Comparison of artificial and natural selections, the case of nutrient acquisition in crop plants

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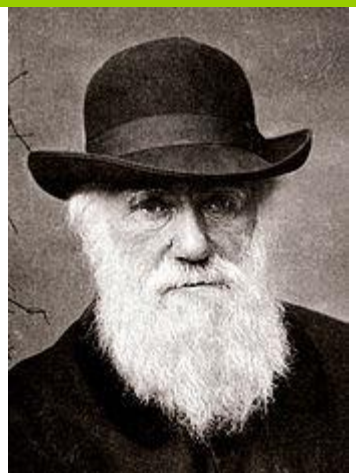
Artificial and natural selections are tightly connected



- Based on the same fundamental mechanisms (genetic variability, transmission, selection)
- Right from the start they have been associated by Darwin
- Organisms used by humans are the result of both natural and artificial selections

Natural selection → **Natural biodiversity** → **Artificial selection** (**Domestication**) → **Artificial Biodiversity**

Yes …. But ….

What is the impact of natural and artificial selections on nutrient cycling and ecosystem properties?

- So far there are very few models comparing explicitly the consequences of natural and artificial selections
- A simple mathematical model to predict the evolution of plants capacity to take up mineral nutrients and its consequences
- Comparison of the consequences of pure artificial or natural selections on production and nutrient losses

Is there space for natural selection within artificial selection in agriculture?

- In traditional agricultures natural selection tends to be important because genetic diversity is maintained and locally managed

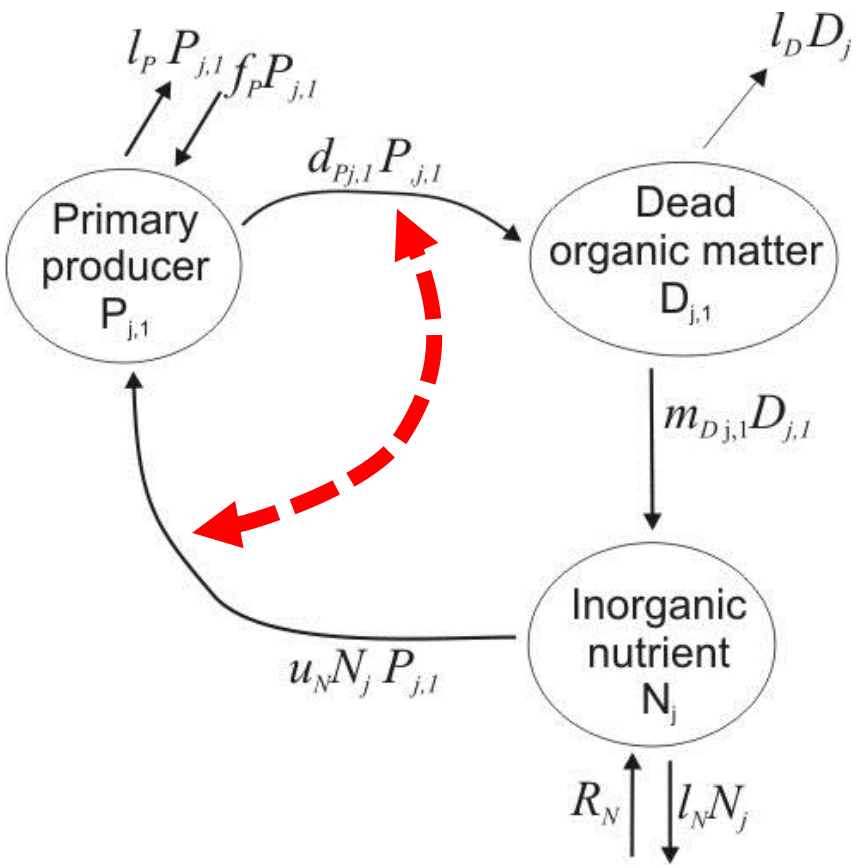
- Artificial selection allows to improve through group selection collective properties of species, e.g. production, biomass

- Idea that crop breeding has increased yield through group selection and a decrease in competitive ability at the individual scale (Denison 2003)

- Natural selection of crops within fields could allow for a better adaptation of crops to local conditions

A simple mean-field nutrient cycling model

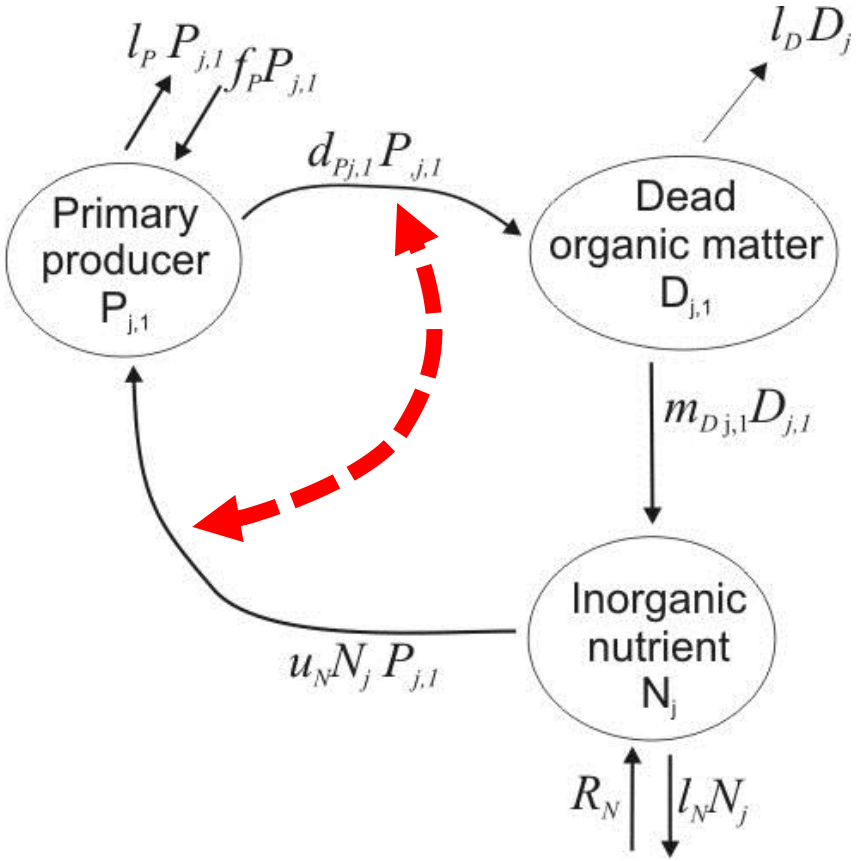
Trade-off



- Use of the adaptive dynamics framework to predict the outcome of natural selection (Geritz 1998)
- **Trade-off between nutrient uptake and losses of mineral nutrient from plants**
- Analytical results

Boudsocq, S., S. Barot, and N. Loeuille. 2011. Evolution of nutrient acquisition ... Proc. Royal. Soc London B 278:449-457.

A simple mathematical model

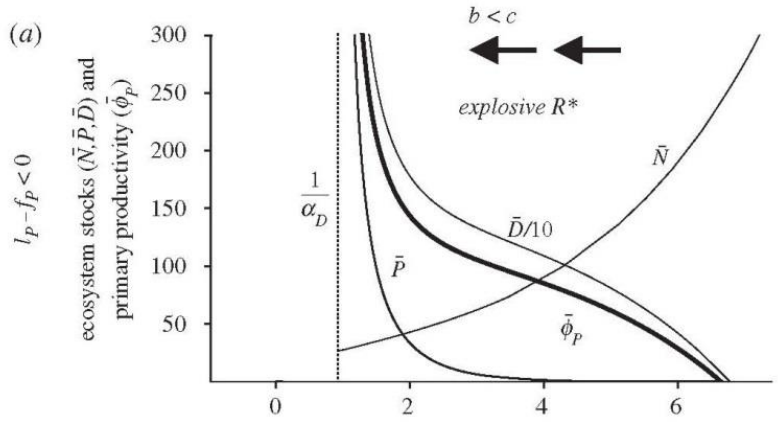


$$\left.\begin{aligned}
\frac{dP}{dt} &= \left(u_{N0} e^{bs} NP\right) - \left(d_{P0} e^{cs} + l_P - f_P\right)P, \\
\frac{dD}{dt} &= d_{P0} e^{cs} P + R_D - (m_D + l_D)D \\
\frac{dN}{dt} &= m_D D + R_N - \left(u_{N0} e^{bs} P + l_N\right)N.
\end{aligned}\right\}$$

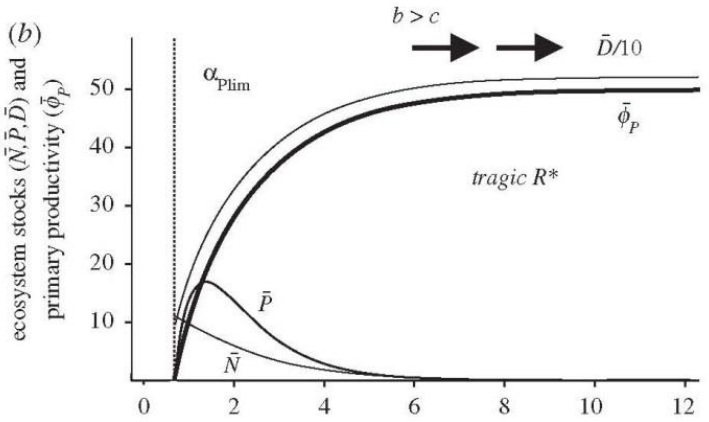
- s is the evolving trait
- Mathematical analyses show that there are 3 types of evolutionary dynamics
- Mathematical analyses allow to determine the ecosystem properties in these three cases

Results of natural selection

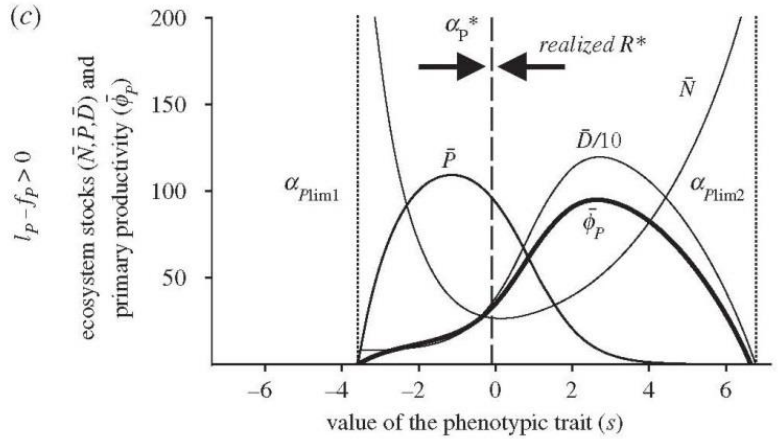
Runaway evolution (explosive R*)



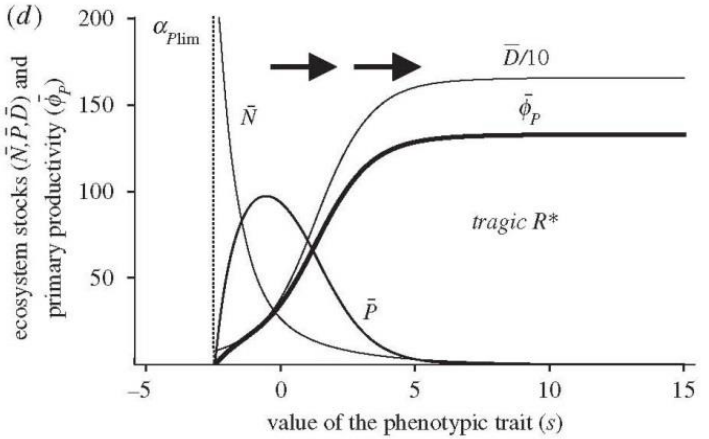
Runaway evolution (tragic R*)



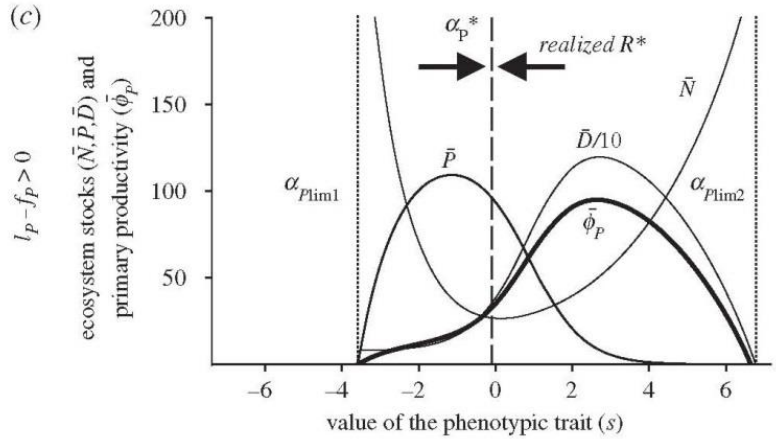
Evolutionary equilibrium (realized R*)



Runaway evolution (tragic R*)



Results of artificial selection?



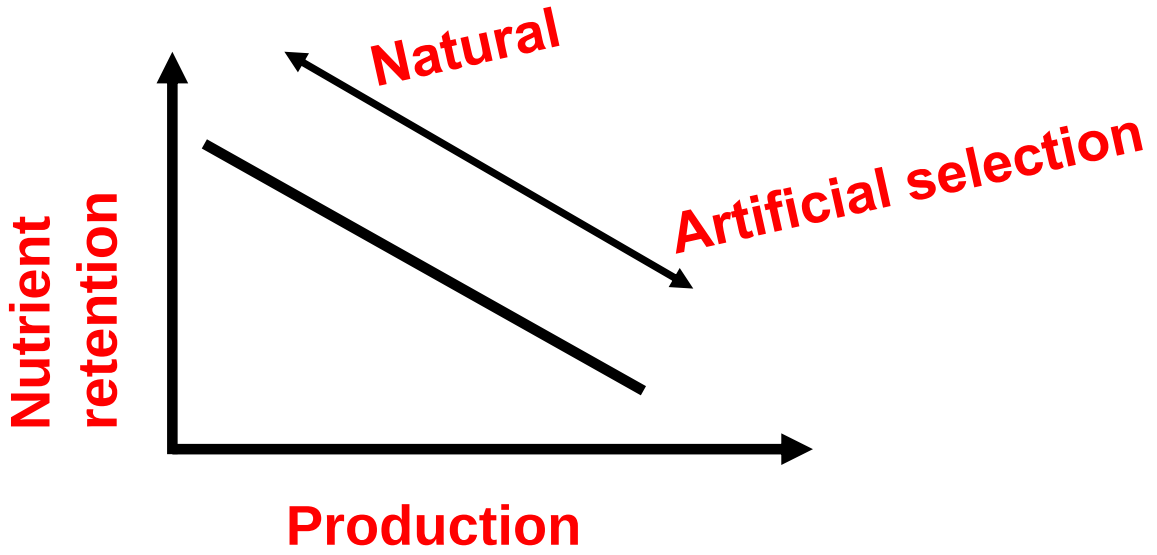
Evolutionary equilibrium

(realized R*)

Evolution leads to a trade-off at the ecosystem scale

- Natural selection is based on individual capacity to take up nutrients, which minimizes the availability of mineral nutrients and minimizes nutrients losses from the ecosystem (a kind of evolutionary R*, Tilman), but does optimize production or biomass

- Artificial selection is likely to optimize production though group selection (thus decreasing individual fitness) … but increases the availability of nutrients and increases nutrient losses



Nutrient cycling and agriculture

Fertilizers

Ecological causes

Evolutionary causes

Nutrient losses

Eutrophication
Increases the non-sustainability of fertilizer production

Conclusion

- The trade-off at the individual scale between nutrient uptake and nutrient losses seems to lead to a trade-off at the ecosystem scale between the yield and nutrient retention, i.e. short term vs. long term

- The model suggests that there is a kind of vicious circle: selecting in an intensive cropping context (high fertilizer inputs, high exportations of nutrients) increases the negative impact of artificial selection on nutrient losses (results not shown)

This gives arguments to integrate some natural selection within crop breeding