Evolutionary Simulation of Plant Strategies

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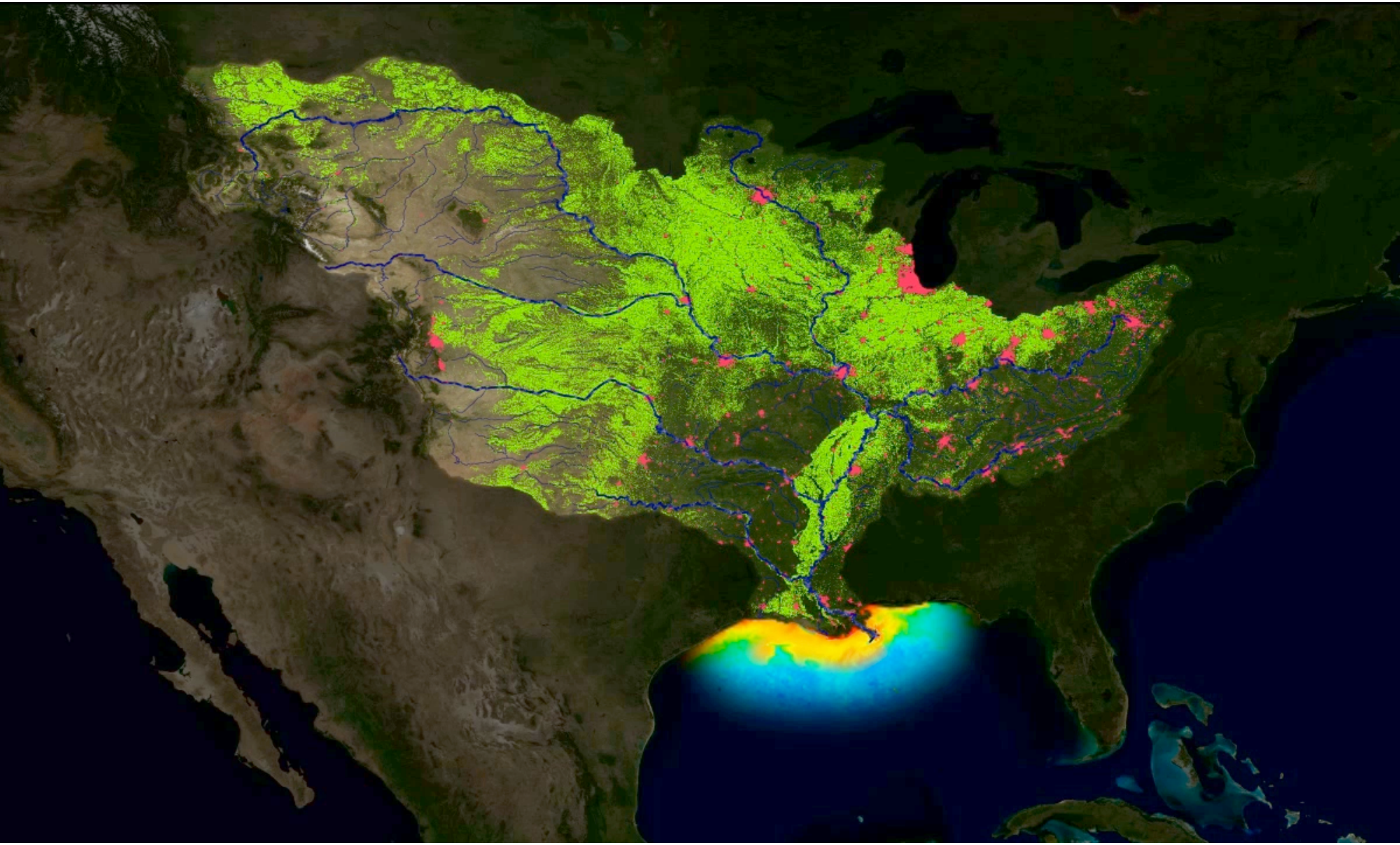
The Land Institute

An Important Factoid Regarding Grains

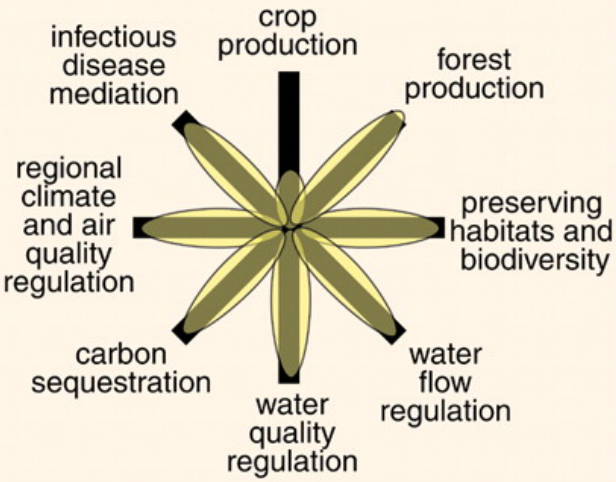
You eat the seeds.

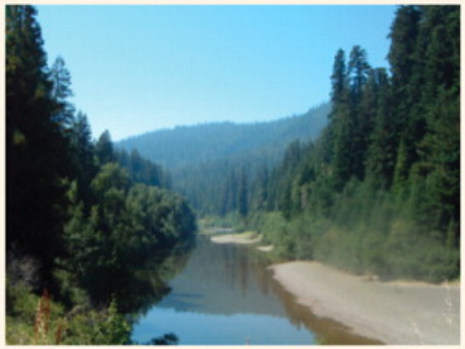
Why?

Why?

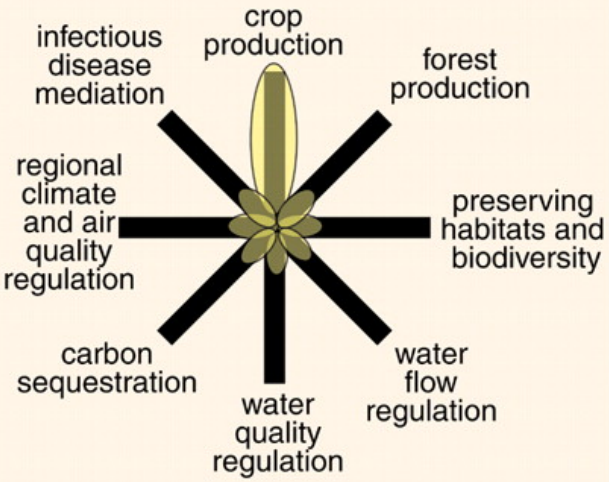


Food Systems

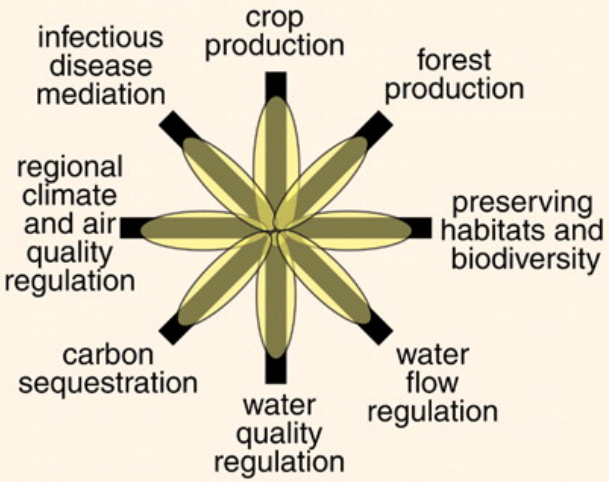




natural ecosystem



intensive cropland

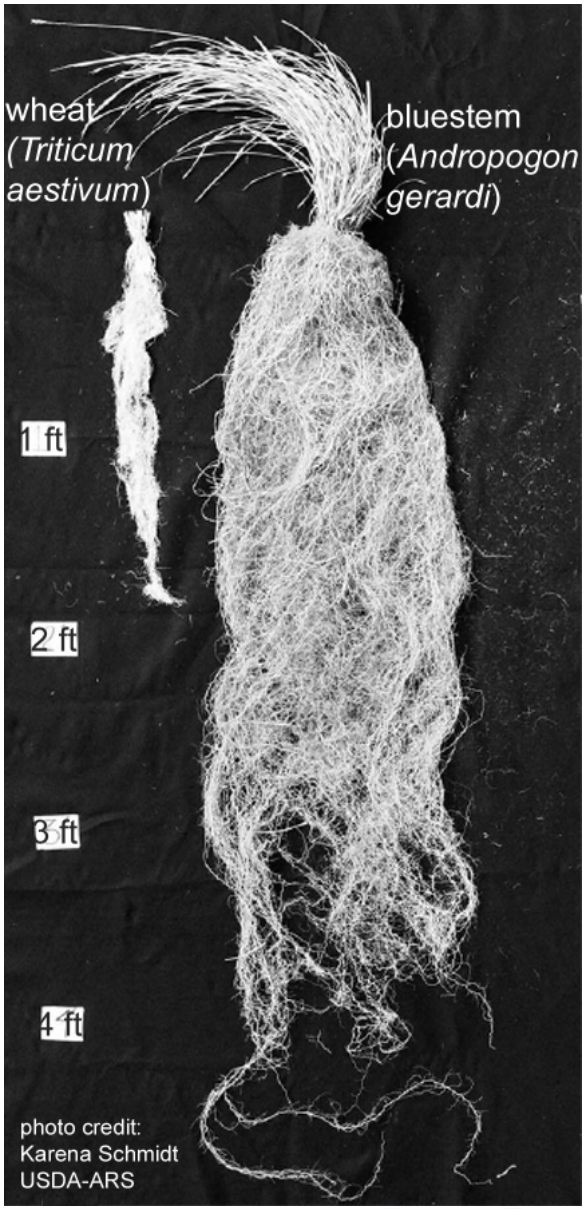


cropland with restored ecosystem services

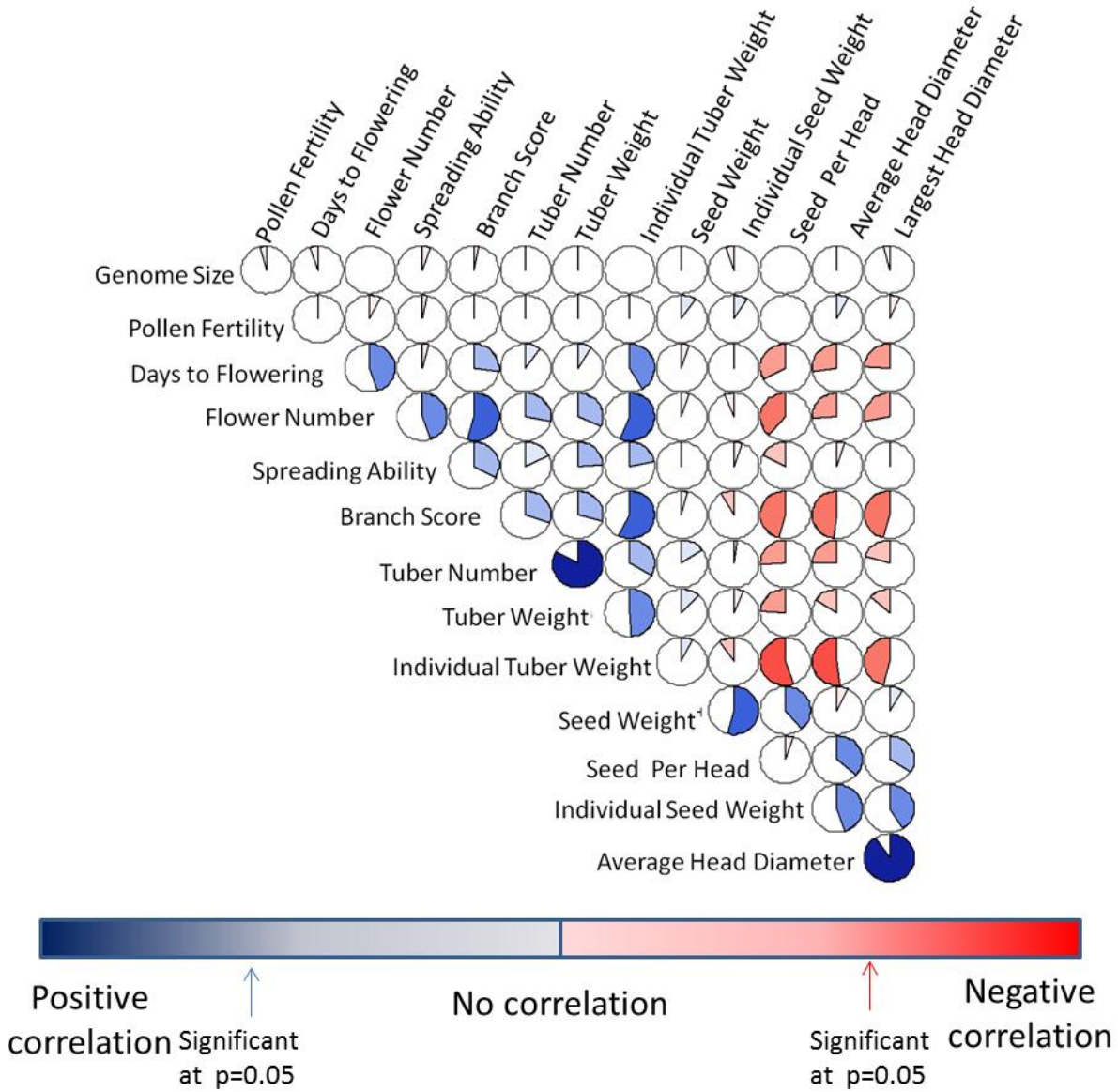
Foley et al., Science 309, 570 – 574 (2005)

Benefits

- Nutrient sequestration
- Soil formation
- Soil retention
- Pollination
- Weed suppression
- Aesthetic
- CO_2 sequestration



Is it possible?



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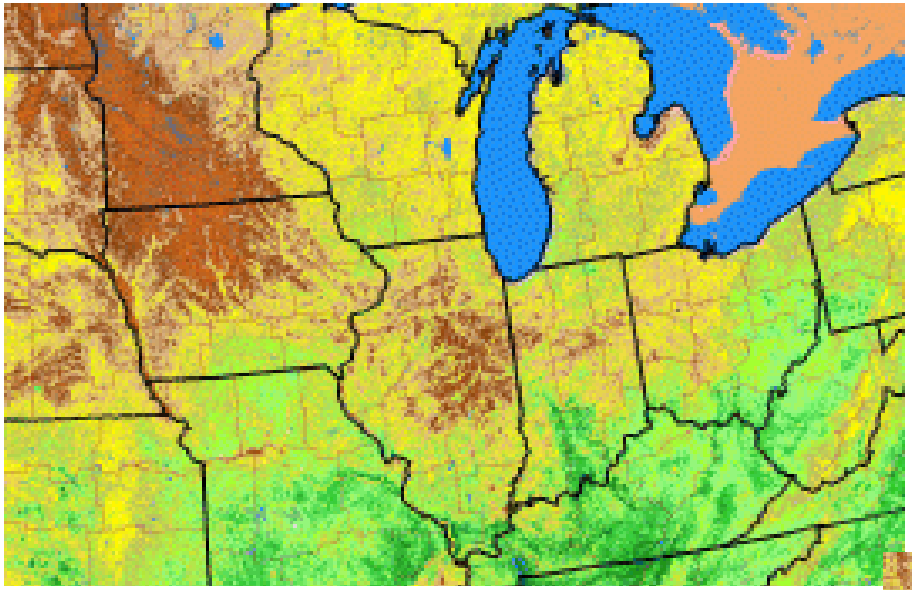
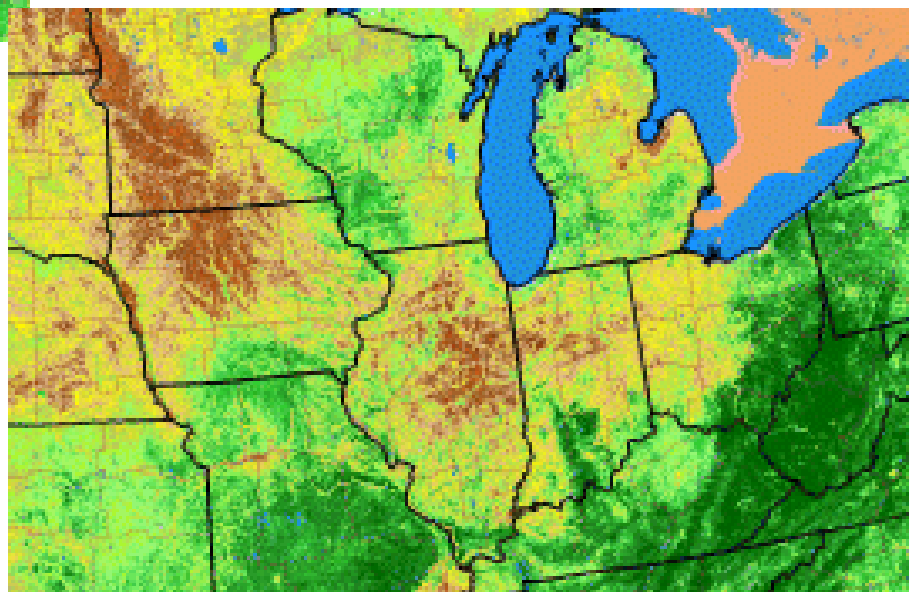


Apr 20 – May 3

May 4 – May 17



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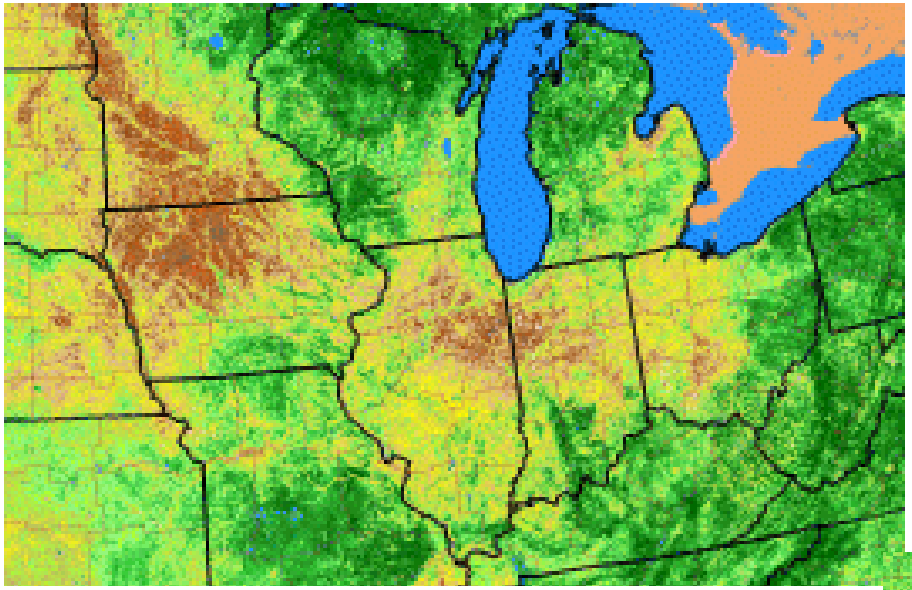
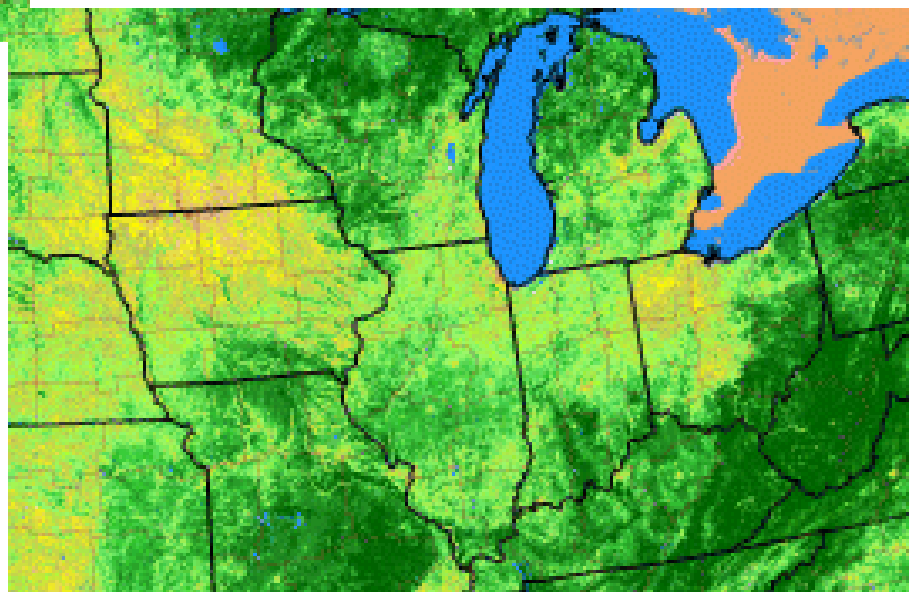


May 18 – May 31

Jun 15 – Jun 28



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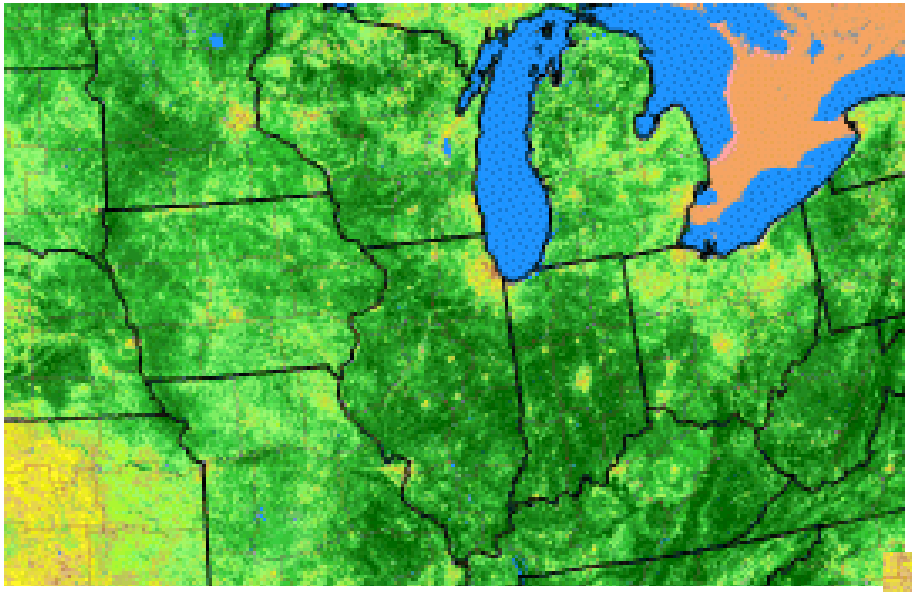
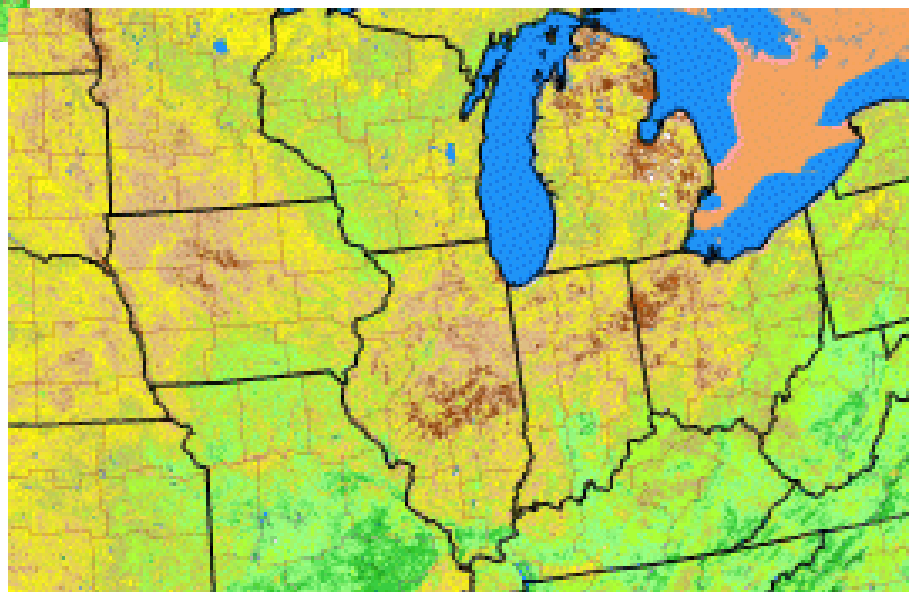


Jul 13 – Jul 26

Oct 5 – Oct 18



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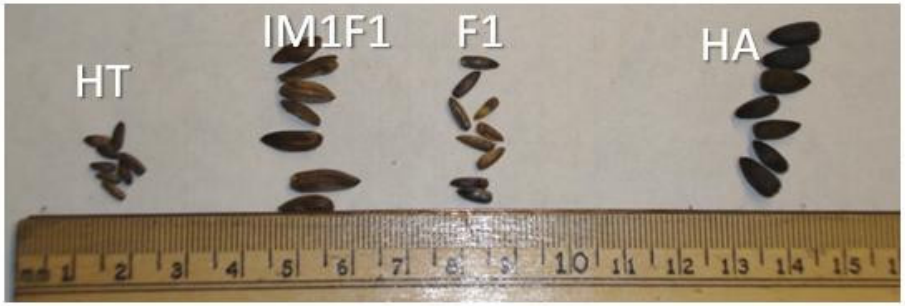
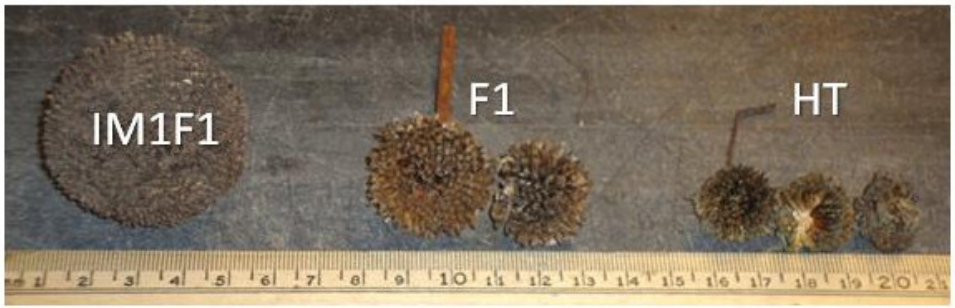
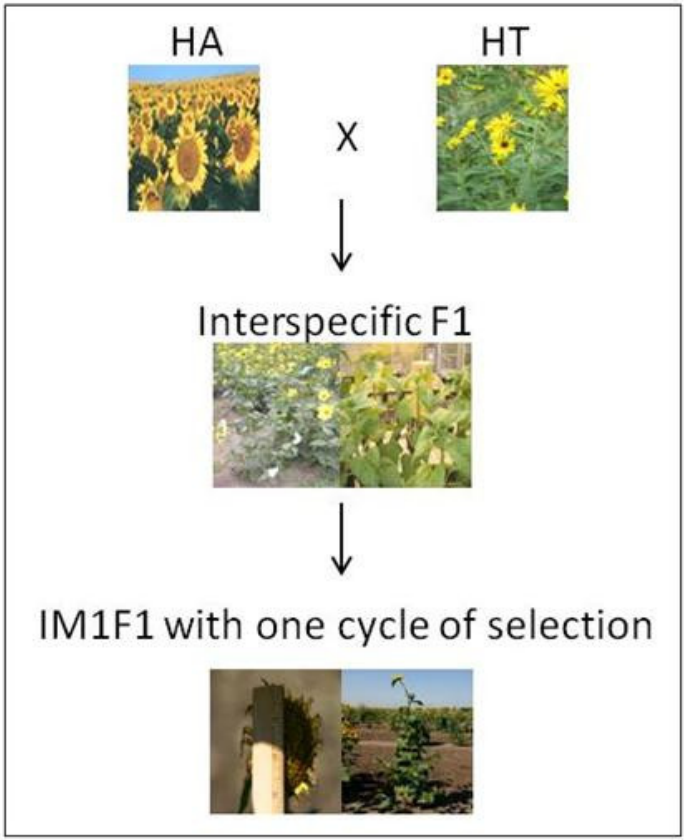






Breeding Efforts

Perennial flax

Intermediate Wheatgrass

Perennial Rice

Perennial wheat

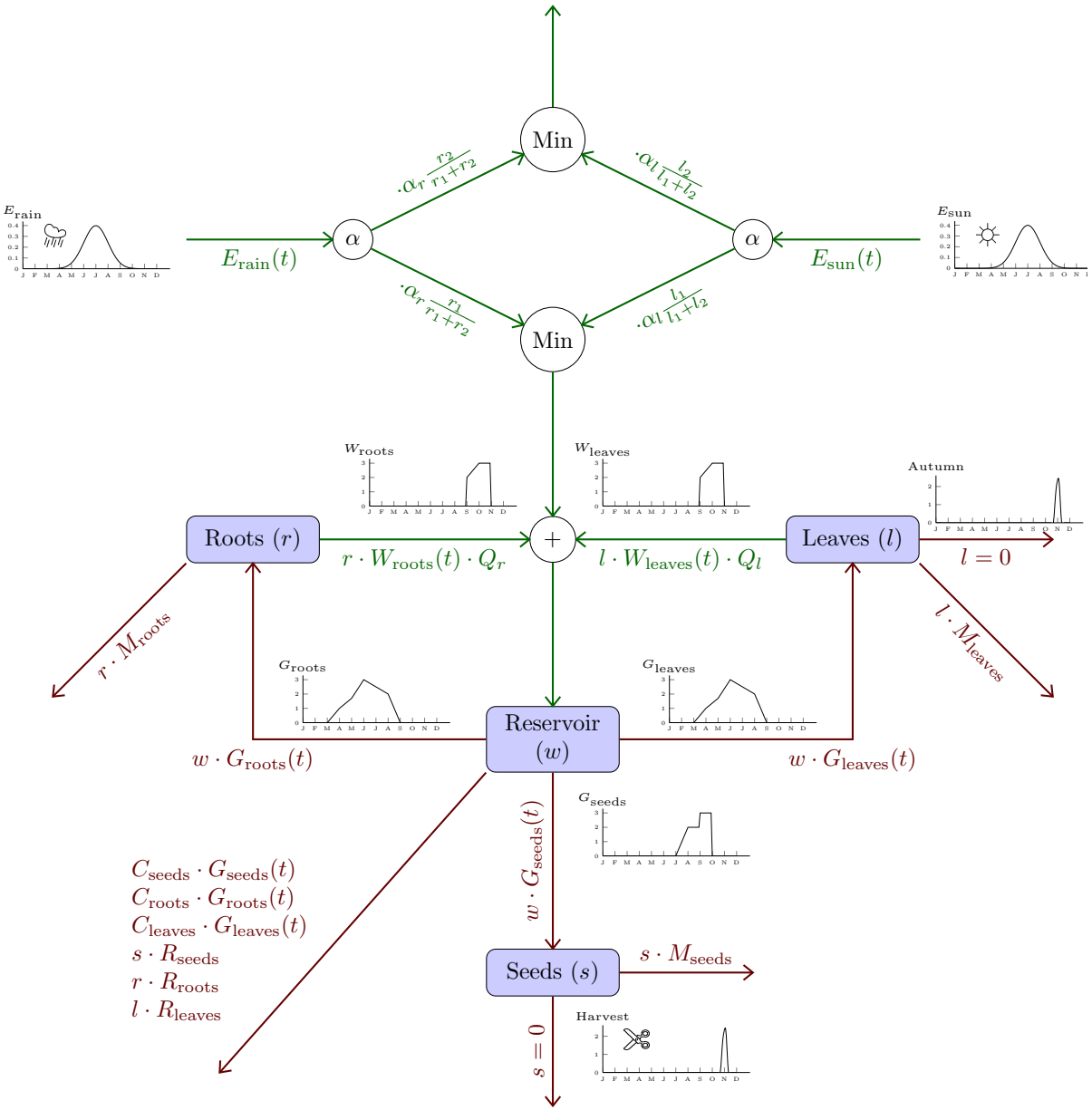
Perennial maize

Perennial sorghum

The Game Plan

- Using a model of natural selection...
  - Reproduce what we see in nature
- Using the same model under artificial selection...
  - Show something new

Physiologic System



Physiologic Equations

Energy comes in

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}seeds = G_s(t) \cdot w_1 - s_1 \cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t) \cdot w_1 - l_1 \cdot W_l(t) - l_1 \cdot M_l$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{r}oots = G_r(t) \cdot w_1 - r_1 \cdot W_r(t) - r_1 \cdot M_r$$

$$\begin{aligned}\frac{\mathrm{d}}{\mathrm{d}t}reserve = {} & \eta_w \cdot \min\left(\frac{\eta_l \epsilon_l l_1}{\max(K_l, l_1 + l_2)} \cdot E_{\mathrm{sun}}(t), \frac{\eta_r \epsilon_r r_1}{\max(K_r, r_1 + r_2)} \cdot E_{\mathrm{rain}}(t)\right) \\ & + l_1 \cdot W_l(t) \cdot Q_l + r_1 \cdot W_r(t) \cdot Q_r \\ & - w_1 \cdot (G_s(t) \cdot C_s + G_l(t) \cdot C_l + G_r(t) \cdot C_r) \\ & - s_1 \cdot R_s(t) - l_1 \cdot R_l(t) - r_1 \cdot R_r(t) \\ & - w_1 \cdot M_w\end{aligned} \tag{1}$$

Physiologic Equations

Energy is derived from two sources, consider one

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}seeds = G_s(t) \cdot w_1 - s_1 \cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t) \cdot w_1 - l_1 \cdot W_l(t) - l_1 \cdot M_l$$

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$$\begin{aligned}\frac{\mathrm{d}}{\mathrm{d}t}reserve = \eta_w \cdot \min & \left(\frac{\eta_l \epsilon_l l_1}{\max(K_l, l_1 + l_2)} \cdot E_{\mathrm{sun}}(t), \frac{\eta_r \epsilon_r r_1}{\max(K_r, r_1 + r_2)} \cdot E_{\mathrm{rain}}(t) \right) \\ & + l_1 \cdot W_l(t) \cdot Q_l + r_1 \cdot W_r(t) \cdot Q_r \\ & - w_1 \cdot (G_s(t) \cdot C_s + G_l(t) \cdot C_l + G_r(t) \cdot C_r) \\ & - s_1 \cdot R_s(t) - l_1 \cdot R_l(t) - r_1 \cdot R_r(t) \\ & - w_1 \cdot M_w \end{aligned} \tag{1}$$

Physiologic Equations

Energy/Inputs are combined to a useable form

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}seeds = G_s(t) \cdot w_1 - s_1 \cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t) \cdot w_1 - l_1 \cdot W_l(t) - l_1 \cdot M_l$$

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Physiologic Equations

This can be viewed in terms of biomass

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}eeds = G_s(t) \cdot w_1 - s_1 \cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t) \cdot w_1 - l_1 \cdot W_l(t) - l_1 \cdot M_l$$

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Parts of the plant **G**row

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}seeds = G_s(t) \cdot w_1 - s_1 \cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t) \cdot w_1 - l_1 \cdot W_l(t) - l_1 \cdot M_l$$

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Growth comes at the expense of the reserve

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}eeds = G_s(t) \cdot w_1 - s_1 \cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t) \cdot w_1 - l_1 \cdot W_l(t) - l_1 \cdot M_l$$

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Biomass **R**espires

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}seeds = G_s(t)\cdot w_1 - s_1 \cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t)\cdot w_1 - l_1 \cdot W_l(t) - l_1 \cdot M_l$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{r}oots = G_r(t)\cdot w_1 - r_1 \cdot W_r(t) - r_1 \cdot M_r$$

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Physiologic Equations

Biomass has **M**ortality

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}eeds = G_s(t) \cdot w - s_1 \cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t) \cdot w_1 - l_1 \cdot W_l(t - l_1 \cdot M_l$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{r}oots = G_r(t) \cdot w_1 - r_1 \cdot W_r(t - r_1 \cdot M_r$$

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Physiologic Equations

Biomass can be **W**ithdrawn

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}eeds = G_s(t) \cdot w_1 - s_1 \cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t) \cdot w \boxed{- l_1 \cdot W_l(t)} - l_1 \cdot M_l$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{r}oots = G_r(t) \cdot w \boxed{- r_1 \cdot W_r(t)} - r_1 \cdot M_r$$

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Physiologic Equations

Some **W**ithdrawn biomass can be regained

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{s}seeds = G_s(t)\cdot w_1 - s_1\cdot M_s$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\mathbf{l}eaves = G_l(t)\cdot w_1 - l_1\cdot W_l(t) - l_1\cdot M_l$$

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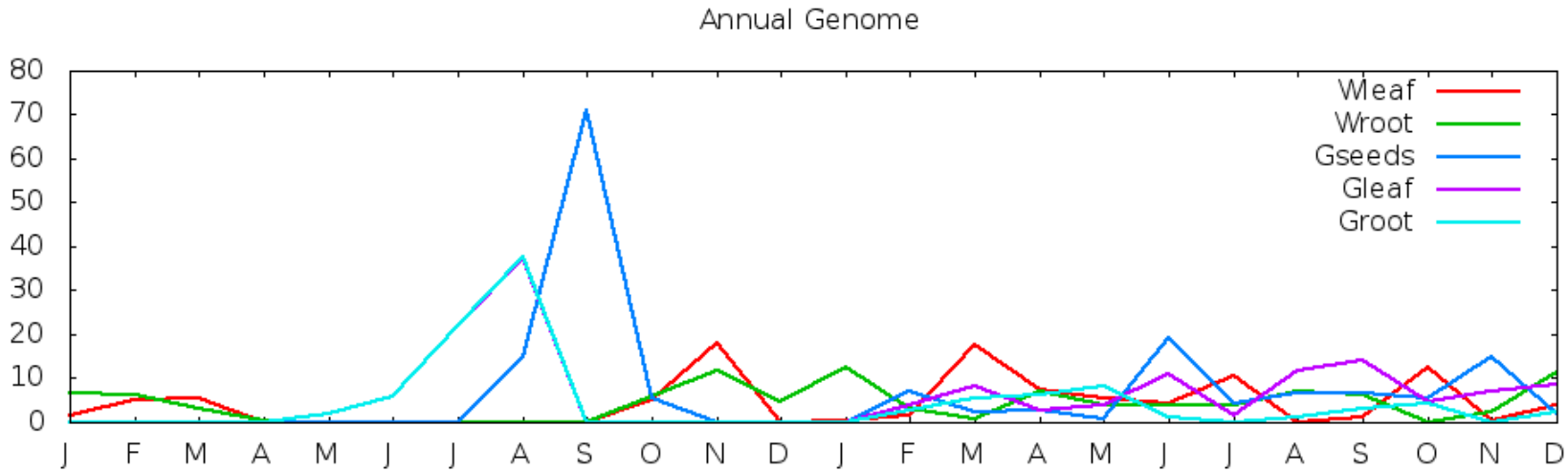
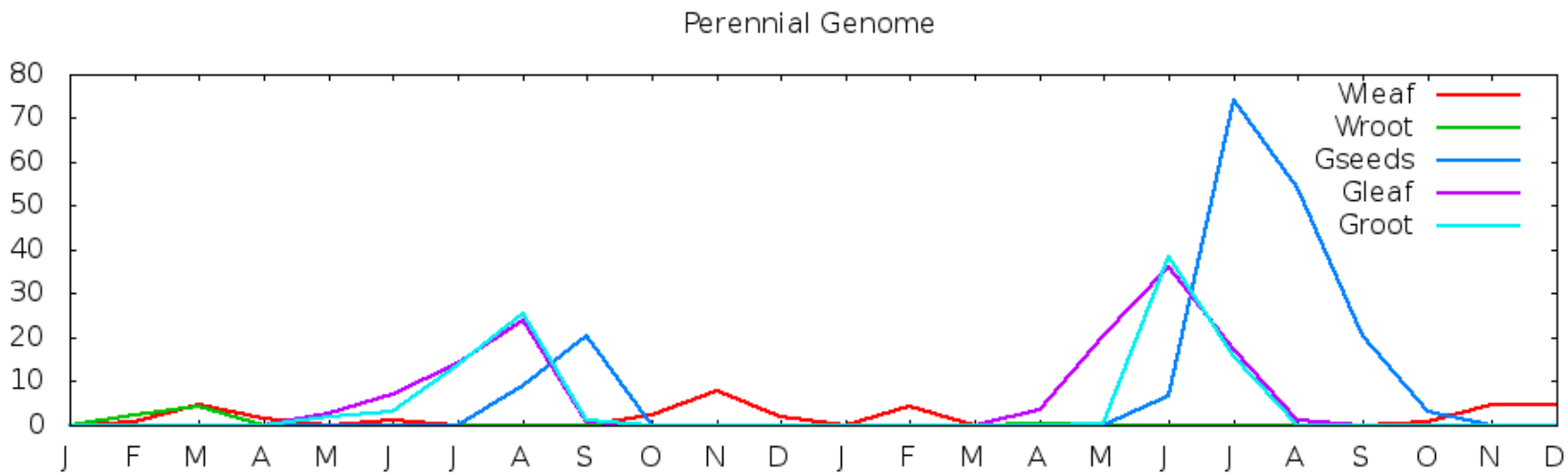
Growth & Withdrawal Functions

Piecewise linear interpolations

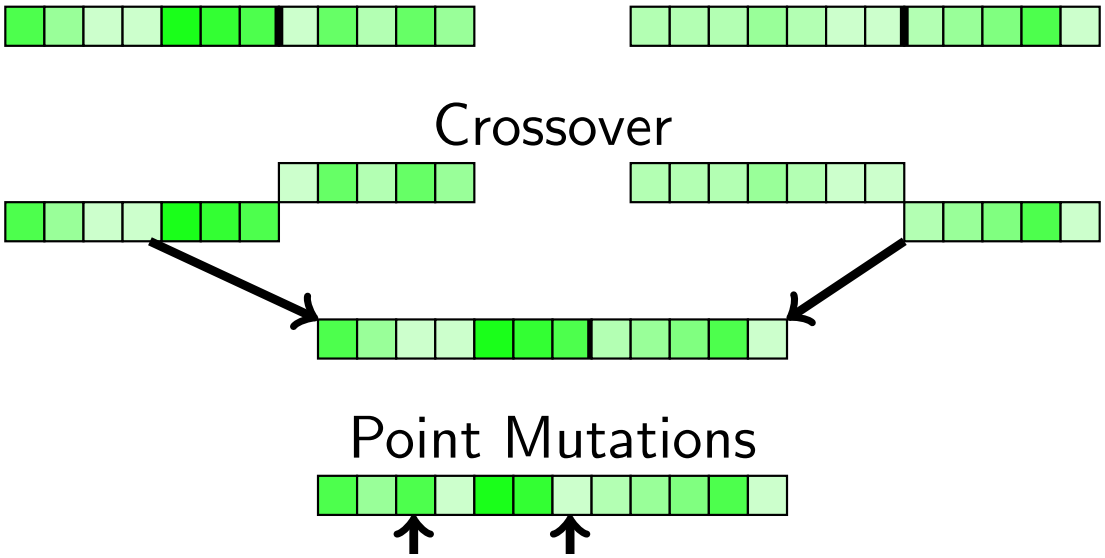
One point per month

Last year repeats





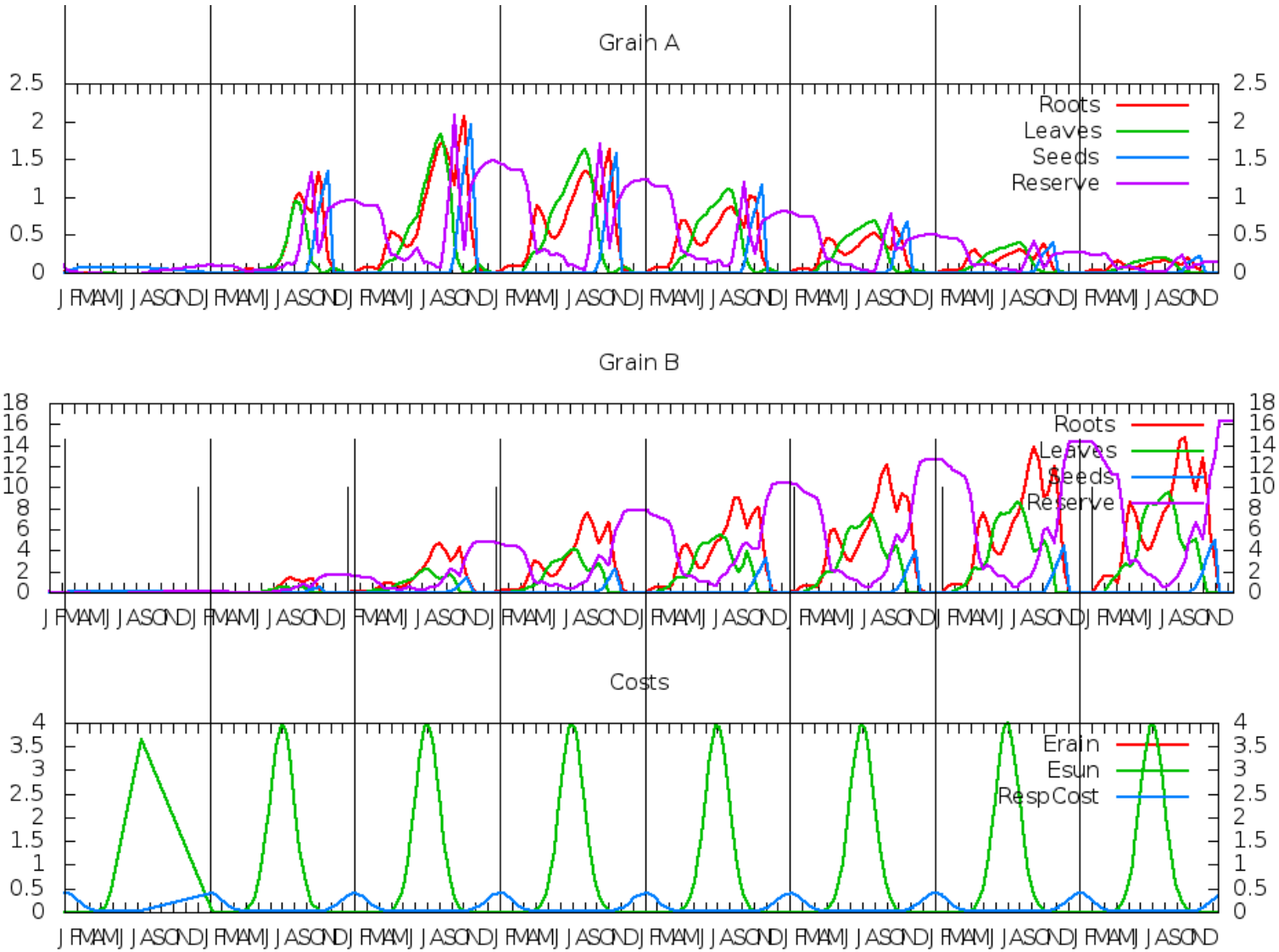
Breeding: Genetics



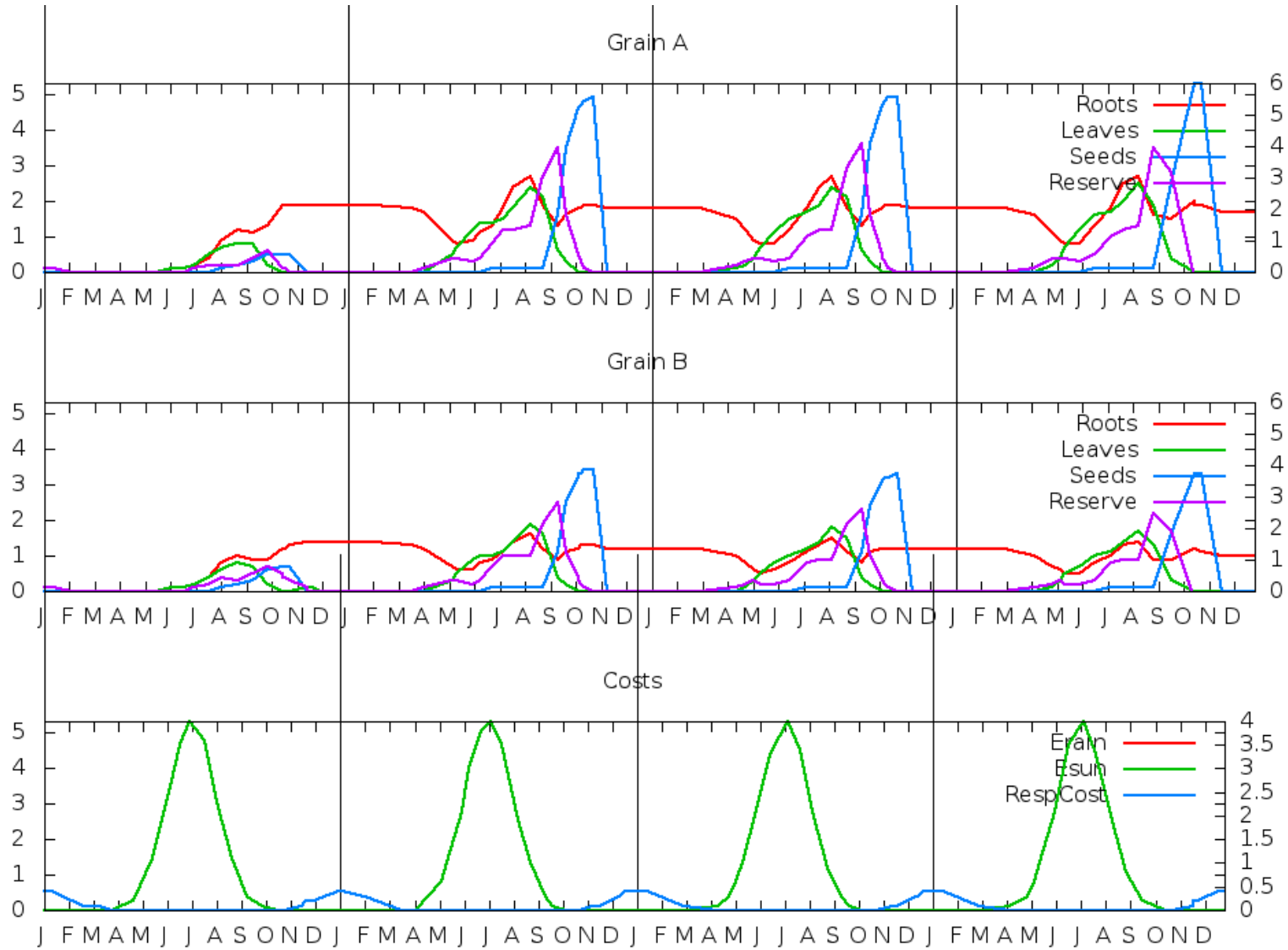
- Crossover points drawn from uniform distribution
- Mutation points drawn from uniform distribution
- Mutation degree drawn from normal distribution
- Gene values always ≥ 0

Breeding: Population

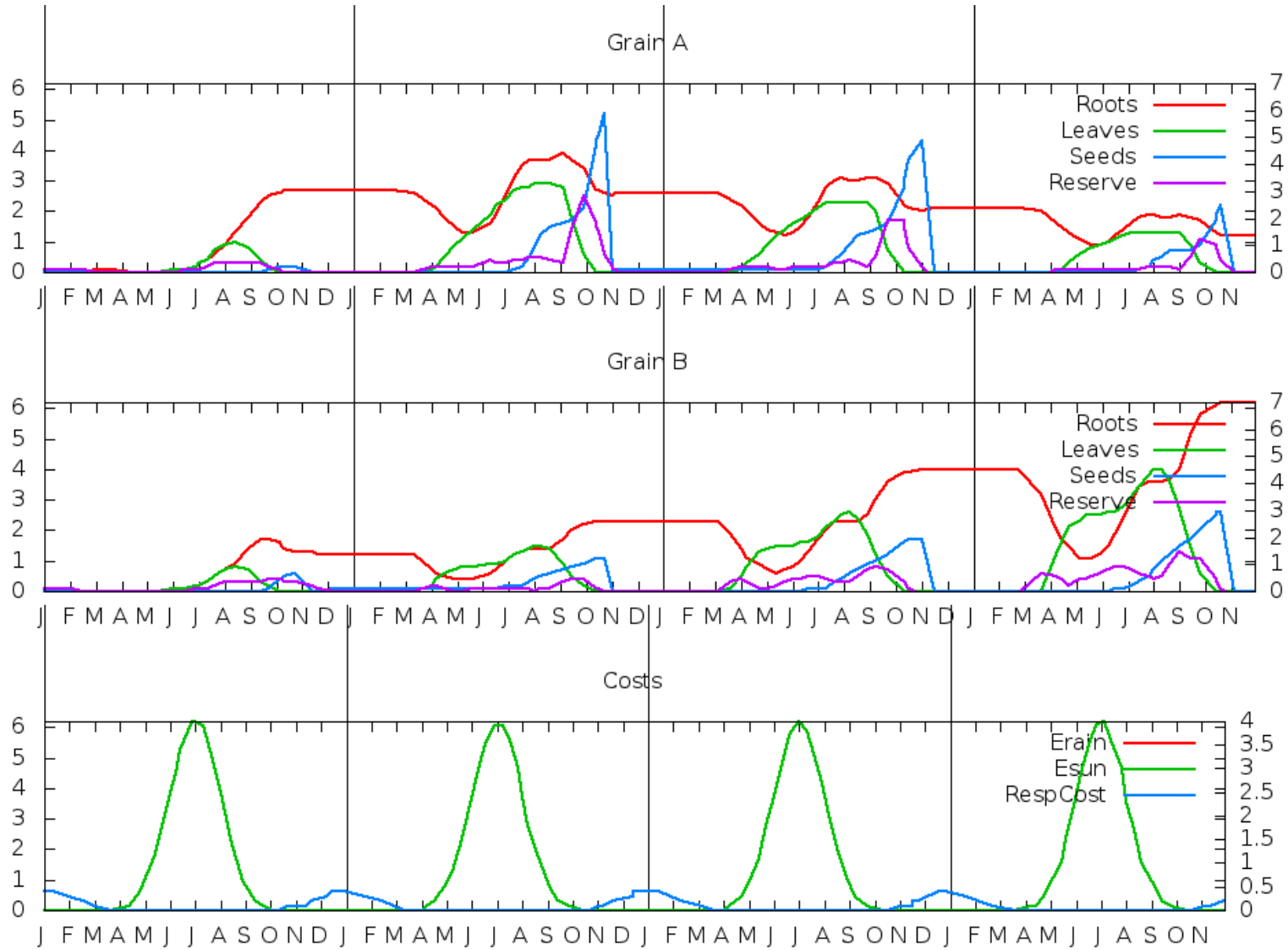
- 50 variants placed in pairwise competition: 2500 plots
- Competitions last 8 years
- Death during a competition $\rightarrow$ Replanting
- Representation in breeding pool proportional to harvest
- 50 new variants generated


Grain A
Roots
Leaves
Seeds
Reserve
Grain B
Roots
Leaves
Seeds
Reserve
Costs
Erain
Esun
RespCost
J FMAMJ J ASONDJ FMAMJ J ASONDJ FMAMJ J ASONDJ FMAMJ J ASONDJ FMAMJ J ASONDJ FMAMJ J ASONDJ FMAMJ J ASONDJ FMAMJ J ASONDJ FMAMJ J ASOND

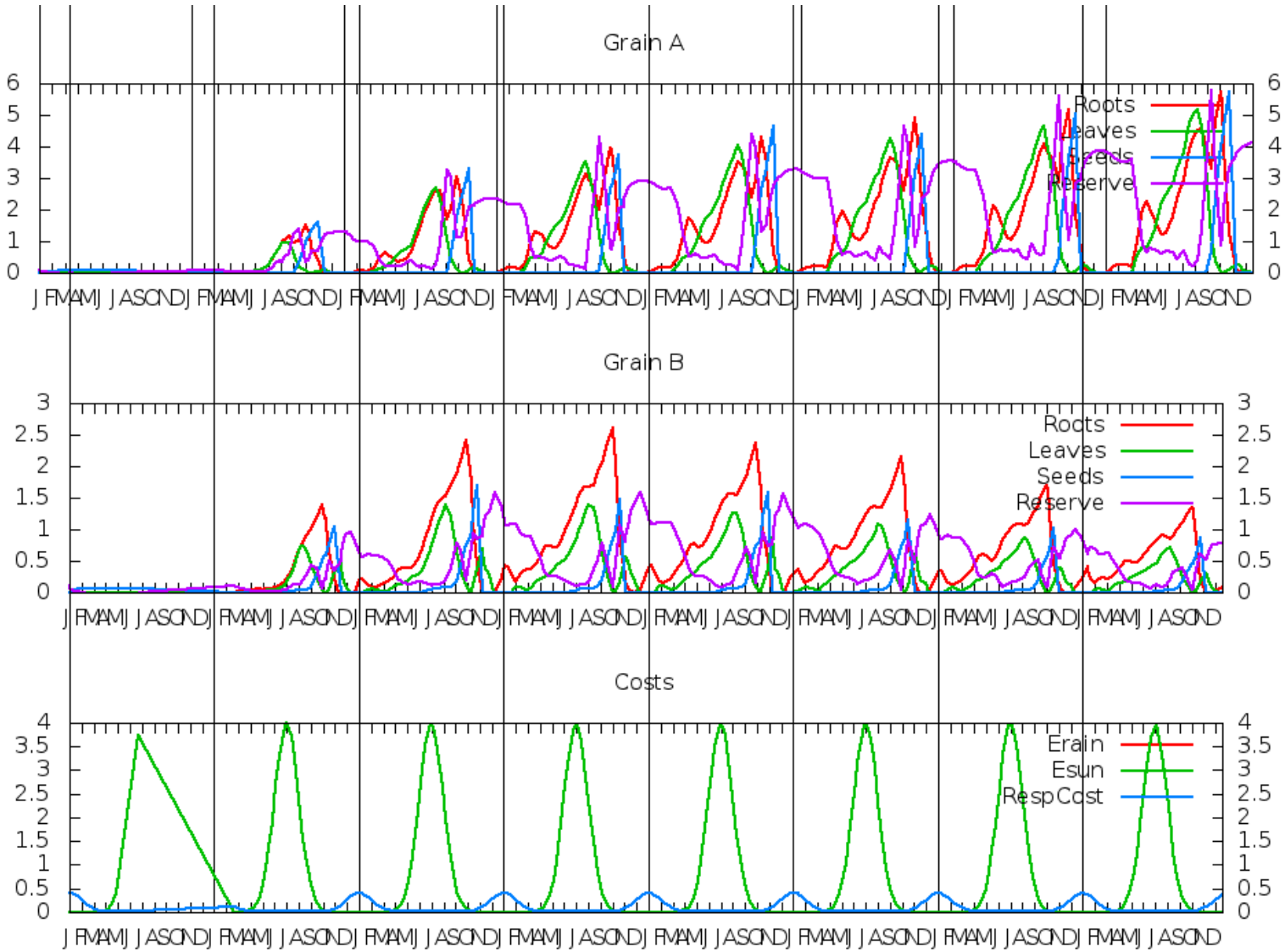
Menagerie
Root Perennial



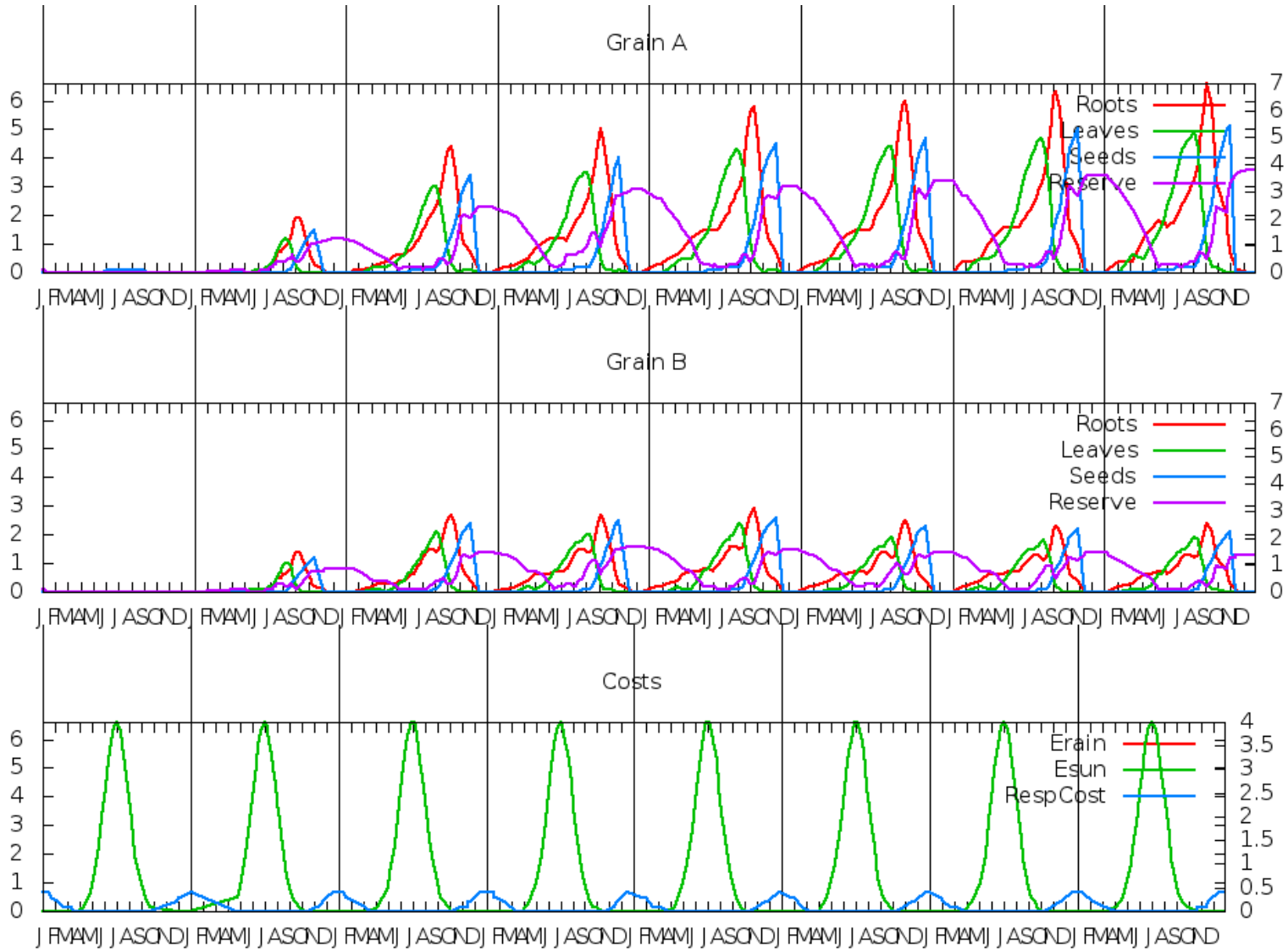
Menagerie
Root Perennial



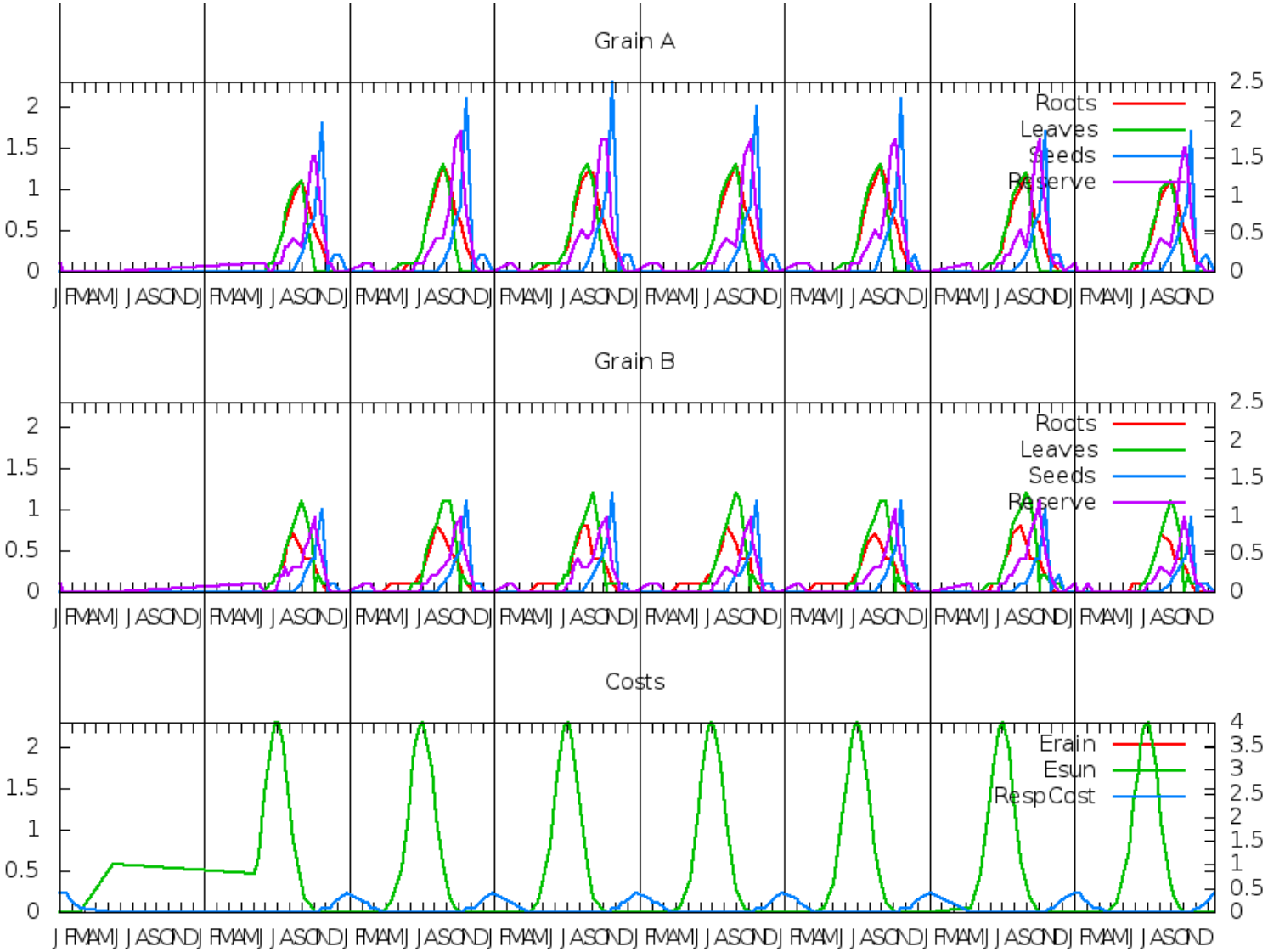
Menagerie
Reservoir Perennial



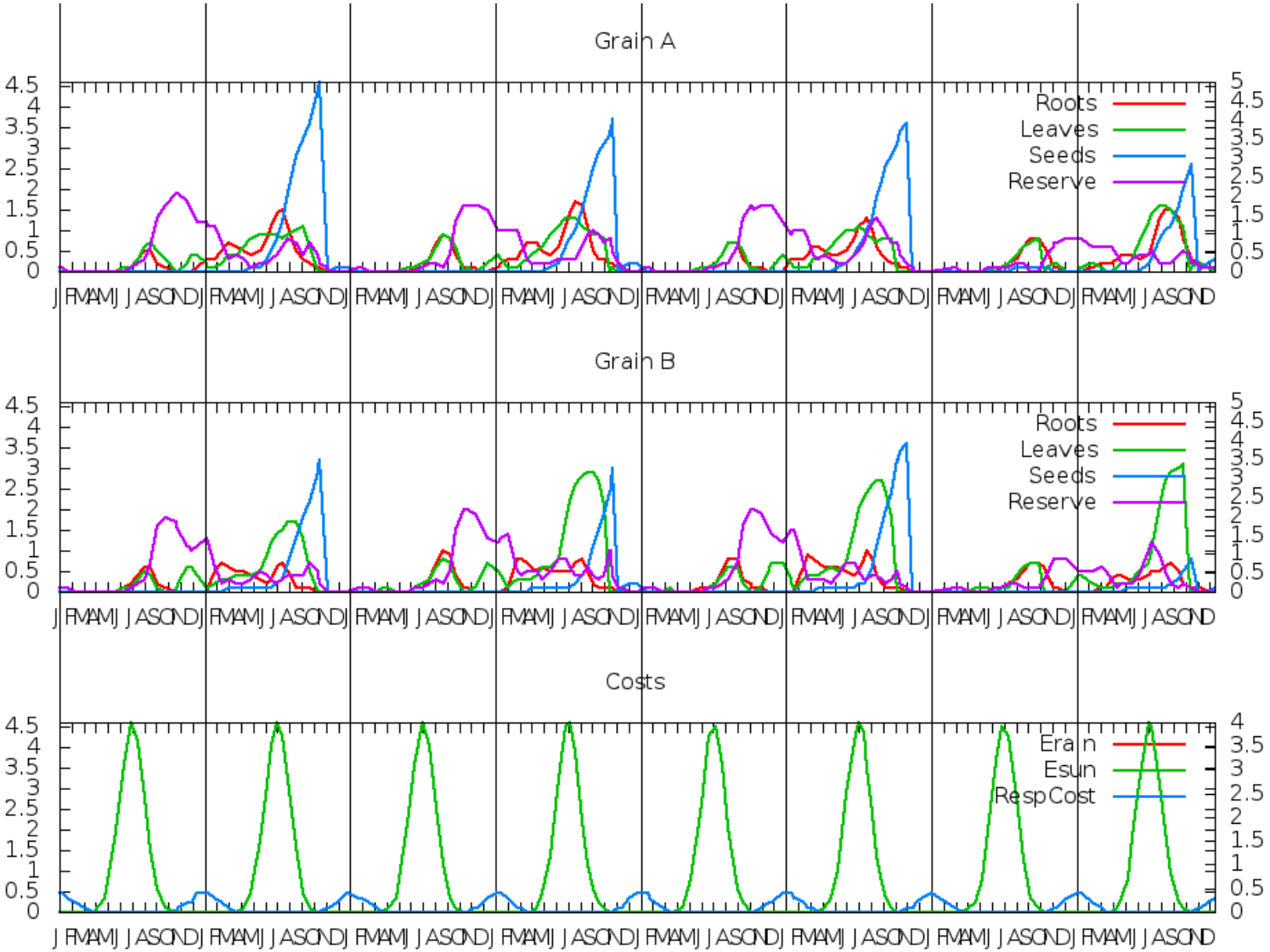
Menagerie
Reservoir Perennial



Menagerie
Annual



Menagerie
Biennial



Questions?

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