSKIN** x FROSTMASTERS - 792 |
| | REINS | WHISTLER | **REINS** x WINDHAM - 774 |
| | HORSEPOWER | AUSTRIAN | **BUCKSKIN** x WHISTLER - 757 |
| | SPURS | | **EXCEL** x WINDHAM - 749 |
| DM Yield Spring 23 | BUCKSKIN | ARVIKA | **COLT** x FROSTMASTERS – 1783 |
| | IL17-7334 | WINDHAM | **BUCKSKIN** x ARVIKA – 1704 |
| | IL17-7339 | FROSTMASTERS | **SADDLE** x FROSTMASTERS – 1654 |
| | SADDLE | AUSTRIAN | **IL17-7334** x FROSTMASTER – 1650 |
| | IL17-1253 | | **HORSEPOWER** x ARVIKA – 1635 |
| DM Yield Fall 23 | ESKER | ARVIKA | **OGLE**x ARVIKA - 822 |
| | SPURS | FROSTMASTERS | **ESKER** x ARVIKA - 820 |
| | BAKER | WHISTLER | **IL17-7334** x ARVIKA – 762 |
| | BUCKSKIN | AUSTRIAN | **HORSEPOWER** x ARVIKA - 756 |
| | SABER | | **RUSHMORE** x ARVIKA - 756 |
| DM Yield across | BUCKSKIN | ARVIKA | **HORSEPOWER** x ARVIKA – 965 |
| | SPURS | WINDHAM | **BUCKSKIN** x ARVIKA - 959 |
| | SADDLE | FROSTMASTERS | **SADDLE** x ARVIKA - 941 |
| | BAKER | WHISTLER | **SABER** x ARVIKA – 938 |
| | HORSEPOWER | AUSTRIAN | **IL17-7339** x ARVIKA – 930 |

# Trait genetic correlations

- High CP.
- Low ADF.
- Low NDF.
- High RFV.
- High DM Yield.

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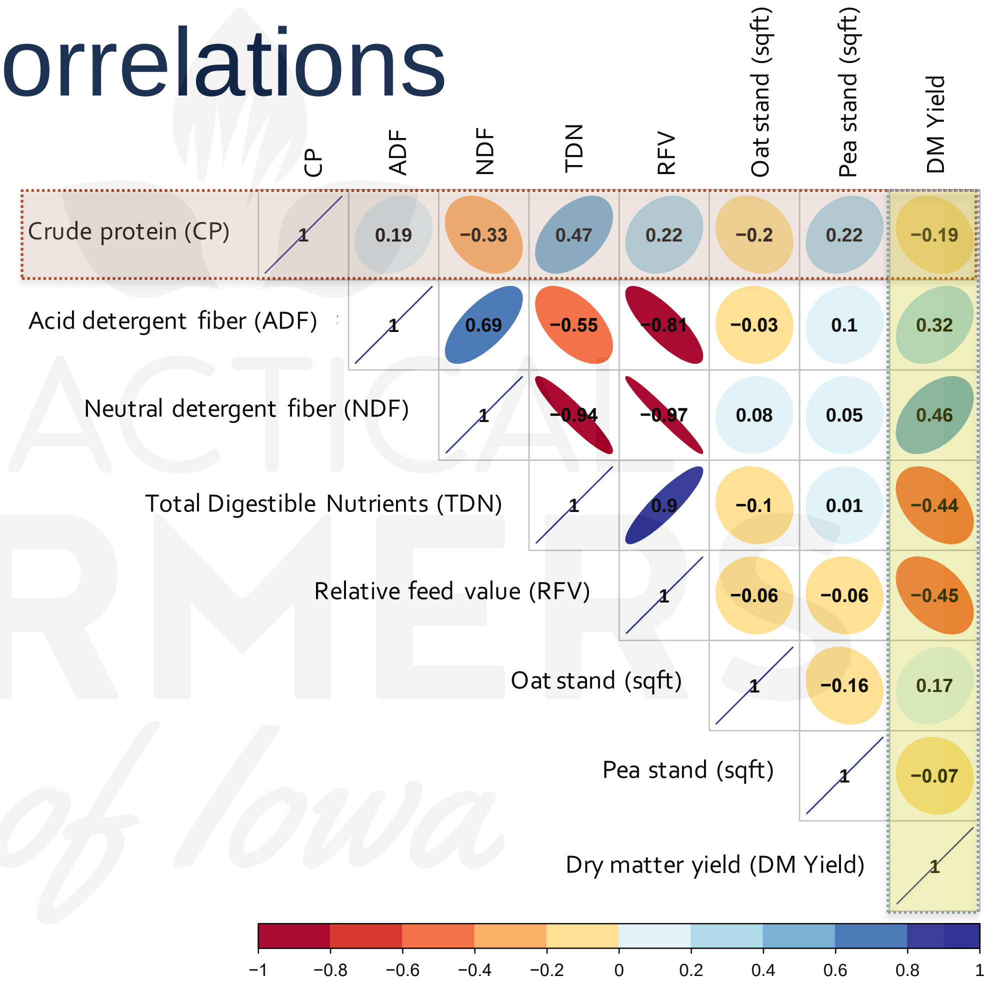




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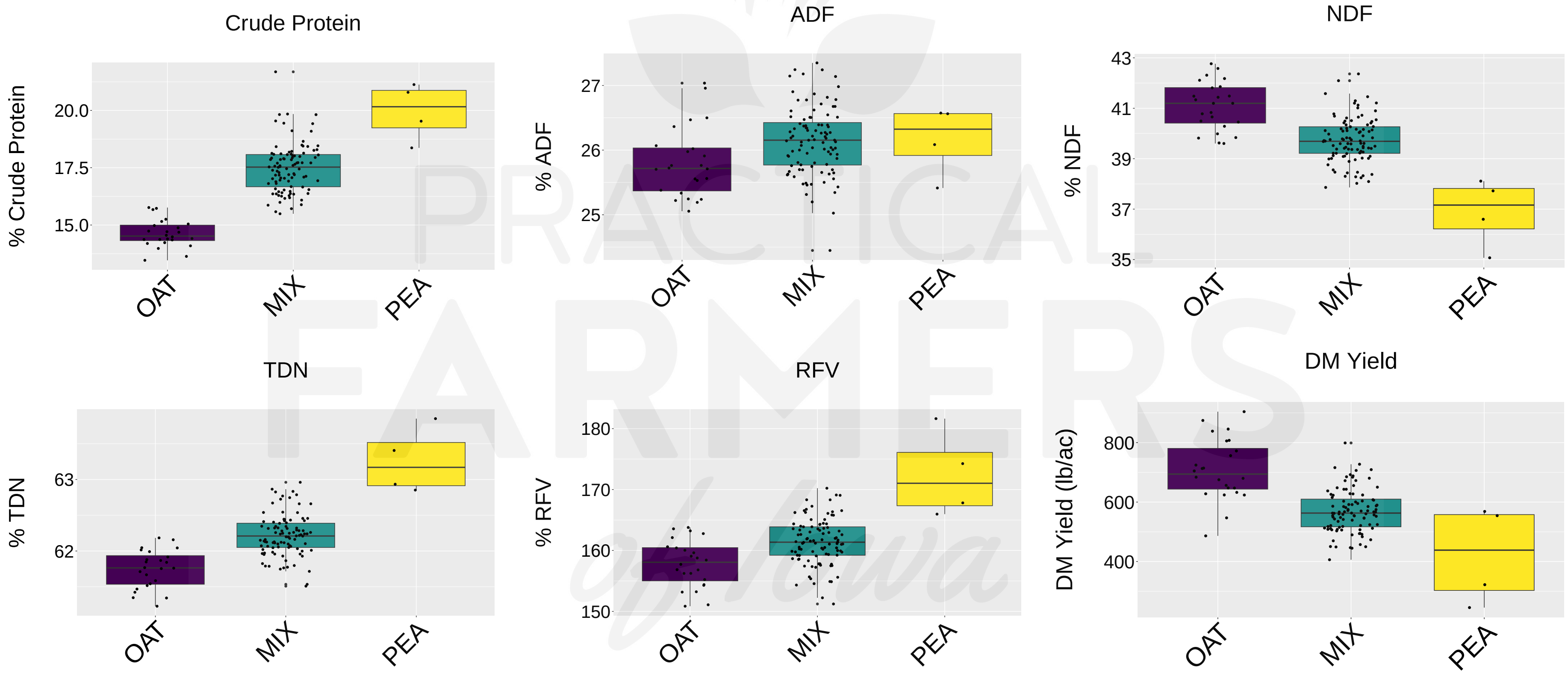
# Yield & Quality – Mono vs. Mix



# GMA & SMA results

| Trait | Oat GMA Variance | $H^2$ | Predicted Mean | Range | Pea-GMA Variance | SMA (oat:pea) |
|---|---|---|---|---|---|---|
| CP | 0.505 *** | 0.77 | 17.5 | 15.49 - 21.69 | 0.233 *** | NS |
| ADF | 0.186 * | 0.4 | 26.15 | 24.45 – 27.35 | 0.625 *** | NS |
| NDF | 0.679 *** | 0.56 | 39.74 | 37 – 42.36 | 0.025 | NS |
| TDN | 0.066 *** | 0.56 | 62.21 | 61.5 - 63 | 6.43E-08 | NS |
| RFV | 12.952 ** | 0.45 | 161.4 | 151.2 - 170 | 4.704 * | NS |
| DMY | 935303.33 *** | 0.62 | 819 | 435 – 1053 | 1767273.65 *** | NS |
| Plant height | 3.894 *** | 0.7 | 38.75 | 31.63 - 48.28 | 20.320 *** | NS |

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Well-performing lines should display high GMA and low SMA.



SMALL GRAINS

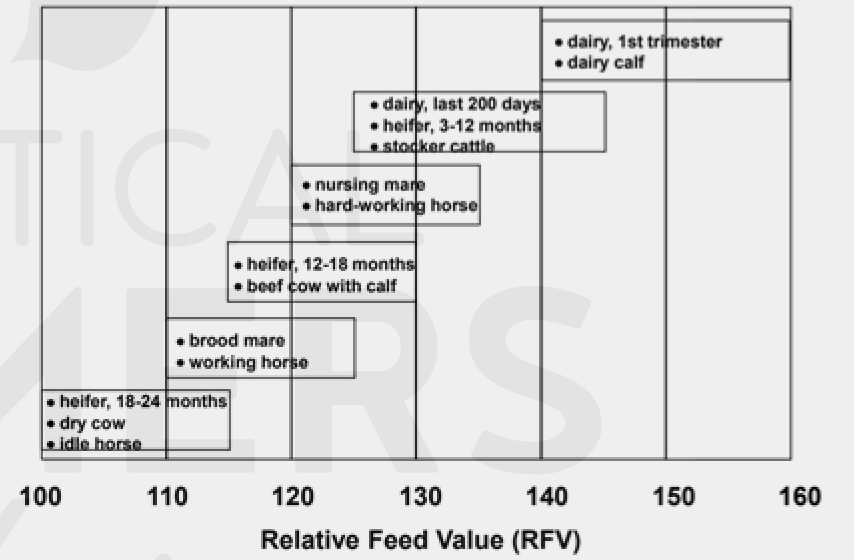
# Ranking the oat-pea mixture performance by forage quality standards

**Quality standards for legumes, legume-grass mixtures, and grasses.**

| Quality Standard | CP | ADF | NDF | RFV |
|---|---|---|---|---|
| | -------- % of DM -------- | | | |
| Prime | >19 | <31 | <40 | >151 |
| 1 | 17-19 | 31-35 | 40-46 | 151-125 |
| 2 | 14-16 | 36-40 | 47-53 | 124-103 |
| 3 | 11-13 | 41-42 | 54-60 | 102-87 |
| 4 | 8-10 | 43-45 | 61-65 | 86-75 |
| 5 | <8 | >45 | >65 | <75 |

Forage Quality Standards

Karla A. Hernandez, 2020




Forage quality needs of cattle and horses

Adapted from Undersander et al., 1994

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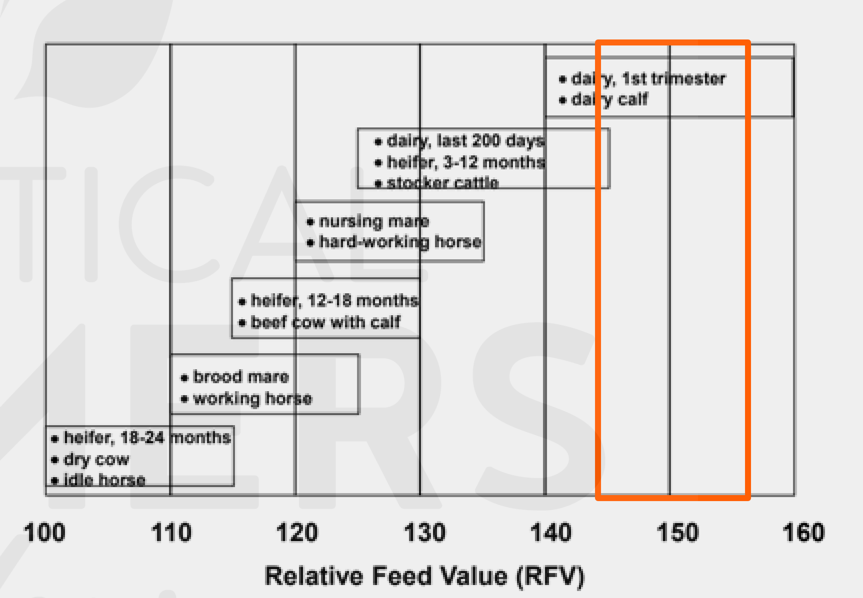
Forage Quality Standards

Karla A. Hernandez, 2020




Forage quality needs of cattle and horses

Adapted from Undersander et al., 1994

**Note: only ~0.5 Ton/ha**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# Ranking the oats, peas & oat-pea

| Ranking Trait | Top 5 oat genotypes (GMA) | Top 4 pea genotypes (GMA) | Top 5 oat-pea combinations (SMA) |
|---|---|---|---|
| **DM Yield Fall 22** | BUCKSKIN | WINDHAM | **SPURS** x WINDHAM - 794 |
| | ESKER | FROSTMASTERS | **BUCKSKIN** x FROSTMASTERS - 792 |
| | REINS | WHISTLER | **REINS** x WINDHAM - 774 |
| | HORSEPOWER | AUSTRIAN | **BUCKSKIN** x WHISTLER - 757 |
| | SPURS | | **EXCEL** x WINDHAM - 749 |
| **CP** | BUCKSKIN | WHISTLER | **COLT** x WHISTLER – 21.6 |
| | EXCEL | WINDHAM | **GOLIATH** x FROSTMASTERS – 19.8 |
| | LEGGETT | AUSTRIAN | **SABER** x WINDHAM – 19.8 |
| | IL17-5238 | FROSTMASTERS | **COLT** x FROSTMASTER – 19.8 |
| | OGLE | | **GOLIATH** x WINDHAM – 19.55 |
| **ADF** | RUSHMORE | AUSTRIAN | **DEON** x AUSTRIAN - 24.4 |
| | SADDLE | WHISTLER | **SADDLE** x AUSTRIAN - 25 |
| | HORSEPOWER | WINDHAM | **CORRAL** x AUSTRIAN – 25.19 |
| | SABER | FROSTMASTERS | **WARRIOR** x AUSTRIAN - 25.3 |
| | IL17-7374 | | **WARRIOR** x WHINDHAM - 25.3 |
| **NDF** | BUCKSKIN | WHISTLER | **COLT** x FROSTMASTERS – 37.86 |
| | COLT | WINDHAM | **IL17-1253** x WHISTLER - 38 |
| | IL17-5238 | AUSTRIAN | **CORRAL** x AUSTRIAN - 38 |
| | CORRAL | FROSTMASTERS | **RUSHMORE** x AUSTRIAN – 38.24 |
| | RUSHMORE | | **SADDLE** x FROSTMASTERS – 38.28 |

# Pea winter survival – Austrian

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# Yield

# UAV-Multispectral yield prediction


Attended a Hands-On Workshop in High Throughput Phenotyping (HTP), 2021, Utah.

Collaborator & Drone Pilot: **Raysa Gevartosky**

Drone: DJI Matrice 300 RTK

Camera: Thermal & Hyperspectral camera (Micasense Altum)

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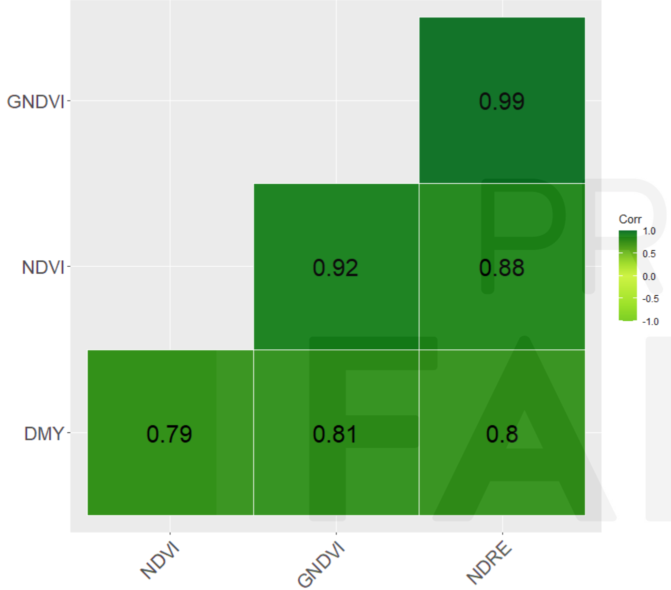
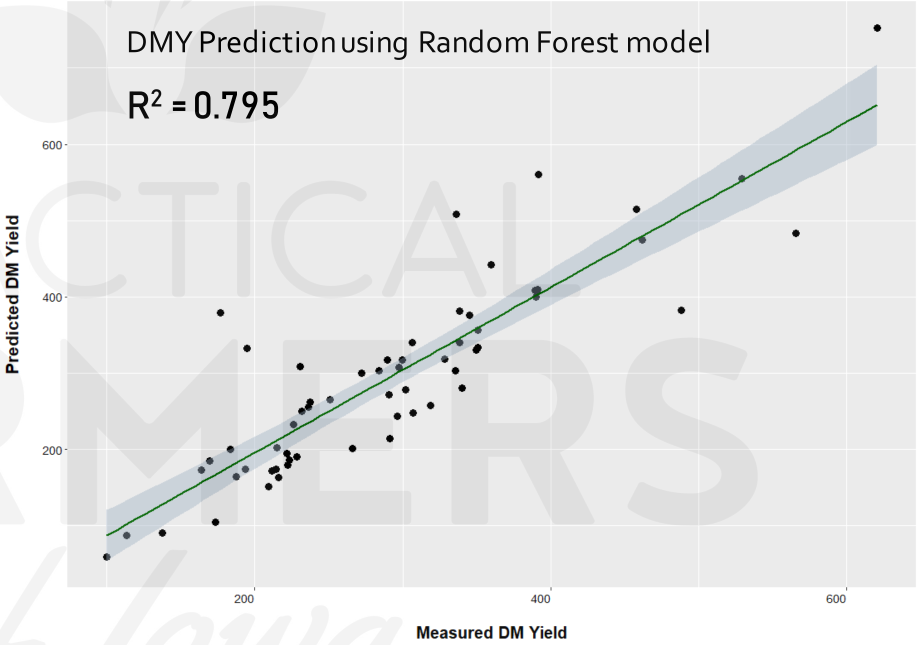
# UAV-Multispectral yield prediction




Correlation plot of dry matter yield (DMY) and UAV–based Vegetative indices

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# Preliminary results indicate

- Significant genetic variability for yield and quality traits. WE CAN DO BREEDING!
- Strong genetic correlations between key forage traits. WE NEED TO CREATE WEIGHTS.
- Oat genotypes display high GMA variance and low SMA variance. GREAT FOR BREEDING LOGISTICS.
- UAVs can be used to predict yield. GREAT FOR BREEDING LOGISTICS.
- Oats: BUCKSKIN and SPURS, & Peas: ARVIKA and WINDHAM are the best yield over all mixtures, with BUCKSKIN/ARVIKA as the best mixture.
- BUCKSKIN/WINDHAM is a good quality mixture. WAIT for 2023 results.
- AUSTRIAN was the only pea that survived winter after one cut.

# Thanks

- UIUC Small Grains
  - **Milcah Kigoni**
  - Jessica Rutkoski
  - Tadele Kumsa
  - Luis Gehrke
  - Anup Dhakal
  - Sheila Scheffel
  - Lucas Munaro
  - Jeremy Logrono
  - Raysa Gevartoski
  - Sophia Arista

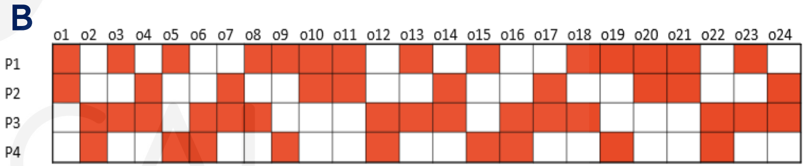
- Funding
  - USDA - NIFA
  - UIUC - ACES

# Questions

# Complete and incomplete factorial experimental designs


96 plots per rep

Simulated

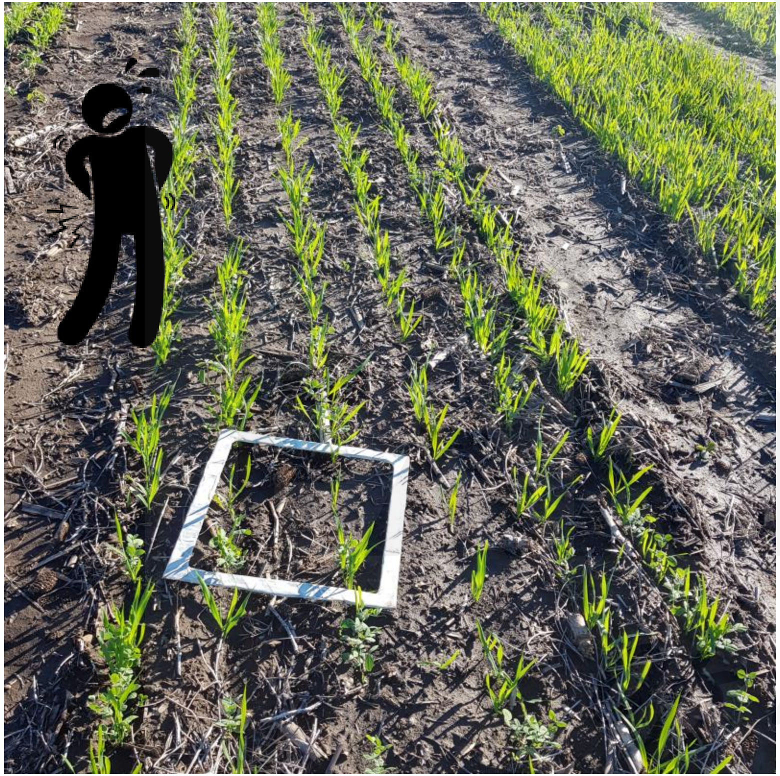



48 plots per rep

- Evaluate accuracy of estimating GMA, SMA, Error variances in complete and incomplete experimental designs
- Design B (incomplete factorial design) proposed for GMA and SMA variances in a resource-efficient way

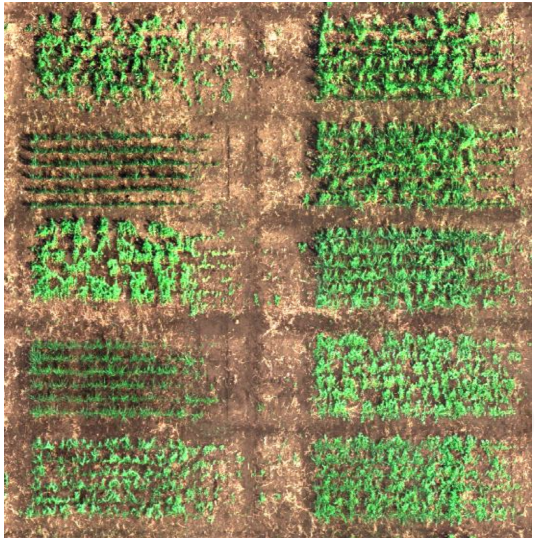
Haug et al., 2021

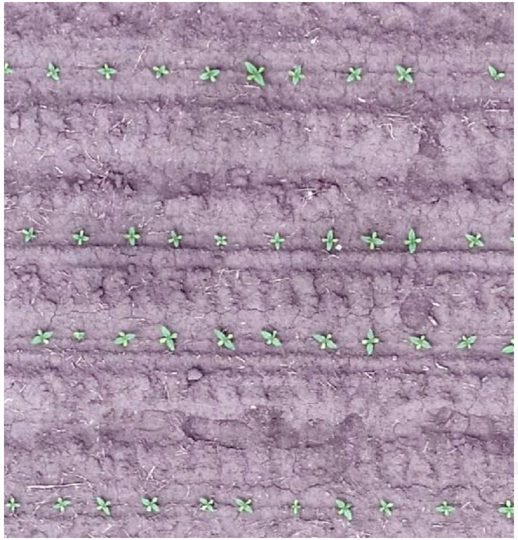
# UAV-based Species Classification in mixed plots



Quadrat method of counting pea and oat per sqft

- Fraction yield is the partitioned yield data of species in a mixture.
    - Producer effect – an individual's effect on its own yield
    - Associate effect – its effect on the companion species' yield
- Characterization of fraction yields enhance GMA selection accuracy





**UIUC Small Grains Improvement**

Micasense Altum RGB sensor
Ground resolution: 6.7 mm/pix
Flight height: 49 ft

NDSU PRECISION AGRICULTURE Flores Research Team Lab

Zenmuse P1 RGB sensor
Ground resolution: 2.9 mm/pixel
Flight height: 40 ft

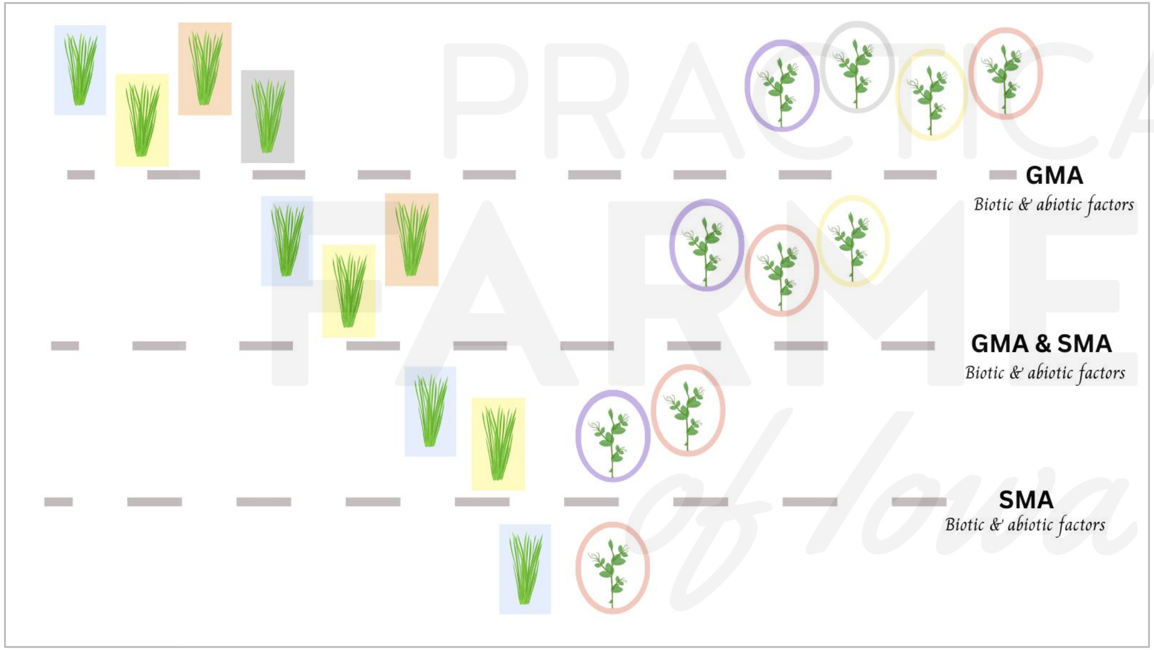
Dr. Flores Paulo
Assistant Professor in Precision Agriculture, NDSU

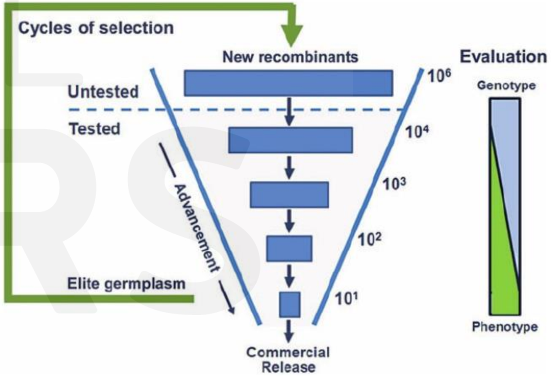
Up-to 96% recall (TPR) observed using NDVI data and random forest multi-classifier for sugar beet vs 3 weed species, Philipp et al., (2017)

3 flights done in Spring 2023 using high resolution camera

# Main Expected Output

## A feasible and efficient breeding scheme for developing oat-pea mixtures with superior forage yield and quality




Cooper et. al (2014)