OREI Naked Barley Project

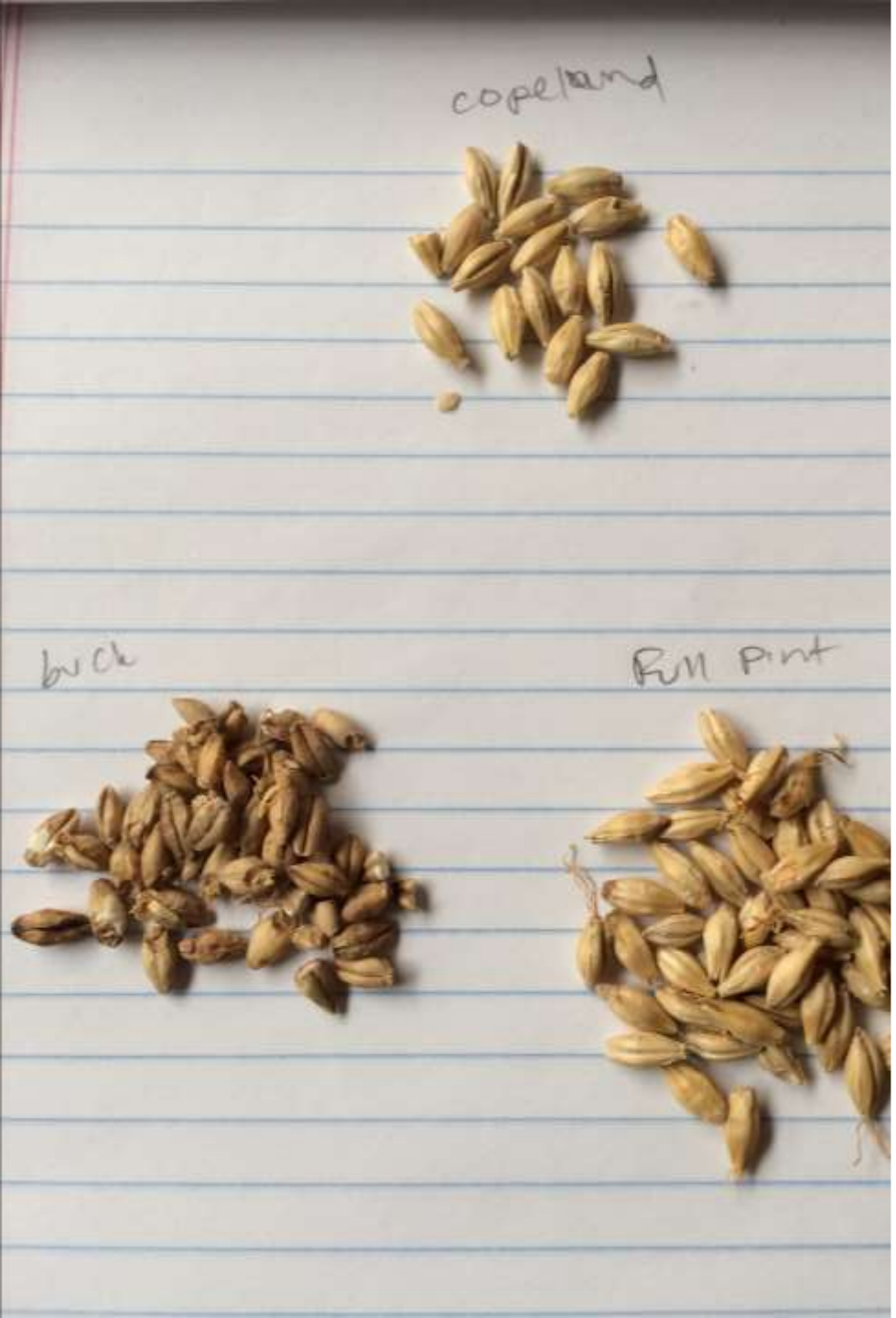
Karl Kunze

Introduction

- Karl Kunze
  - PhD Candidate- Mark Sorrells with the Small Grains Breeding Program
  - Research Interests
    - Organic Naked Barley-Weed Competitive Ability & Disease Resistance
    - Conventional Winter Malting Barley-Germination & Dormancy, Breeding Methods
  - Larger goals
    - How can we leverage technology in organic research
    - How can develop relationships between breeders, farmers, maltsers, chefs, and consumers to breed crops that benefits the interests of everyone involved
    - Development of new crops into new markets

Developing Multi-use Naked Barley for Organic Farming Systems I & II

- Funded by USDA-NIFA-OREI for three years 2017-2020
- Currently renewed for 3 years 2020-2022
- Participating States
  - Oregon, Wisconsin, Minnesota, California, and New York
- Main Objectives
  - Applied Field and Breeding Research
  - Barley Education
  - Outreach events



What is naked barley?

- Controlled by the *nud* gene that determines naked vs. covered(or hulled)
- Arose as a single mutation in ~ 6500 BCE
- *Nud* allele present-dominant- hull adheres to the kernel
- *nud* allele absent-recessive- hull falls off the kernel at harvest
- Traits related to Naked Barley
  - Threshability
  - Embryo Damage and Germination
  - Seedling Vigor
  - Test weight/Yield
  - Disease resistance
  - Beta Glucan content
- For the context of this webinar, I will refer to hulled barley as **covered barley** and the free-threshing hulless barley as **naked barley**

Organic Naked Barley Regional Trials

- Trials to evaluate potential variety releases, future breeding lines and develop experience in growing naked barley
- Each Trial consists of 20-25 lines and 3 replications, both separate winter and spring trials
- Grown in different locations around the country
  - NY & OR-Winter and Spring all 3 years
  - WI-Spring 2 years and 1 Winter
  - MN,WI-Spring 3 years
- Learn which lines grow well in which regions
- Make selections from our Project to develop breeding populations for part II of the multi-use naked organic barley project

Diversity Panels

- “Pre-breeding selection”
- Collection of lines from parents that are crossed from wild relatives to elite lines
- Some of parent lines are sourced from barley landraces around the world
- Both Spring and Winter Diversity panels
- ~380 lines tested for the Winter Diversity Panel
- ~250 lines tested for the Spring Diversity Panel
- Locations
  - NY & OR-Winter and Spring
  - WI & MN-Spring
- Take notes on the diversity panel for multiple uses
  - Genome wide association studies
  - Find potential lines with traits that we as breeders would like and cross them
  - Efficient way to measure some traits of interest for many lines in a more manageable field size

Traits of Interest

- Quality Traits
  - Malting, Food, and Feed Traits
- Agronomic Traits
  - Yield
  - test weight, heading date, height, lodging etc..
  - Pre-harvest sprouting measurements
- Disease Traits
  - Region specific: Major disease concerns
    - Fusarium head blight
    - Smut
    - Rust
    - Spot Blotch
- Weed Competitive Ability
  - Vigor
  - Barley growth measurements
  - weed measurements
  - Aerial Imaging & Drones/UAV

Quality Traits

Malting Quality

- Barley has been the optimum grain for malting and brewing/distilling
- High majority of barley for malting is with covered barley
  - Protection of kernel
  - Hull filtration
- Advances in brewing technology can mitigate disadvantages of no hull
- Naked Barley has potential for higher levels of malt extract
- Traits that breeders select for
  - Large and soft kernels
  - Round and plump grains
  - Low/moderate Beta-glucan 6-12%
  - Mid range protein 10-12%

Food Quality

- Barley has rich traditional and culinary significance around the world, but has become significantly less common until recently
- Demand for food barley is increasing based on knowledge of the benefits of whole grain nutrition and fiber
- Uses of Food Barley
  - Flour
- What to select for in Food Quality
  - Moderate to high beta-glucan
  - High Protein
  - Whole grain nutrition-Minerals and Antioxidant capacity

Feed Quality

- Most global barley production is used for animal feed
- Feed barley lines are hardy plants that can produce high yields and are not constrained by malting/food quality bottlenecks
- Naked Barley is been heavily selected in Canada to feed non-ruminant animals, such as Pigs
- More information on grain quality will be a separate webinar

Brief Overview of Quality Traits in field

- Quality traits vary greatly by line and by environment
- Most naked lines are quite high in beta glucan
- Will need to breed naked barleys that have considerably lower beta glucan
- Winter
  - NY
    - Most protein values 10-13%
    - Beta glucan-very high for some lines~500(target range is <200)
- Spring
  - NY-Protein values were very high(>12% for many lines), particularly in drought years
  - Beta glucan was also very high for most lines >300

Agronomic Traits

Winter and Spring Barley Variety Trials

- What is winter barley?
  - Barley that requires a period of vernalization, or period of cold temperatures, before the barley can flower
  - Associated with this trait are genes that aid in some degree of winter tolerance
  - More sensitive than other cereal crops
- Spring Barley
  - No vernalization requirement
  - If planted in the fall, initiation of flowering would occur in winter and kill the plant

Where to Grow Winter Barley

- Where can you grow it?
  - Currently, the northern range for winter barley is the NY and PA in the North-east and most areas in the Pacific Northwest
  - NE-plant in mid-September to October
  - OR/WA plant in mid October
- Winters in the mid-west, New England and Canada are too severe for reliable winter barley

Life Cycle of Organic Winter Barley

- Vigor-right after planting
  - Depending on planting date and onset of freezing temperatures, winter barley can become very well established
- Vigor and canopy growth
  - March(OR) or April(NY)
  - Barley growth initiates once daily high temperatures start reaching ~45-50F
- Barley Heading
  - Mid April in OR & Late May-Early June in NY
  - Too early of heading in PA(mid May) occasionally results in some frost damage issues
- Maturity and Harvest
  - NY-harvest winter barley early July
  - OR-late June/early July
  - WI- mid July

Where to Grow Spring Barley

- Predominant type of barley grown in Midwest, Upper New England, and Canada grain regions
  - Currently, winters are too severe
  - Drier climates, especially towards the Dakotas makes for near ideal barley growing conditions near maturity
- Spring barley can be challenging in Pacific Northwest, milder NE regions
  - Mid-summer humidity & unpredictable rain events
  - When planted in April, barley is competing more with the weeds for light and resources

Life Cycle Growing Spring Barley

- Late March/Early April for all regions(maybe later in NY if ground is too wet)
- Barley tillering and vegetation growth starts approximately 2-3 weeks after planting
- Heading
  - Late June/early July in most regions
- Maturity and harvesting
  - NY- Late July
  - Mid-west and OR-Early to mid August

Winter Survival

- What is Winter Survival?
  - Ability of barley to survive winter conditions
  - Visual percentage estimate that starts when daily temperatures are consistently above freezing
- What factors affect winter survival
  - Degree of establishment before freezing temperature
  - Severity of the winter
  - Snow cover
  - Field defects
- Challenges with winter survival
  - Difficult trait to quantify accurately due to numerous environmental factors
  - Winter survival pressure is variable, so we can only select for it every 2-3 years in NY when we have appropriate conditions
- Quick Example of variability
  - We have a line “10.1150” that had 70-80% winter survival for the past three years 2017-2020
  - This year in 2021, the winter survival for “10.1150” was 10% even though the winter was mild

Winter Survival

- Midwest-Severe winters of the mid-west are the major limiting factor of growing winter Barley
- NY region
  - Most lines of our regional trials have decent winter survival but overall, there is lower survival compared to our conventional winter barley
  - If our winter naked barley diversity panel certainly had variation in winter survival, indicating that genetic variation exists
- Major takeways for winter survival
  - **Multiple years** of testing is needed to ensure that winter naked barley varities perform well in NY winters
  - Do not plant too late or else winterkill will significantly increase
- Environmental factors play a key role in winter survival
  - Do you have snow cover if temperatures are low
  - Do you have decent soil structure and even fields(no water collection areas, uneven ground)

Height and Lodging

- Height is an important characteristic for barley
  - Tall barley can be useful for WCA but also increases susceptibility to lodging
  - Too short barley is often less vigorous, a particular problem in organic conditions
- Lodging-where barley falls over
  - Components of lodging
    - Height
    - Weak stem strength
    - Over Fertilization
    - Soil structure
    - Unknown
  - Weather events

Height and Lodging Results

- Generally, heights are taller for winter lines compared to spring
  - 70-90cm winter
  - 50-70cm springs
- Lodging
  - Relatively minor issue for winter lines, some spring lines were susceptible
    - Purple Valley was particularly susceptible

Pre-harvest Sprouting

- Pre-harvest sprouting- when barley grain starts germination in the field before it is harvested(abbreviated PHS)
- A particular problem in NY, where rain events can occur during harvesting windows
    - We had a particularly bad year for spring barley in 2018
- Selection for high germination, particularly in some spring barley germplasm, has inadvertently made barley extremely susceptible to PHS
- In our program, we test most of our trials(both barley and wheat) for PHS
    - Harvest spikes at physiological maturity
    - Dry the samples for 3-4 days
    - Place in a mist chamber for 3 days
    - Score 5 spikes for each entry
- Scores are based on root and coleoptile growth on a 0-9 scale

Pre-harvest Sprouting Results

- Winter Variety Trials
  - Most lines had very low pre-harvest sprouting(0-2)
  - Lines that were susceptible were expected to be PHS susceptible(5-7)
- Spring Variety Trials
  - Some inconsistent data due to stressed environments where our spring barley grew(within sample scores varied significantly)
  - More lines had susceptibility to PHS(3-6)

Yield Winter Barley

- Yield of some naked barley lines is comparable to conventional lines in NY
- Well managed organic land is important
- The cooler temperatures in April and May are particularly favorable for winter barley growth and development
- Weed pressure was insignificant for winter naked barley in NY locations
- The lack of hull reduces yields by about 13% in naked barley compared to conventional

Winter Barley Yields New York(3 years)

Entry	Yield kg/ha	Bushel /acre	Yield rank
1_4	5576.8	83.09	2
10.1150	5137.1	76.54	12
10.1618	5197.8	77.45	10
AMAZE 10	4896.9	72.96	16
Buck	5212.5	77.67	8
DH130910 (Covered)	5802.5	86.46	1
DH133535	5075.3	75.62	13
VA15H-79 WS	4551.5	67.82	22
mean	**5139.1**	**76.57**	
Coefficent of Variance	0.145		

Yield Winter Barley

- For increased yields, we will need to develop breeding lines from parents that have shown high performance in target environments
- Some environments are still too cold and extreme for growing winter barley but..
- As climate change affects the growing conditions across the US, it could provide some benefits in regards of longer growing seasons in more regions of the US

Winter Barley Yields Oregon(2 years)

Entry	Yield kg/ha-OR	Bushels /acre	Yield Rank
1_4	3790.48	56.48	2
10.1492	3478.69	51.83	5
Alba (covered)	4273.35	63.67	1
AMAZE 10	2045.8	30.48	21
Buck	2911.29	43.38	15
DH133535	2965.98	44.19	13
VA15H-79 WS	2091.3	31.16	20
Mean	**3072.67**	**45.78**	
Coefficent of Variance	**0.267**		

Winter Barley Yields Wisconsin(1 year)

Entry	Yield kg/ha	Bushels /acre	Yield rank
1_4	2343.99	34.93	7
AMAZE 10	2384.16	35.52	6
Buck	2743.37	40.88	2
DH133535	2265.61	33.76	8
Local line(Covered)	2206.43	32.88	10
VA15H-79 WS	1709.63	25.47	17
mean	**2578.71**	**38.42**	
Coefficent of Variance	0.154		

Organic Spring Barley Yields

- Spring barley yields are not very high for NY, MN and WI
- Germplasm is more adapted to pacific northwest conditions
- Barley does not like high temperatures during development
  - Problematic in NY and mid-west
- Weed pressure is high
  - Spring barley does not have as much of a headstart compared to winter barley
- Organic land management
  - You **need** well managed Organic land

Genotype	Yield-NY	Yield rank-NY	Yield-MN	Yield rank-MN	Yield-WI	Yield rank-WI	Yield-OR	Yield rank-OR
BB5	896.19	19	996.66	14	531.72	20	5903.01	3
Havener	1083.88	14	1045.17	12	707.99	9	5596.09	6
MS1054111-01	1684.71	1	1202.17	6	699.73	10	4919.07	12
mean	**983.12**		**658.85**		**725.52**		**4069.18**	
Mean bushels/acre								
Coefficent of Variance	0.524		0.449		0.051		0.086	

Threshability

- Threshability-capacity in which the hull completely dissociates from the grain
  - We have found in our trials that a in a number of our naked barley lines, that the hull does not always want to fall off the grain
  - Some lines are a bit “modest” so to speak
- We’ve had to pay closer attention and score our lines both in the variety trial and diversity panel
- Winter grains-Some degree of hull adherence occurs, but most lines have decent threshability
- Spring Grains- threshability was an issue for all locations
- Takeway: The “naked” phenotype is more complex in different enviornments

Storage

- Every state has different stages in storage and upscaling of varieties
- NY-we have an established foundation growout system but lack the capacity of the breeding program to grow out and store large amounts of grain
- OR-down stream market chains that accept naked barley are an issue
- More thought and consideration is needed at this stage in the value chain

Barley Diseases

Fusarium Head Blight

- Fusarium Head Blight(FHB) is a serious disease for both barley and wheat in the NE and mid-west
- Fusarium's alternate host is corn stubble, which results in excess inoculum for most agricultural regions
- The disease grows in the spaces between kernels, making 6-row barley particularly susceptible
- The FHB growth produces a toxin called Dioxyonthalenal (DON), a vomitoxin that is not something we want in our foods
- Pesticides at flowering reduce FHB growth but we do not have that in organic agriculture

Fusarium Head Blight nursery

Entry-Winter	FHB Severity	FHB Incidence	DON ppm
1_4	6.8	26.8	11
10.1150	35.3	81.8	
10.1618	31.8	84.3	20.3
AMAZE 10	15.6	77	13.5
Buck	21.5	63.5	23.1
DH130910 (Covered)	11.7		23.9
DH133535	9.8	46.8	50.9
VA15H-79 WS	30.6	70.2	27.9
mean	**35.14**	**75.18**	**22.85**
Coefficent of Variance	0.21	0.19	0.22

- In NY, we have a separate nursery dedicated to screening for FHB and DON
- Entries are inoculated with Fusarium head blight at flowering and scored 3 weeks later
- Winter barley-2 years
- Spring barley-1 year
- DON values should be **<1 ppm** for food and malt quality barley
- Major Takeaway-most lines are highly susceptible, particularly 6 row lines
- Overcoming FHB should be a top priority for organic grains breeding in humid climates where FHB thrives

Smut

- A seed borne disease in both wheat and barley
  - Both loose and covered smut
- If you see smut in your grains contamination has already occurred
- Seed treatments has made smut a minimal problem in conventional barley
- Organic solutions are limited, so genetic resistance is one main solution
- We've been working on selection for genetic resistance in organic barley

Rusts

- Stripe Rust
  - major disease in the Pacific Northwest- where the cool, wet weather in the winter favors its development
  - Resistance is achieved by fungicides and selecting resistant varieties
  - Variability in resistance exists in tested lines
- Leaf Rust
  - Disease that mainly affects spring barley in the mid-west, southeast and occasionally the NE

Scald

- Leaf fungus that prefers cool temperatures during barley vegetation growth
- Found predominately in winter barley lines
  - Symptoms are mild to moderate depending on variety, both in NY and OR
- Selection for resistance has been difficult, as plant pathologists have much difficulty isolating the pathogen
  - Successful isolation is also suggested to be race specific
- In our experience, both with organic and conventional winter barley, symptoms can be highly variable, even within a field
- Variety selection will be essential since fungicides are not an option

Spot Blotch

- Barley fungus that overwinters in barley stubble, can also be seedborne
- Thrives in warm, humid climates and is particularly problematic in spring barley
- Spot blotch symptoms appear after barley flowers and symtoms be accelerated by rain events
- All of our spring lines are susceptible, but to varying degrees
  - CDC lines have some resistance
  - Limited variation in susceptibility in our diversity panel(most lines were susceptible)
- Timing of scoring is important
- Solution to spot blotch: Select for resistance

Disease Resistance: Organic Grains

- Cereal diseases are most likely going to be the largest bottleneck in organic grain development
- Selection for resistance in winter and spring organic barley for their respective pathogens will need to rely on techniques beyond just field phenotypic evaluation
  - Marker assisted selection
  - Pathogen isolation and marker development
- Cultural practices can play a large role in mitigating disease pressures as well
  - Crop rotations
  - Where/when you plant

Winter Barley Management Takeaways NY

- Pros
  - If winter barley is planted early enough, and the winter is not too extreme, winter barley performs very well in organic conditions
  - Weed pressure in our farm research systems has been minimal
    - Some chickweed
  - In our 3 years of growing organic winter naked barley, we have not needed to perform any kind weed management
    - Maintaining soil structure from the winter minimizes disturbance in the soil, preventing opportunities for weed seed germination
- Cons
  - Many lines were very susceptible to Fusarium head blight, a fungus that produces DON, a vomitoxin
  - Yields still need to be improved

Spring Barley Takeaways NY, MN and WI

- In our 3 years of growing organic spring barley, 2 out of the 3 have been very challenging
  - Late planting dates(early to late May)
  - Drought like conditions during vegetative growth
  - Poor organic land at secondary locations
- Yields in 2018 and 2020 were very low
- Needed persistent weed management
- Barley diseases a constant threat
  - FHB and Spot Blotch
- Significantly more breeding and evaluation will be needed to find spring barley germplasm adapted for NY, MI and WI conditions

Where to Purchase Naked Barley

- Winter Naked Barley
  - Buck-Washington State Crop Improvement
  - Streaker-Hummingbird Wholesale or Territorial
    - Both have been grown in acre grow outs here in NY
  - Amaze 10-Virgina State
- Spring Naked Barley
  - CDC Clear, CDC McGuire*, and CDC Ascent-CDC Canada
  - Meg's Song and Havener-Washington State Crop Improvement
  - Purple Valley and Karma- Tuality Grains

NY: Winter Naked Barley Breeding Population

- Crossed top preforming naked barley lines to covered lines with good malt quality and yield in Spring 2018
- Conventional covered lines in crosses:
    - KWS Scala- high yield, good malt quality, low FHB and DON
    - DH130910(Lightning)-high yield, good malt quality, moderate FHB and DON
    - SY Tepee-high yield, good malt quality, low FHB and DON

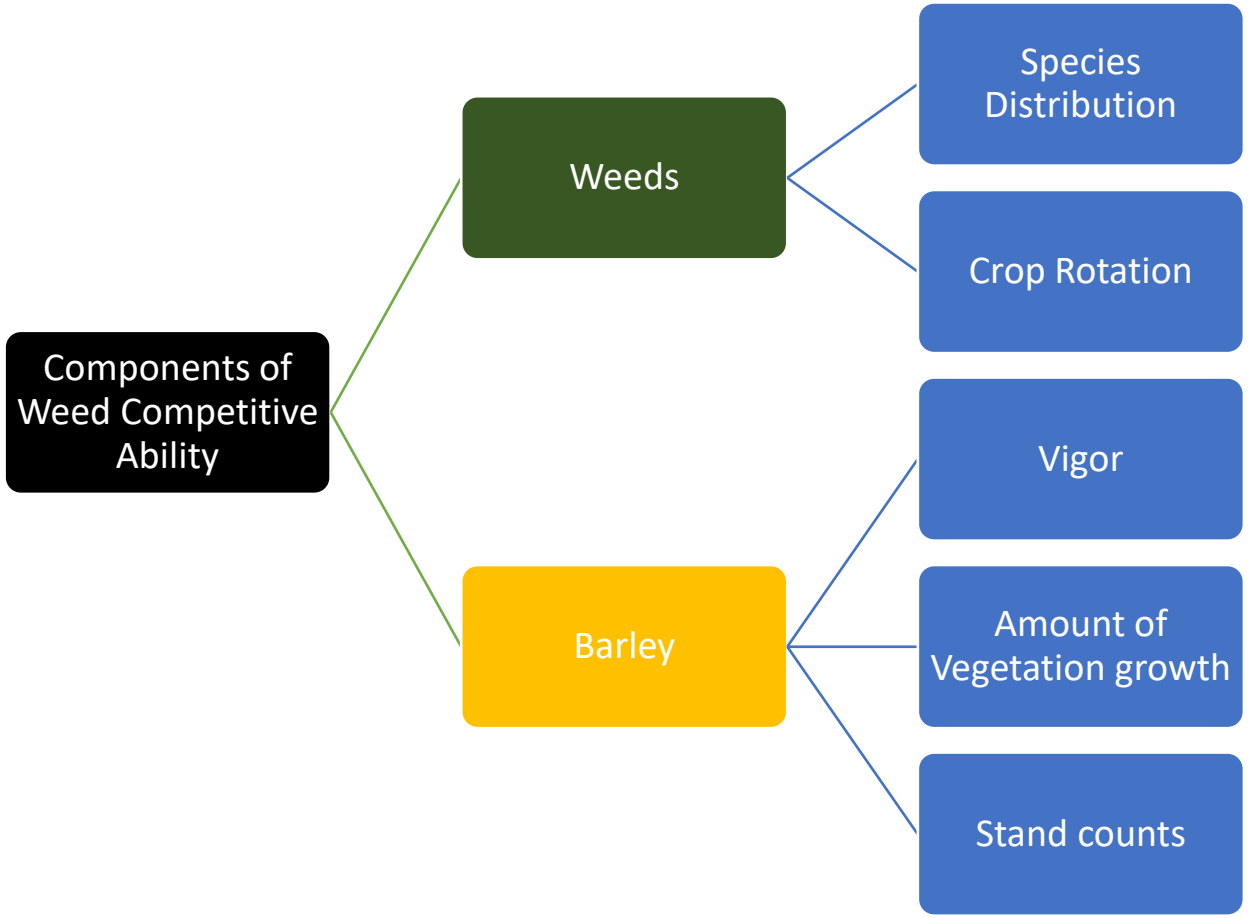
- Resulted in ~450 F_3 lines evaluated in an organic field environment for the 2020 field selection

Weed Competitive Ability

Weed Competitive Ability(WCA)

Definition: Ability for a crop to compete against or tolerate weed pressure

- Significant problem in Organic Systems versus conventional barley
- Difficult to measure due to the dynamics of weed populations
- Highly Dependent on the environment

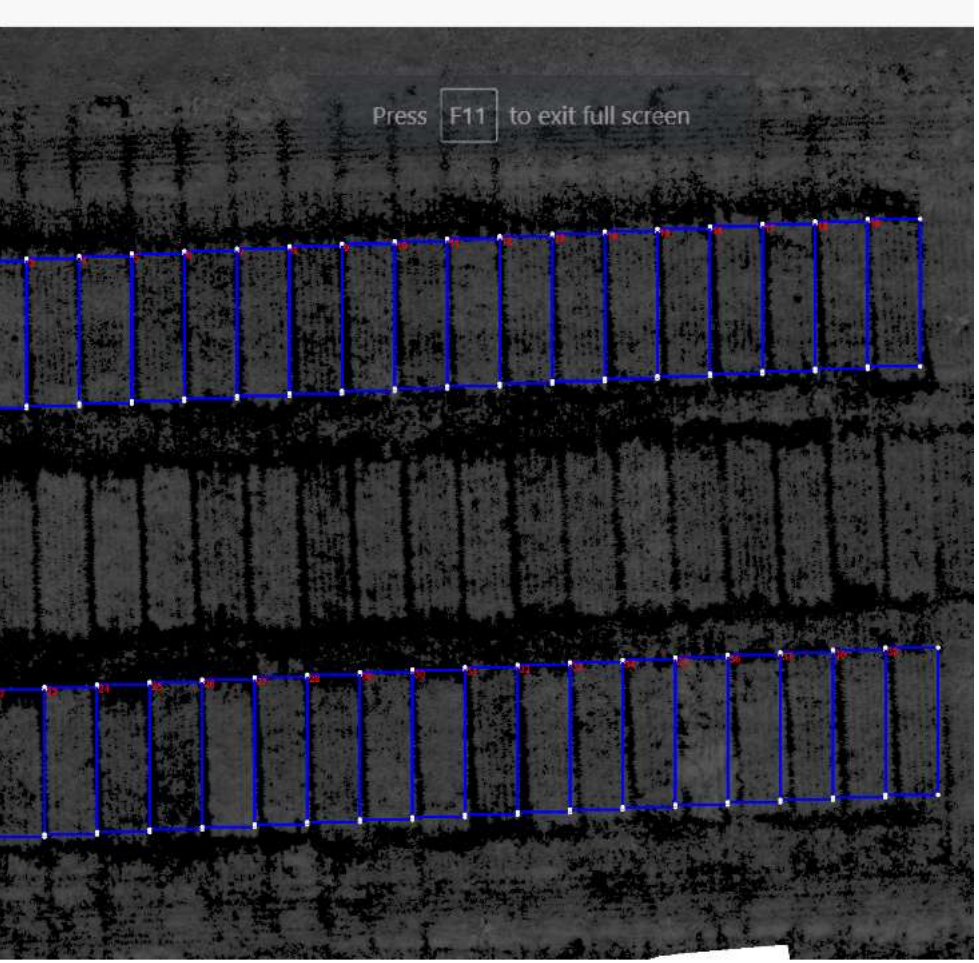


How do we Measure WCA?

- The project has been measuring different components of barley vigor as well as weed estimates
  - Barley/Weed/Ground cover estimates at multiple time points
  - Vigor ratings
  - Early Height
- Results have been a challenge to model accurately due to the highly environmentally specific nature of weeds in barley fields
- Weed seeding is one possible solution, but consistent weed growth doesn't always cooperate, even when you want them to grow!

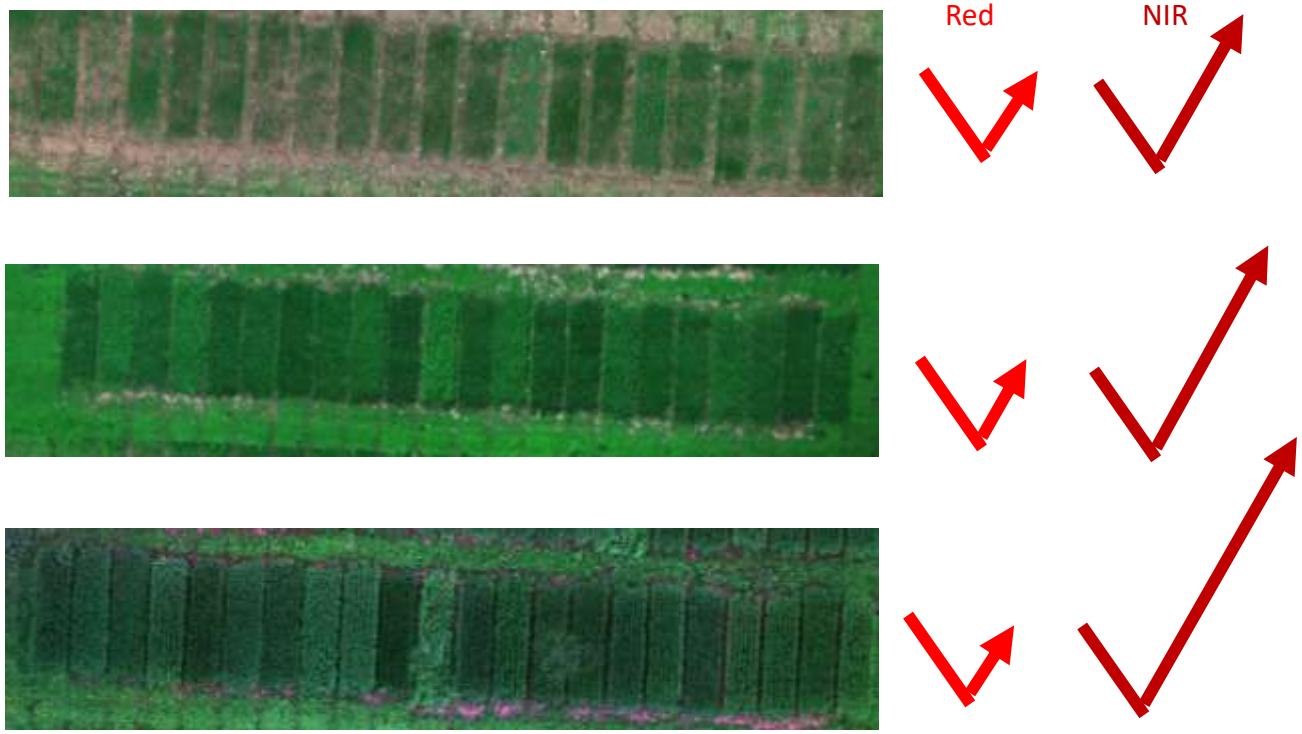
Possible Solution: Utilize Aerial Imaging

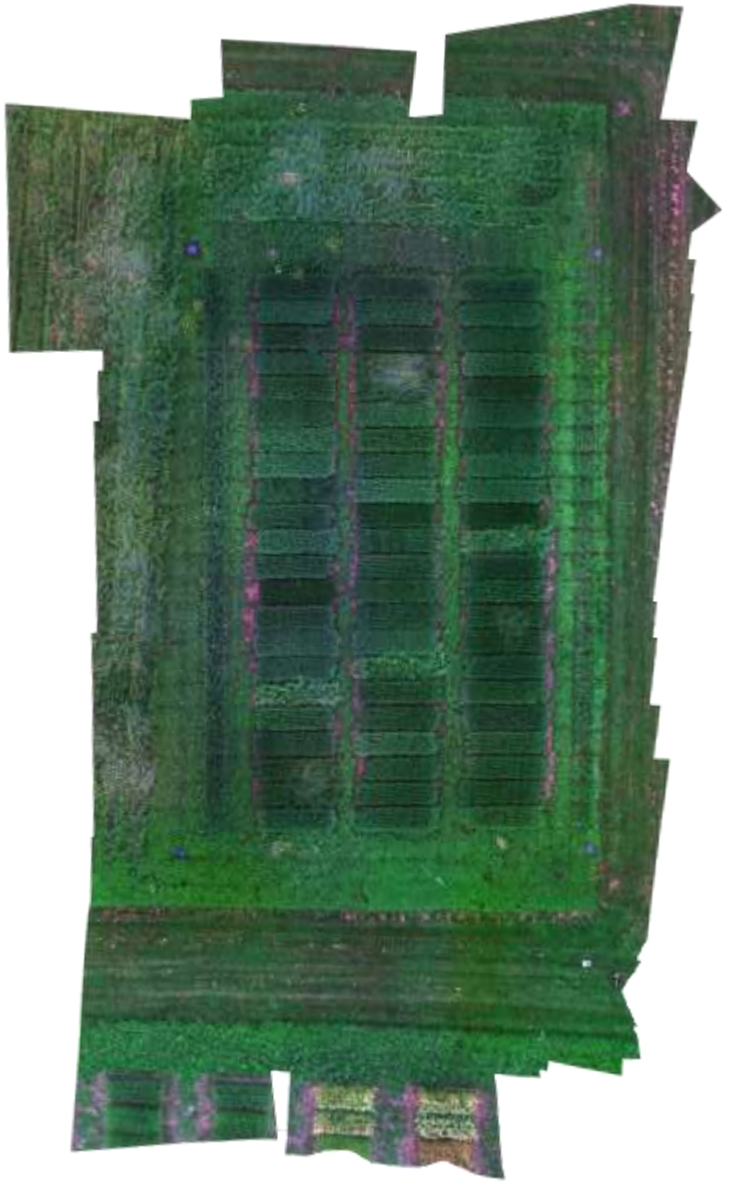
- UAV(Unmanned Aerial Vehicles, or “drones”) are becoming a potentially useful tool for modeling plant growth in the field
- Camera’s attached to the UAV can capture light reflectance data that can be used to measure the health of the barley plots and the amount of vegetation growth
- If we can measure vegetative growth repeatedly over the life cycle of the barley, we may be able to select for barley lines that develop vegetative growth at a quicker rate
- Faster vegetative growth earlier in the season could be a useful method for the barley to outcompete the weeds



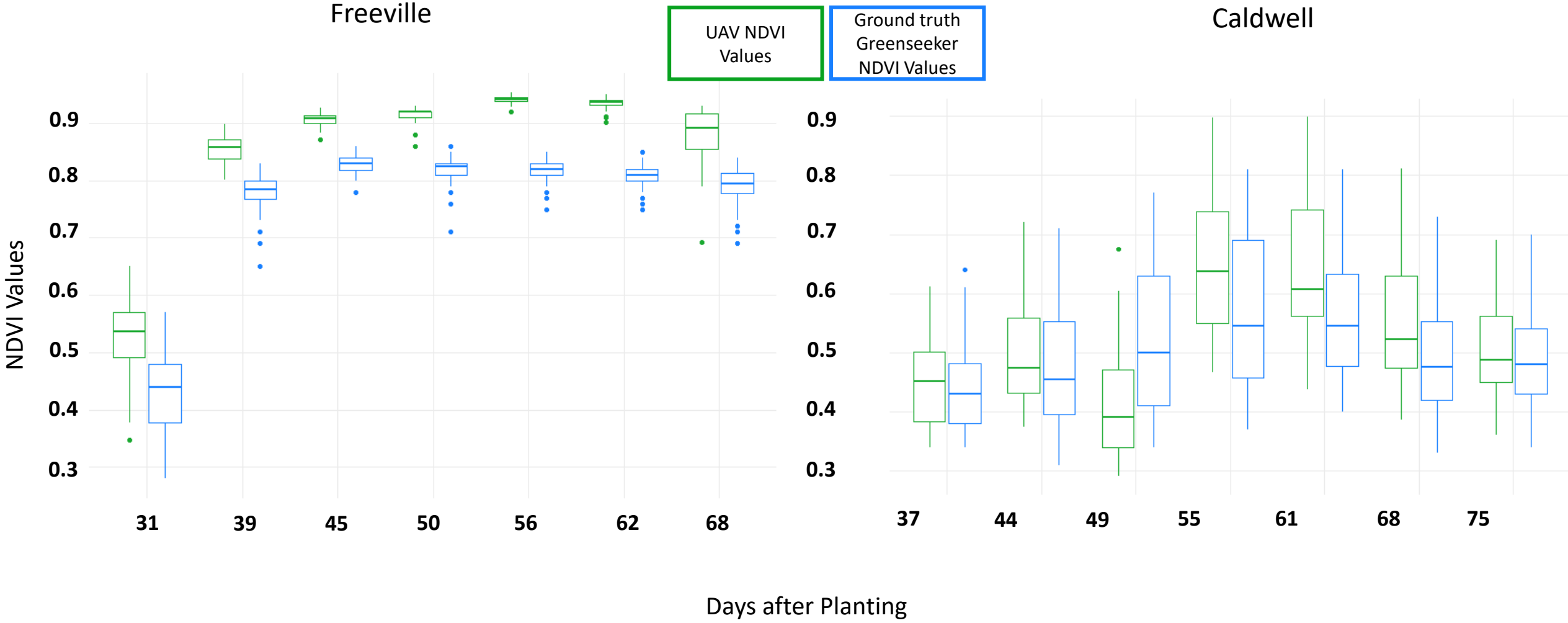
Basic Process for Aerial Imaging

- Develop a flight path for your fields
- On target days, you fly the UAV using the flight path
- Collect images from the attached camera and use a processing software
  - Pix4D or OpenDrone Map
- Used stitched images in a plot polygon pipeline
  - Imagebreed
- Pixel Values are returned for each plot
  - Can calculate indexs that are related to vegetation growth for each plot, such as NDVI


Red
NIR



Distribution of NDVI Values Over Time 2019



Applications in Organic Plant Breeding

- Provides a highly quantitate method of classifying vegetation growth
  - Higher precision than visual estimates
- Could have even greater applicability where vegetative biomass is the end product
  - Alfalfa
  - Cover crops
- Work that is needed to move Aerial Imaging to organic systems
  - Learning to set up flight paths and understanding software can be tricky
  - Cameras and drones are becoming more affordable, but they are still somewhat expensive
  - Software for stitching images is either hard to use for new users(Drone Map) or very expensive for a license(Pix4D)
- Difficult for aerial imaging processes to differentiate crop vegetative growth from weed growth

Next Steps in the Project

- Developing a naked barley **N**ested **A**ssociated **M**apping population(NAM) for marker assisted selection
  - 3 parent lines are common in all crosses
  - 5 lines crossed are specific to each participating program-OR, CA, WI, MN and NY
  - Lines were selected from diversity panels and from high performance lines tested in each program
- Utilize both marker assisted selection at early stages of breeding development and send partially replicated lines to each program for field selection

Questions?

- Feel free to email me at *khk44@cornell.edu*
- Social media
  - LI: Karl-Kunze
  - Github: karlkunze
  - Twitter: @kunzx37
- Both projects are part of research grants awarded from the USDA OREI
- Conventional winter malting barley work is funded by New York State Agriculture and Markets

END