The Future of Plant Breeding: Synthetic Biology

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Crop Design

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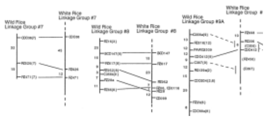
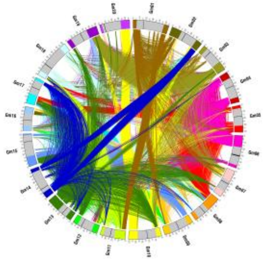
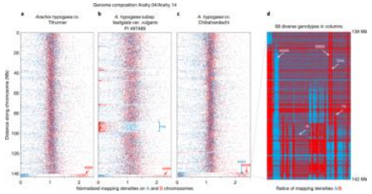
Career

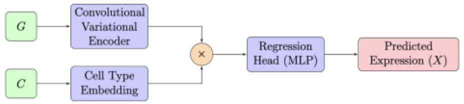
Keywords: Plant Breeding; Chromosome Biology; Genomics; Polyploidy; Evolution/Domestication; Crop Wild Relatives

Potato	WildRice	Soybean	Soybean	Corn	Corn
Rice	Rice	Rice	Rice	Soybean	Soybean
sorghum		Common bean	Peanut	Canola	Peanut
		Legumes	Legumes	Wheat	…
				Cotton	









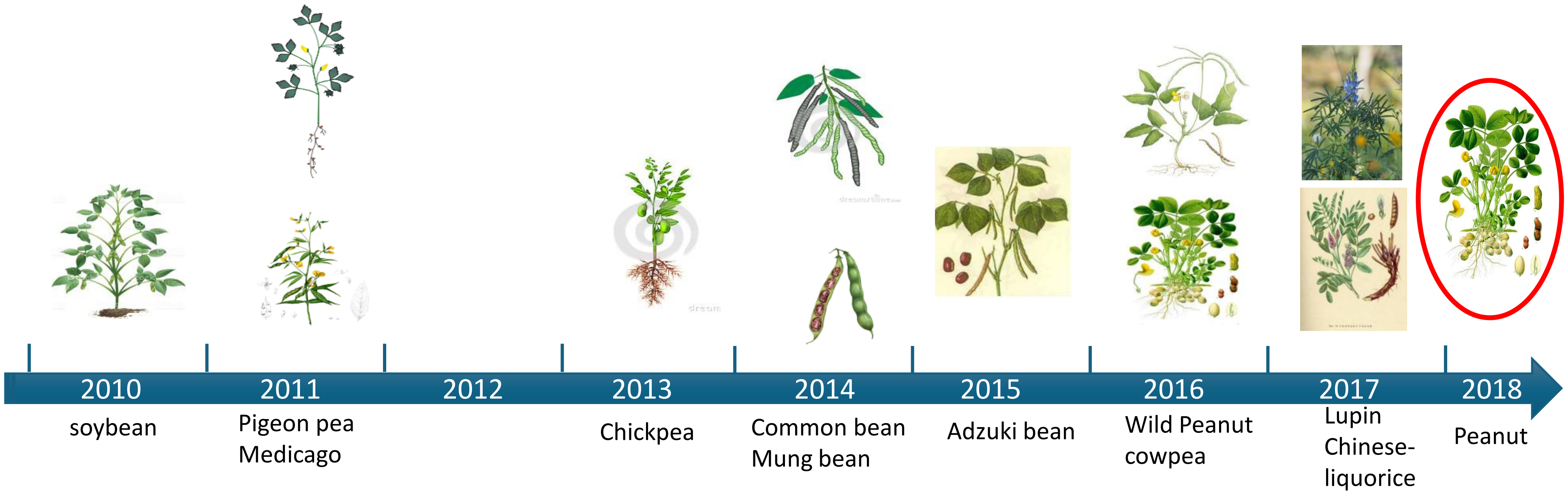
1996 1999 2001 2011 2019 2024

Legume Reference Genomes

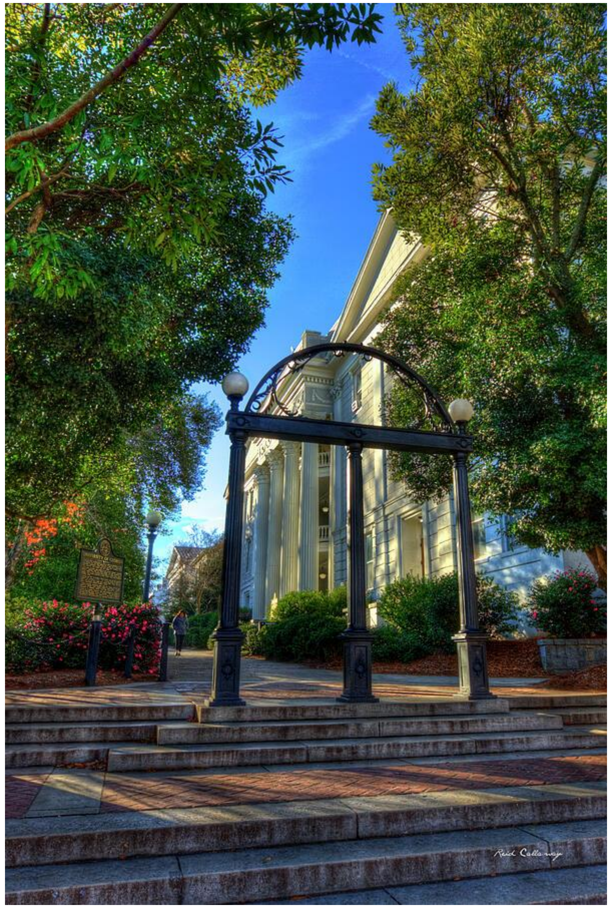
Fabaceae: Third largest family of flowering plants

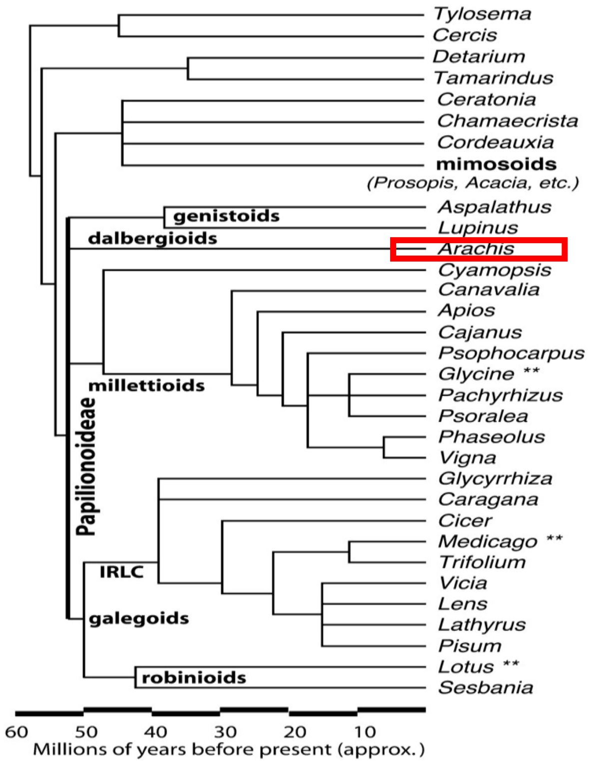
- Many economically important species
    - Trees, forages, grains, etc.
    - Bean, soybean, alfalfa, peanut, pea, chickpea, pigeonpea, lotus, lupins, etc.
    - Most economic crops in Papilionoideae

- Known for nodulation—fixation of atmospheric N



A story of peanut—an iconic American crop





Peanut (*Arachis hypogea)*

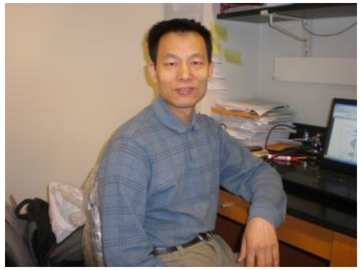
- Native to South America
- Domesticated in Peru
- Geocarpic—seed develop underground
- Important protein and oil source
- ~2.7 Gbp genome
- 100’s of wild relatives

Wild peanuts are endemic to South America

David and Soraya Bertioli

Carolina Chavarro

Carolina Ballen-Taborda



Dongying Gao

In total about 100 wild species

Photos José F.M. Valls

The peanut genome – Two subgenomes

A-genome diploid wild

A. duranen

2n=20

B-genome diploid wild

A ipaensis

2n=20

ication

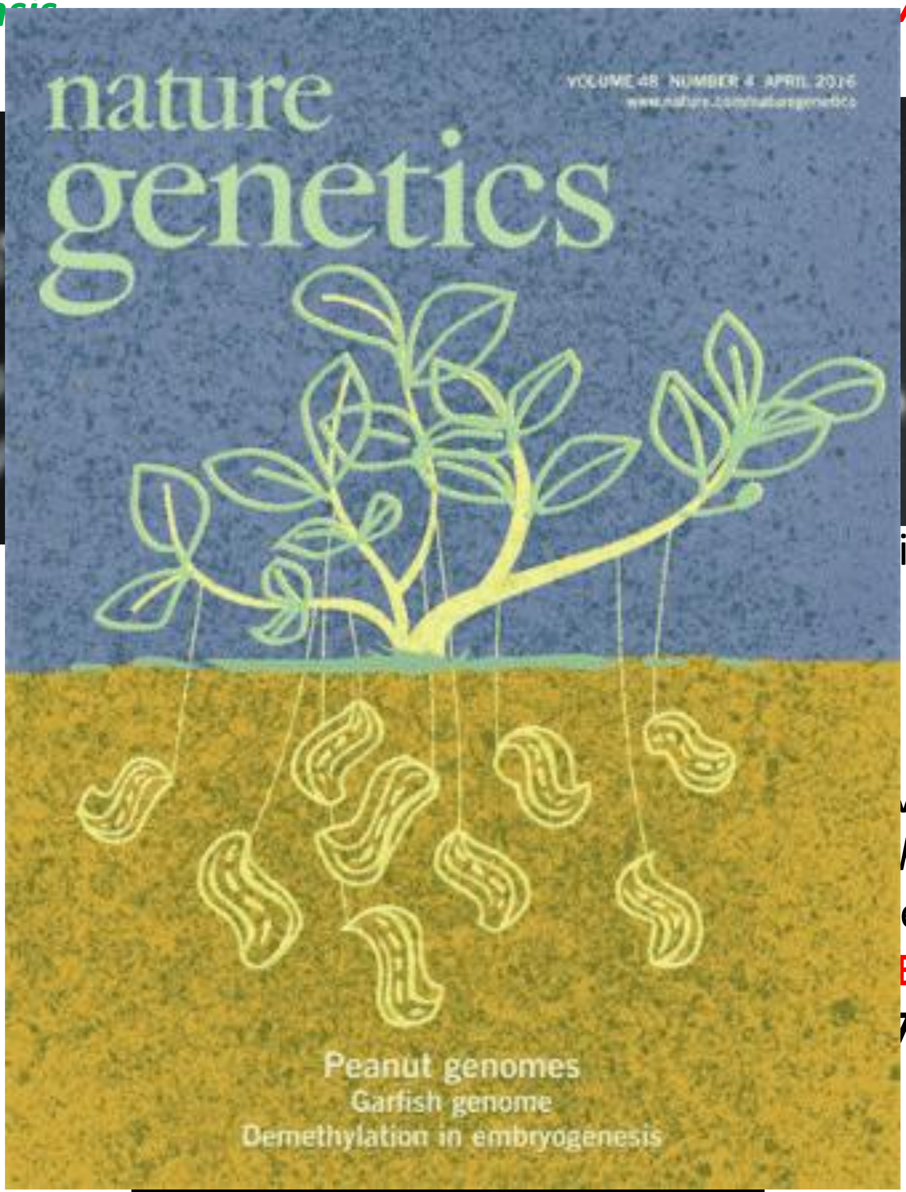
vated

his hypogaea

etraploid 2n=4x=40

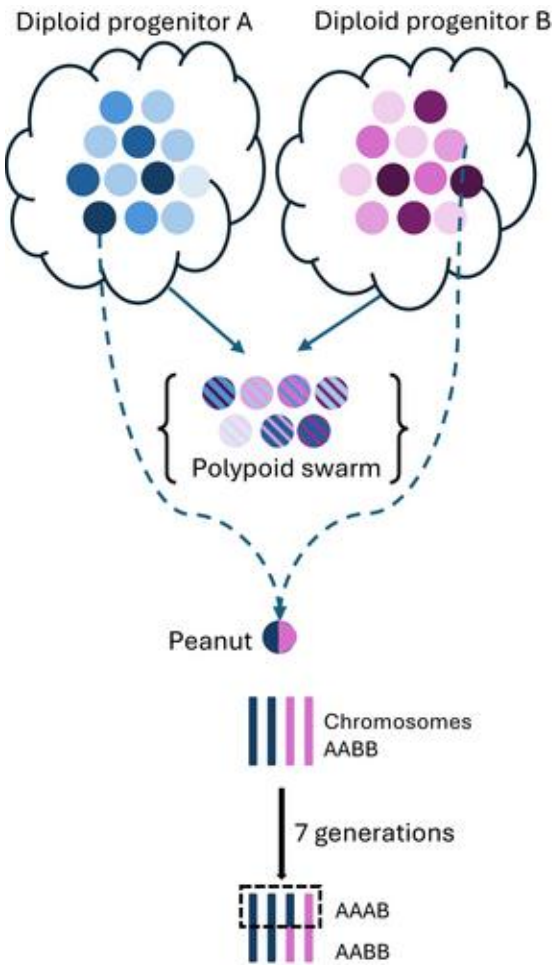
B

7 Gb



Genome size estimates:
Temsch & Greilhuber, 2000, 2001

Peanut domestication bottleneck



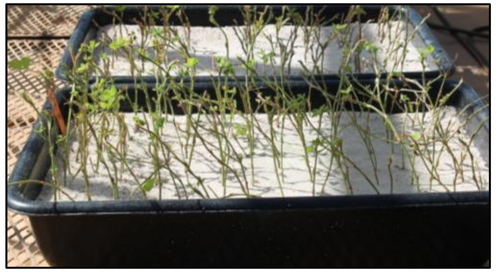
- Founders all diploid species. (*A. duranensis* and *A. ipaensis*), non-sympatric
- Polyploidy and domestication were coincident (<9,000 yrs ago)
- A single event ??!
- B genome (*A. ipaensis*) is 99% similar to B subgenome
- **Useful traits left behind!**

Earliest radiocarbon dating of peanut is ~7-10K yrs BP (Dillehay et al., 2007, Science)
Molecular dating of polyploid is 9 yrs BP (Bertioli et al. 2016. Nat Genet.)

Resynthesis of domesticated peanut

Manual cross B x A diploids

F1 sterile hybrid



Colchicine treatment

Cutting growth

Peg emergence

Pod development

Interploidy manipulations: peanut lines with improved disease resistance

Runner-886 Line-111-10-461

Original cultivar

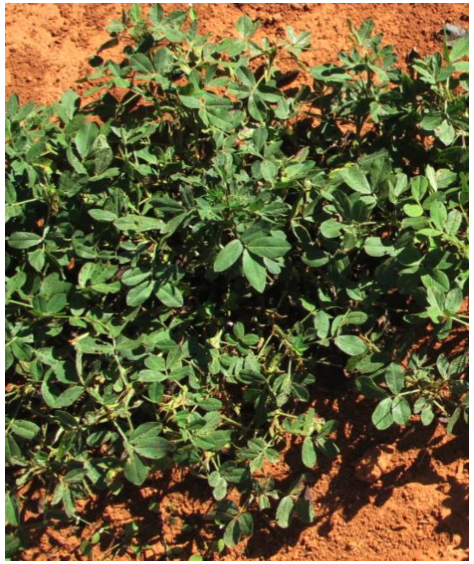
Runner-886

end of season Late Leaf Spot damage

pod types

Improved line with disease resistance from wild species

Line-111-10-461



good agronomic traits

Crop Design

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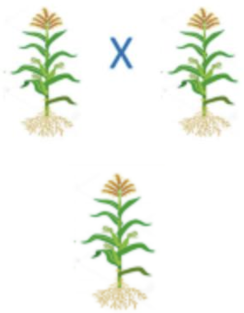
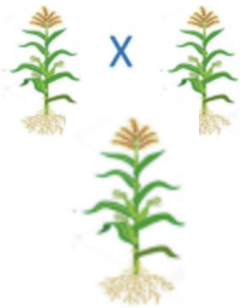
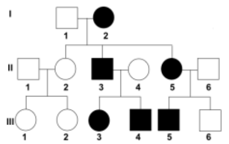
Revolutions in plant breeding



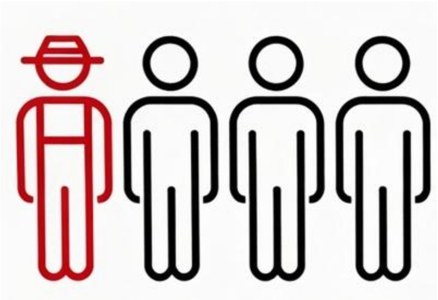


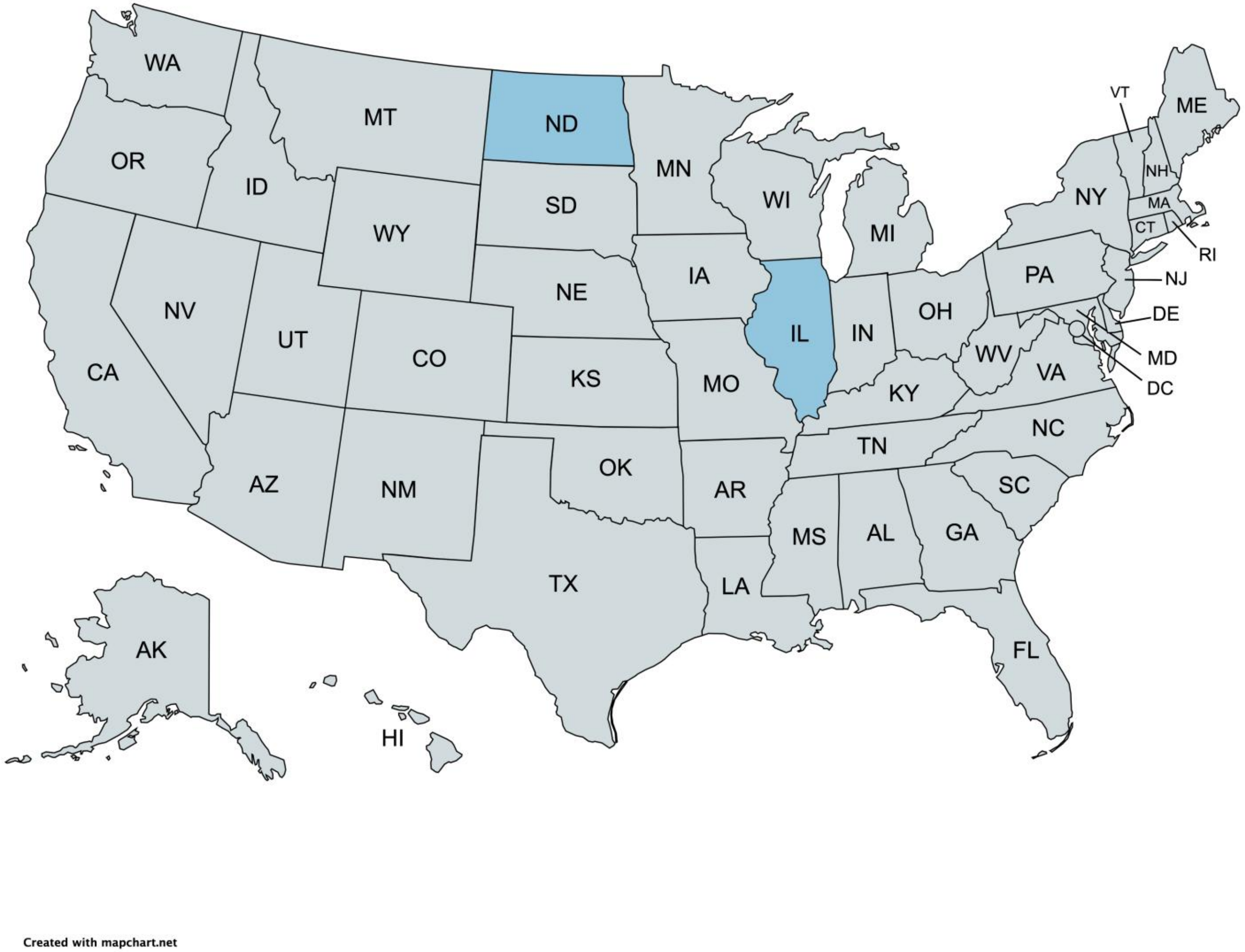


Selective Breeding	Hybrid Breeding	Genomic Breeding	Crop Design
Thousands of years	1930s	2000s	Future
Desired traits incorporated with many other traits that have be selected against	Only in a few crops (corn), big yield boost	Informed parent and progeny selection	Design-build-test-learn cycle using all tools to predictively create genotype for target environment and output
Random, slow, large populations, lots of testing	Similar process to selective breeding	Less random, faster, more targeted populations and reduced testing	Faster yet, uses all tools, informed by end users, requires technology at scale

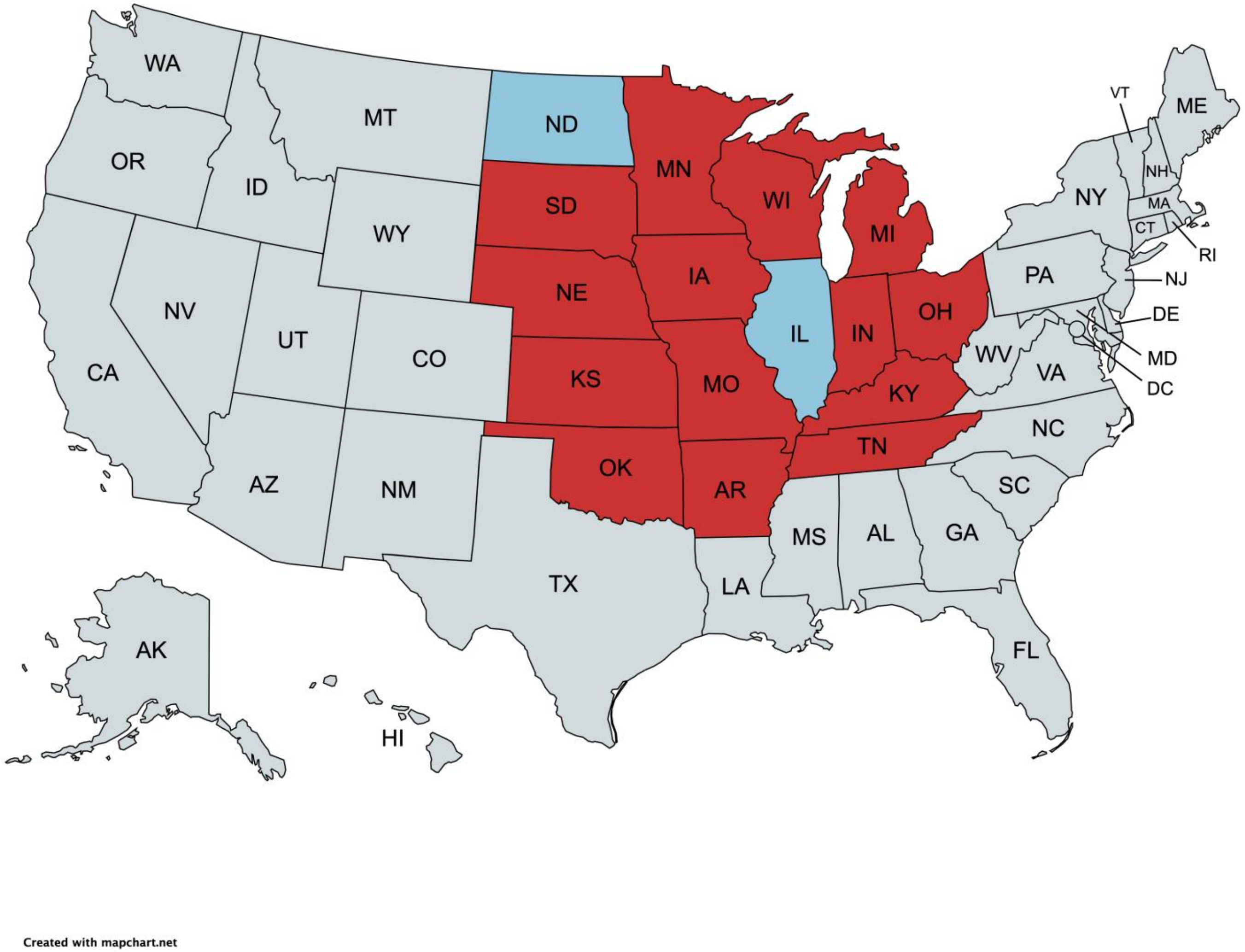
Land to produce 2 billion bushels corn in 1930

1930s

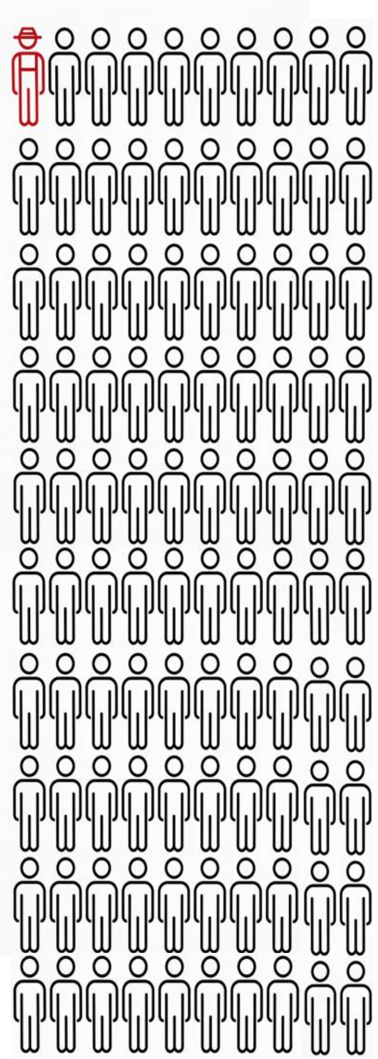




Land that would have been needed to produce 14.5 billion bushels in 2020s



Present

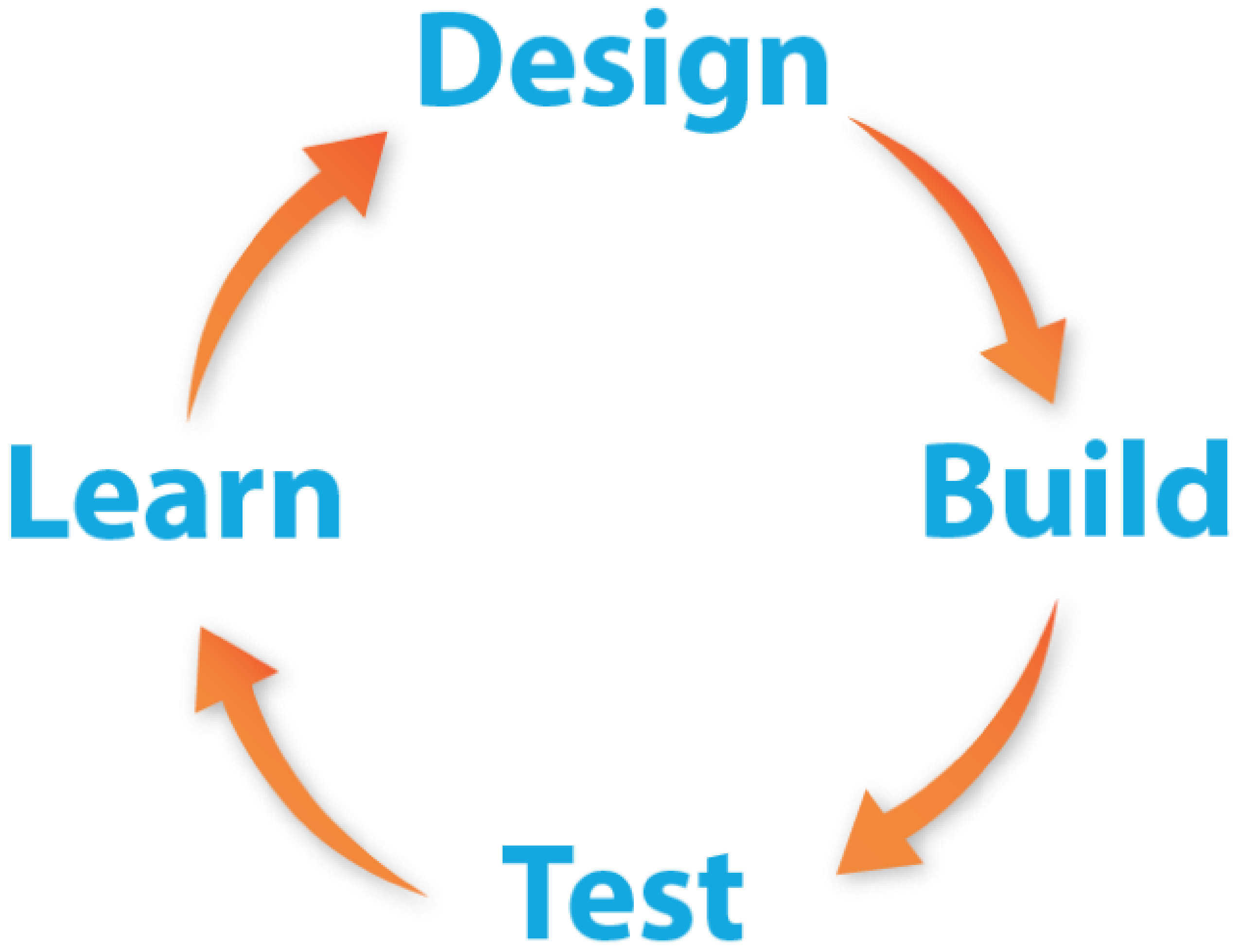


How do we go from finding needles in a haystack to designing the needle?

Crop Design

Synthetic biology

- Define the problem
- Set goals
- Identify biological function
- Plan sequences/circuits/pathways

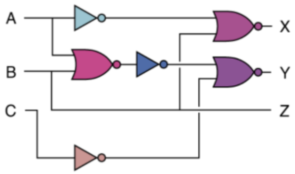


Building out Crop Design

Activities/Research

Learn

- Modeling across scales



Design

- Modular toolkits
- Improved Quantitative models

Build

- Editing/transgenesis at scale
- In vitro testing systems
- Protected culture cycling

Test

- Scaled field testing
- Integration into breeding pipelines

Partners

Institute for Artificial Intelligence
UNIVERSITY OF GEORGIA

Institute of Plant Breeding, Genetics and Genomics
College of Agricultural & Environmental Sciences
UNIVERSITY OF GEORGIA

Institute for Integrative Precision Agriculture
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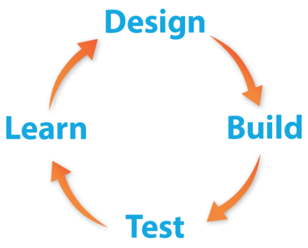
Crop Design: in practice

Breeding

- GxE
- Cycle time
- Genetic Variation

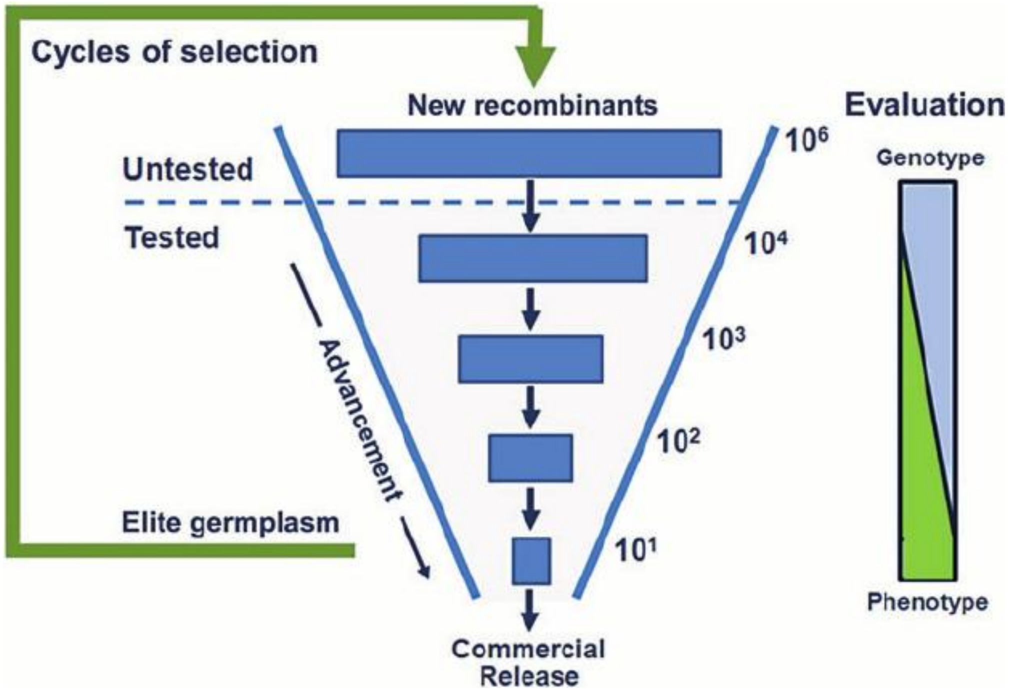
Trait engineering



Crop Design: Cycle Time

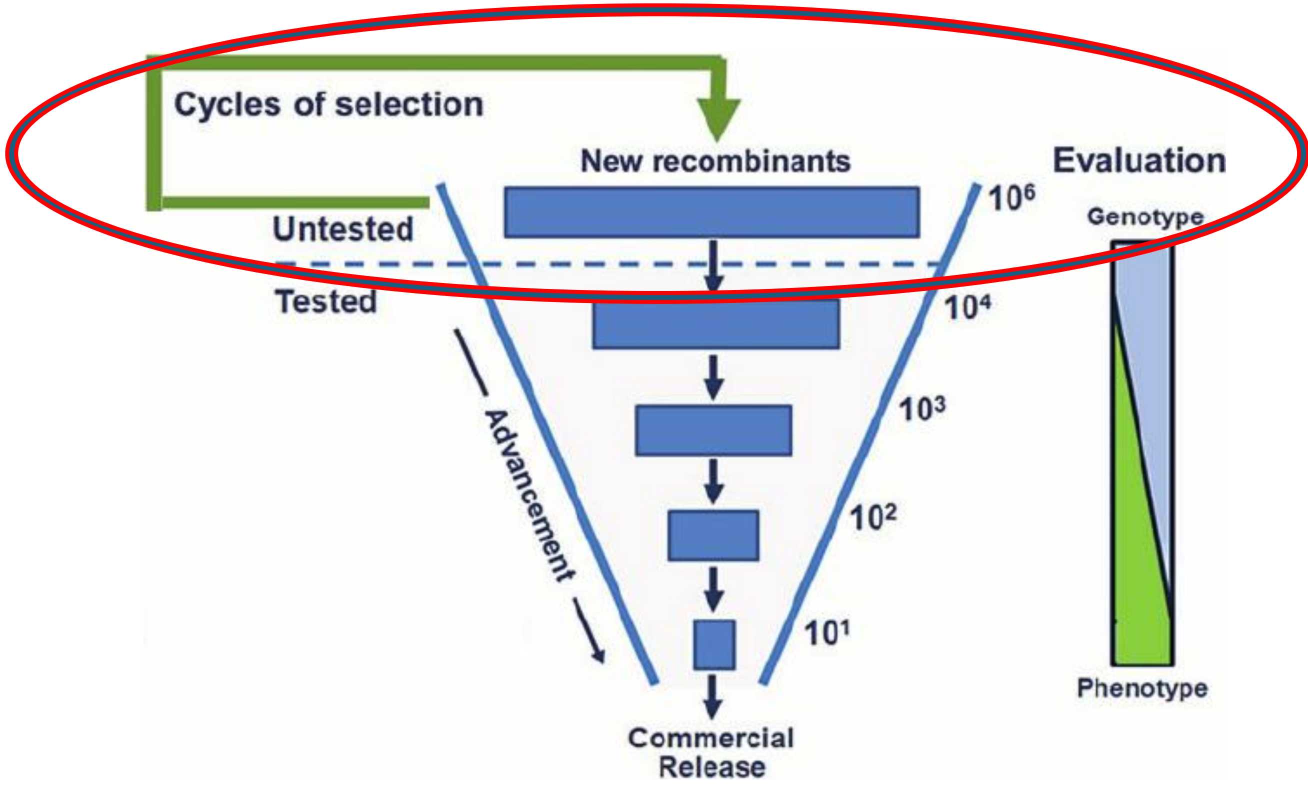
$$R = h^2S/t$$

Traditional breeding

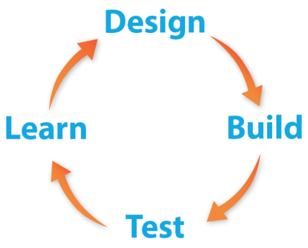


Cooper et al., 2014

Rapid breeding



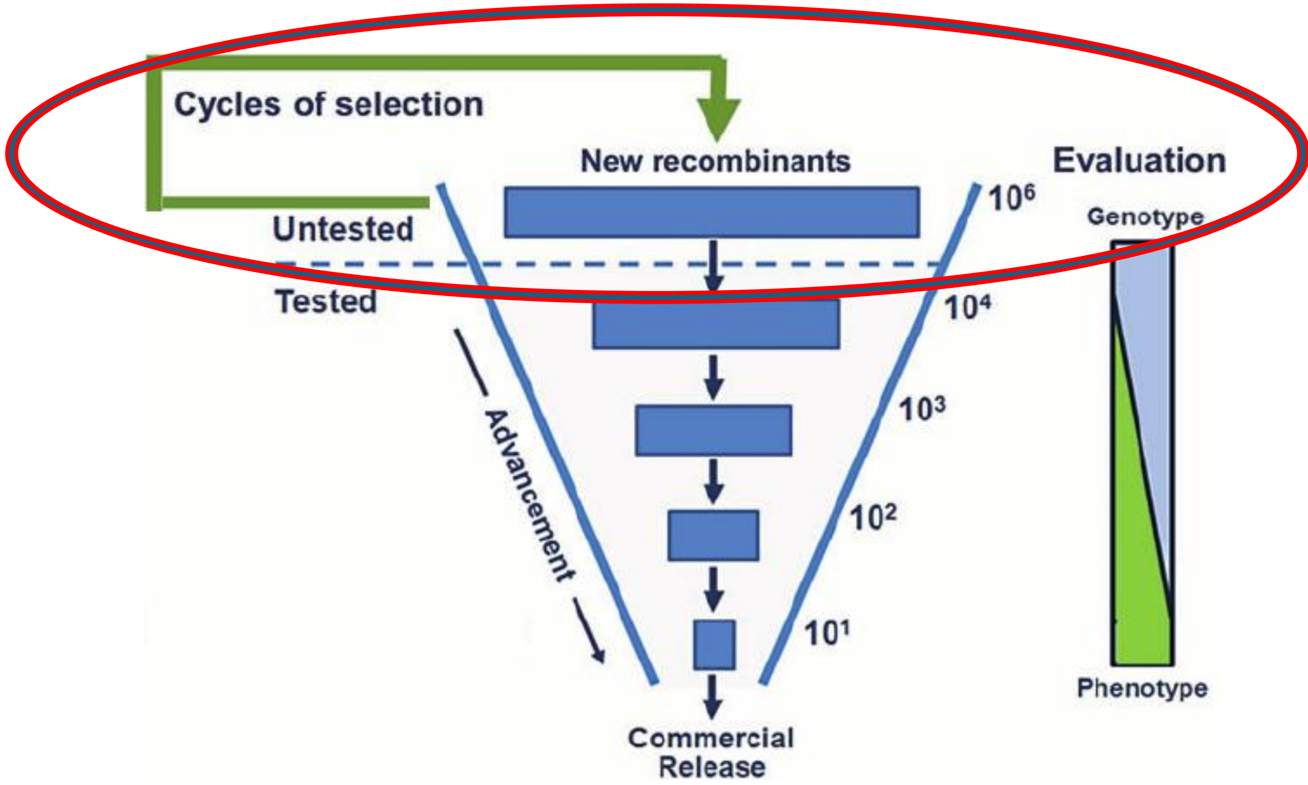
My variation of Cooper et al.



Crop Design: Cycle Time

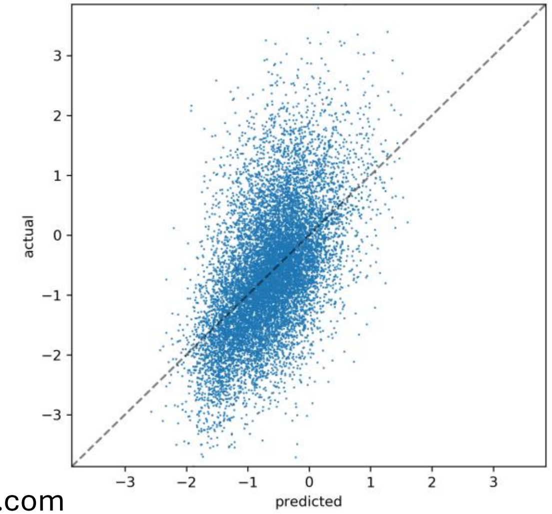
$$R = h^2S/t$$

Rapid breeding



What is needed?

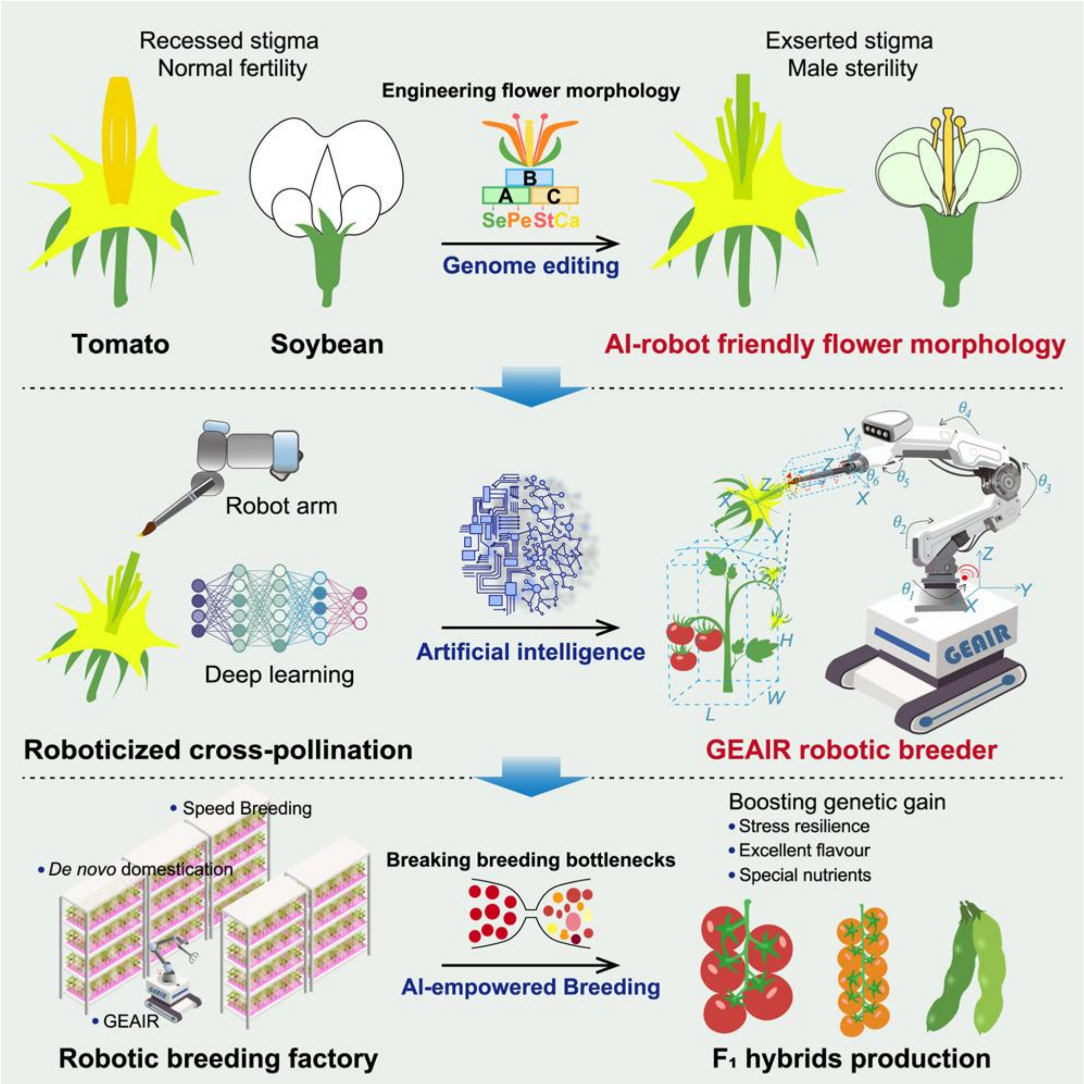
- Predicted performance of progeny & parents
- Balancing fitness traits
- Continuous feedback of performance data
- Ability to explore genetic variation
- Tools to cycle rapidly



https://stats.stackexchange.com

My variation of Cooper et al.

Crop Design: cycle time future state



"Engineering crop flower morphology facilitates robotization of cross-pollination and speed breeding."

Xie et al. 2025. Cell. doi: 10.1016/j.cell.2025.07.028

Crop Design: in practice

Breeding

- GxE
- Cycle time
- Genetic Variation

Trait engineering

Crop Design

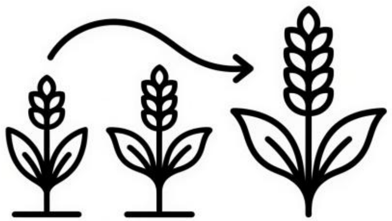
What does a farmer need?

What does a consumer want?

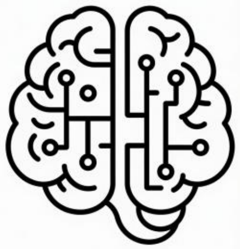
Toolbox

Maize Genome

Breeding methods



Artificial Intelligence



Gene editing