Plant diversity to reduce vulnerability and increase drought resilience of permanent and sown productive grasslands

A. Lüscher[1,2], K. Barkaoui[3], J.A. Finn[4], D. Suter[1], M. Suter[1], F. Volaire[5]

[1]Agroscope, Zurich, Switzerland
[2]Swiss Grassland Society, Zurich Switzerland
[3]CIRAD, UMR ABSys, Montpellier, France
[4]Teagasc, Wexford, Ireland
[5]CEFE, CNRS, INRAE, Montpellier, France

EGF 2022. Session 3

Agroscope

What a great team: THANK YOU!






Contents

Introduction

Intra-specific diversity is a pillar for adaptation
- Evidence
- Application

Inter-specific diversity is a pillar for adaptation
- Evidence
- Application

Conclusions

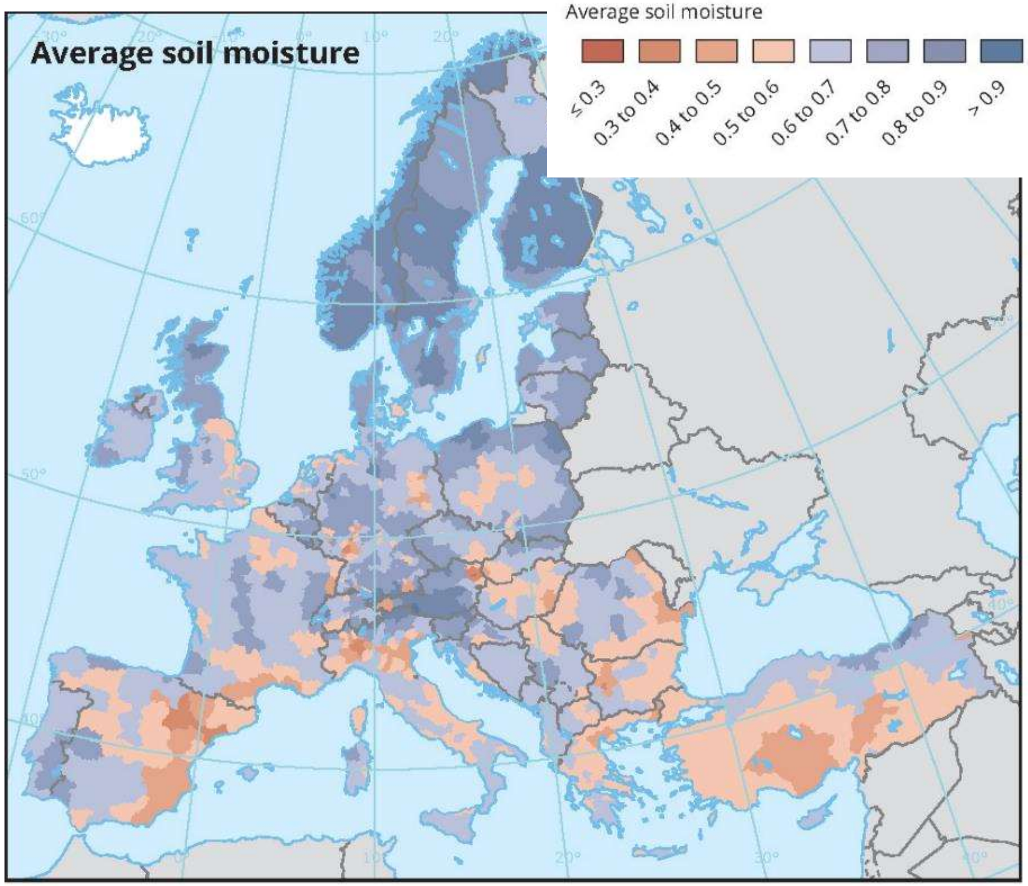
Focus on
productive grasslands, plant diversity, summer drought, S – N gradient

A wide range of summer drought stress

Central and Northern Europe
Intensity: Moderate
Duration: Short
Regularity: Irregular, unpredictable

Mediterranean Europe
Intensity: Severe
Duration: Long
Regularity: Regular, predictable

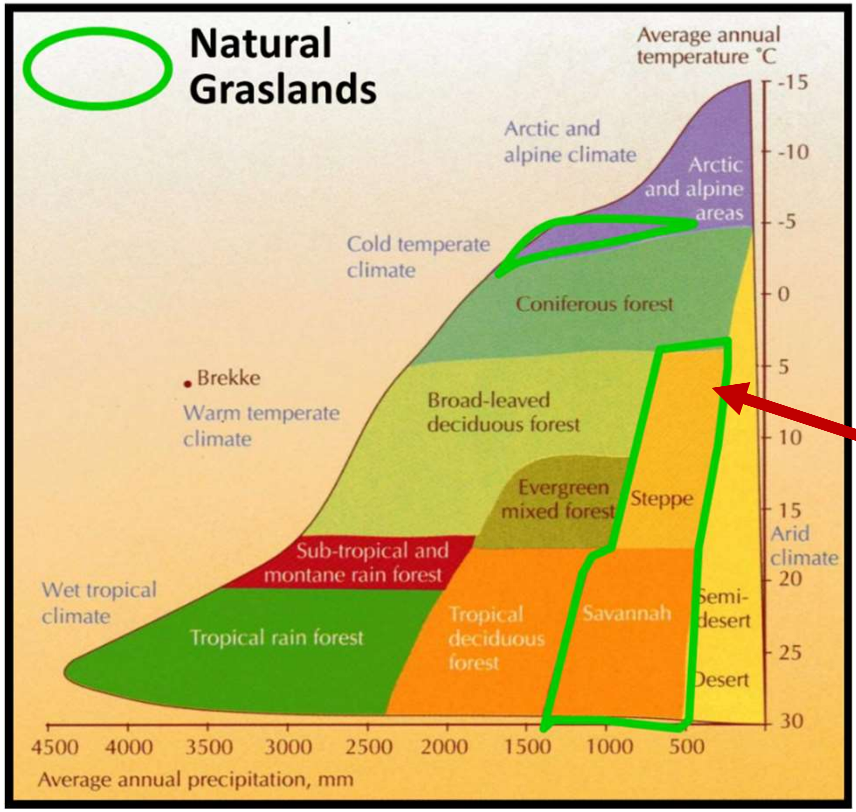
Expectation
Intensity: Increase
Duration: Increase
Regularity: Increase (in the North, and off summer in S)



Reference data: ©ESRI

Natural grasslands thrive where nothing else grows

Ultimate proof of adaptation potential of grasslands

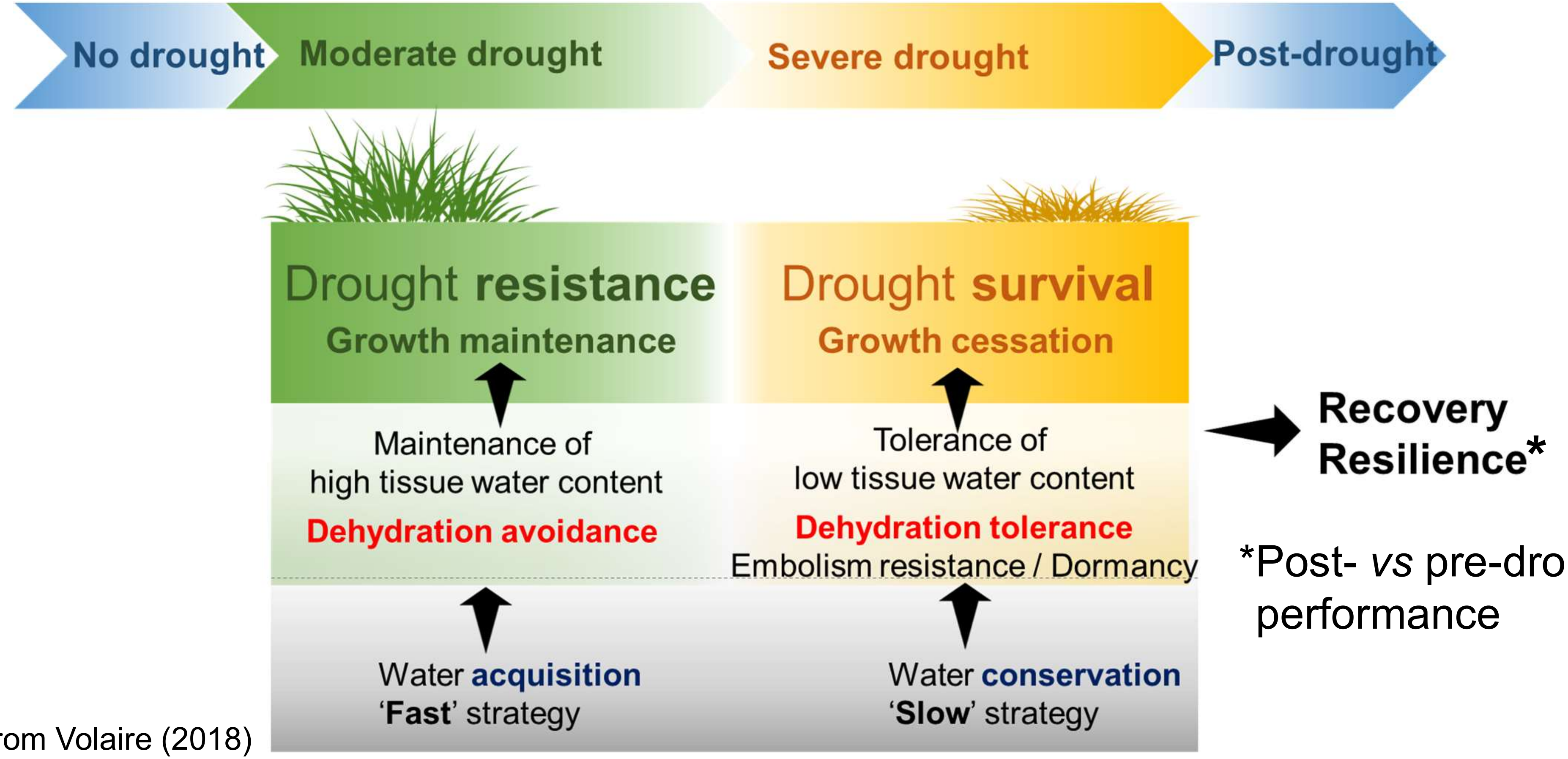


Adapted from Reich *et al*. (1997)

Intra-specific diversity

A pillar for drought adaptation

Successful plant strategy depends on stress severity



*Post- *vs* pre-drought performance

Adapted from Volaire (2018)

Trade-off: growing under moderate drought *vs* surviving severe drought

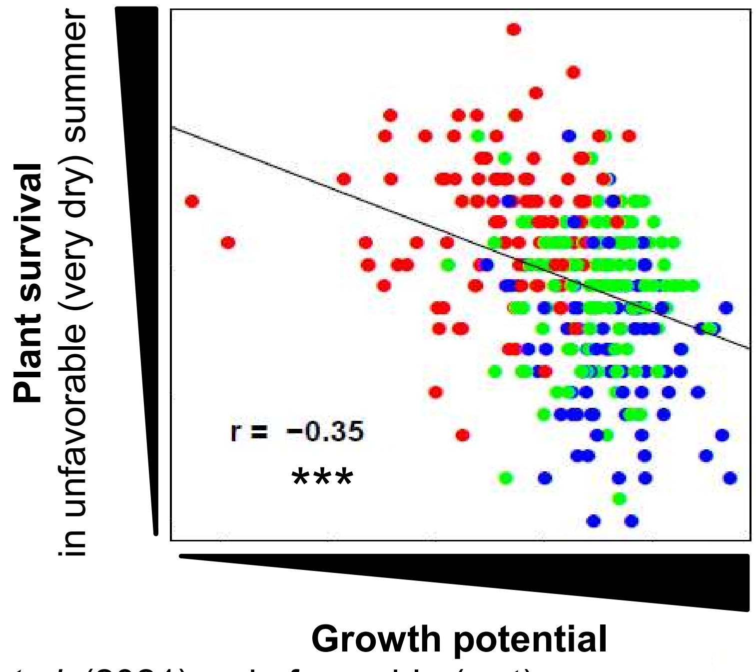
‘Stay green’ and keep growing under moderate drought: Temperate and Northern

- Not dormant, grow in wet summer
- Soil water depletion
- Lower survival under severe drought

‘Knowing when not to grow’ under severe drought: Mediterranean

- Summer dormant = cessation or reduction of growth, irrespective of the water supply (Volaire & Norton, 2006)
- Greater survival of severe droughts

385 natural populations of *L. perenne* from all over Europe



Keep *et al.* (2021)

Valuing of intra-specific diversity

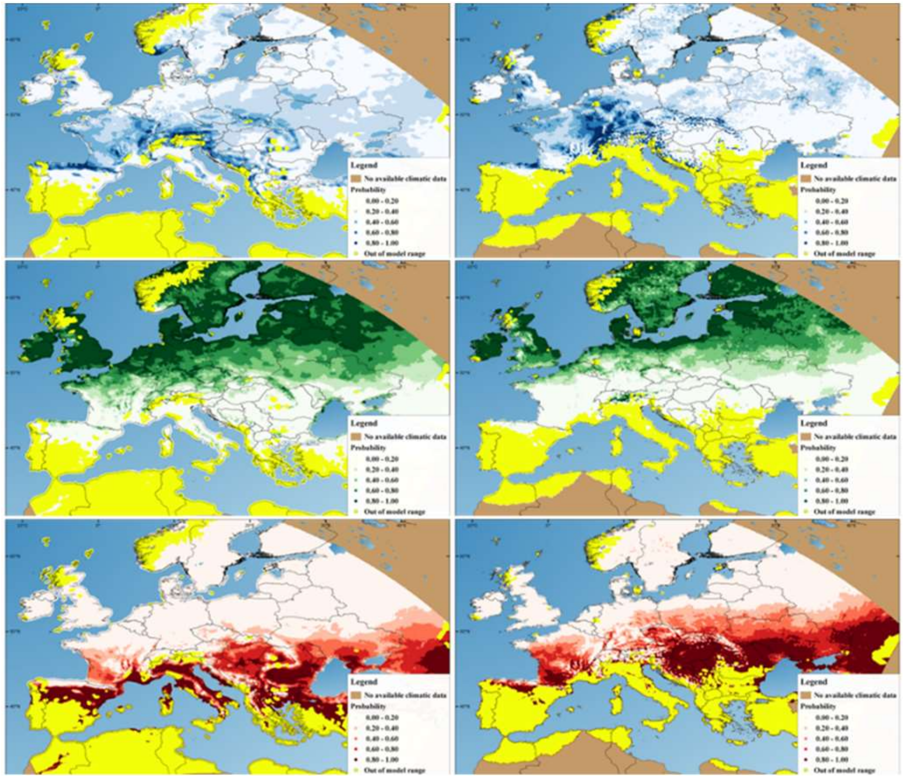
Balancing the trade-off between productivity and stress survival is a central issue in plant breeding for adaptation to drought

- It determines grassland resistance and resilience
- The right balance is context specific:
  it depends on the severity and frequency of summer droughts
- Shift in biogeographic distribution towards the Nortn
- Volaire *et al*. (2014), Ergon *et al*. (2018)

Agroscope

Shift in biogeographic distribution: *L. perenne*

1989-2010 **2041-2070**
(RCA4, AR5 RCP 8.5)



Keep *et al*. (2021)

Group 2) Temperate, poorly adaptated to drought

- Regression in the South, expand in the North

Group 1) North, dehydration avoidance (stay green)

- General regression

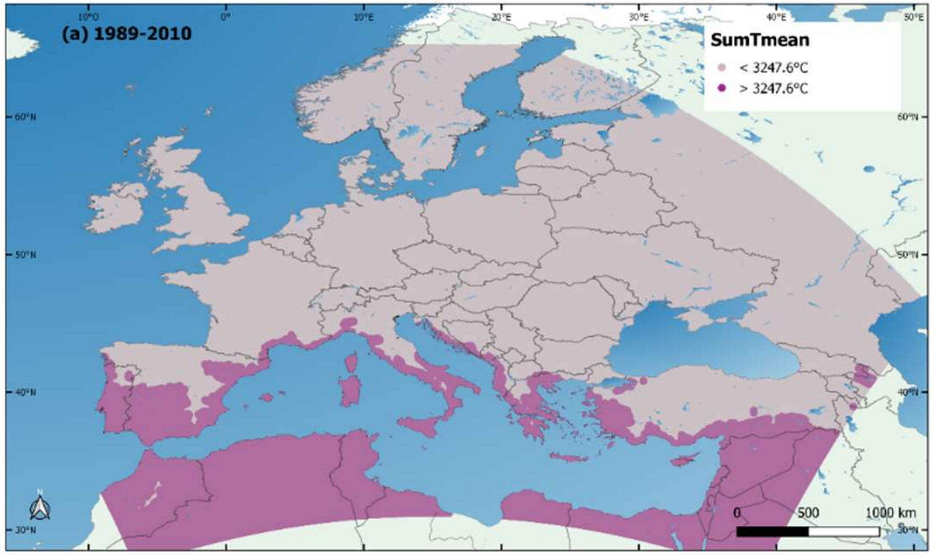
Group 3) Dehydration tolerance and dehydration escape from hot and dry sites (South Europe)

- General expansion

Also for *Dactylis glomerata* Shihan *et al*. (2022)

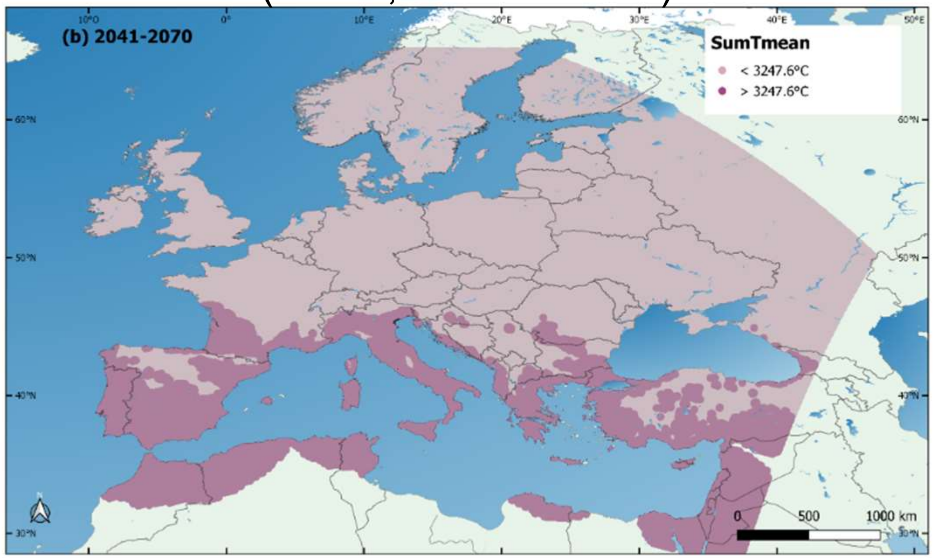
Expansion of areas where summer dormant *Dactylis glomerata* will be adapted

1989-2010



2041-2070

(RCA4, AR5 RCP 8.5)



Shihan *et al*. (2022)

Valuing intra-specific variability

<u>Current situation</u>

Less than 2% of available cultivars of perennial forage species are adapted to severe drought

⇨ Important to better value genetic diversity

<u>How to do it?</u>

Tapping into Mediterranean and semi-arid genetic resources

Testing plant material for summer growth potential and summer dormancy level

Measuring dehydration tolerance in standardised conditions:

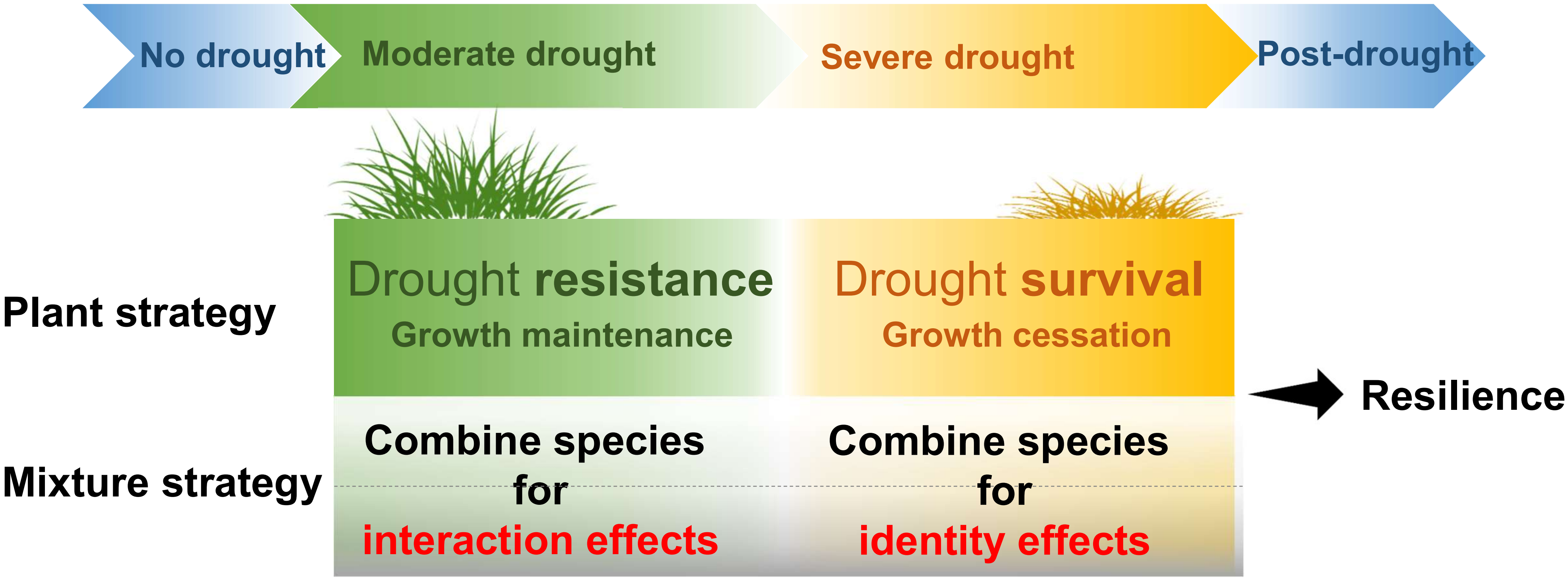
- Soil water potential leading to 50% mortality
- Embolism resistance
- Volaire *et al*. (2014, 2018), Norton *et al*. (2016)

Agroscope

Inter-specific diversity

A pillar for drought adaptation

Successful species combination depends on stress severity

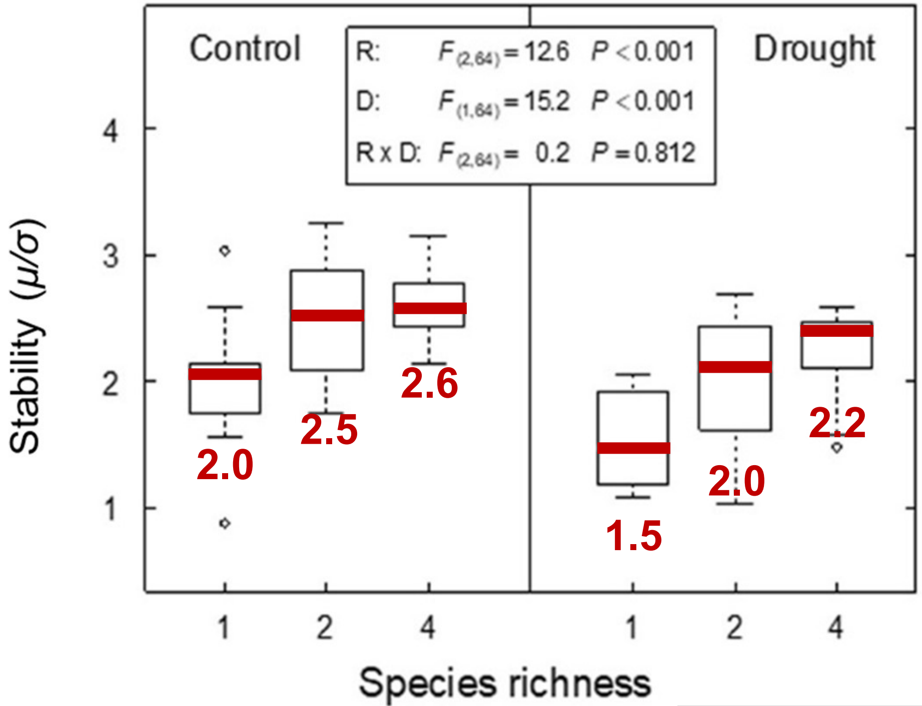


Lüscher *et al.* (submitted)

Agroscope

Species diversity increases stability of yield

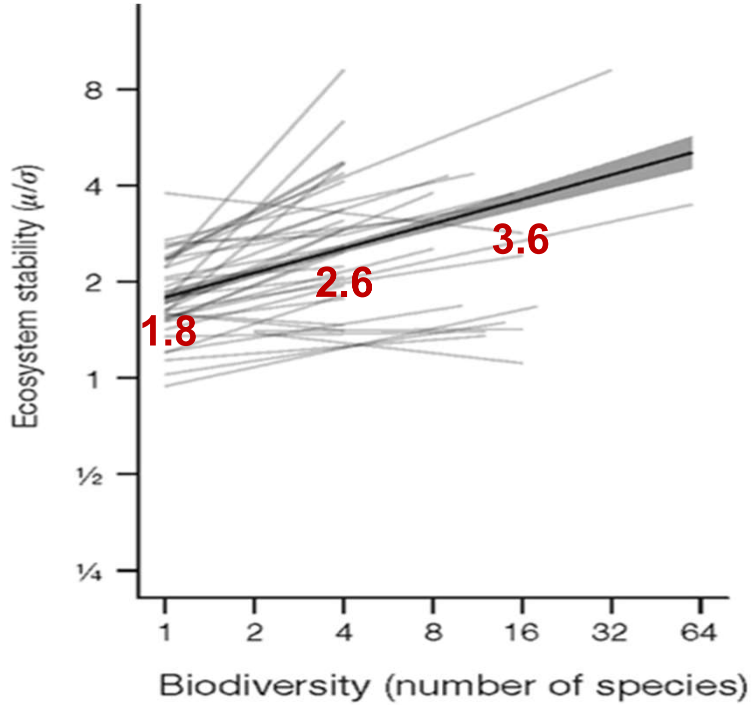
Productive grassland



Haughey *et al.* (2018)

Meta analysis

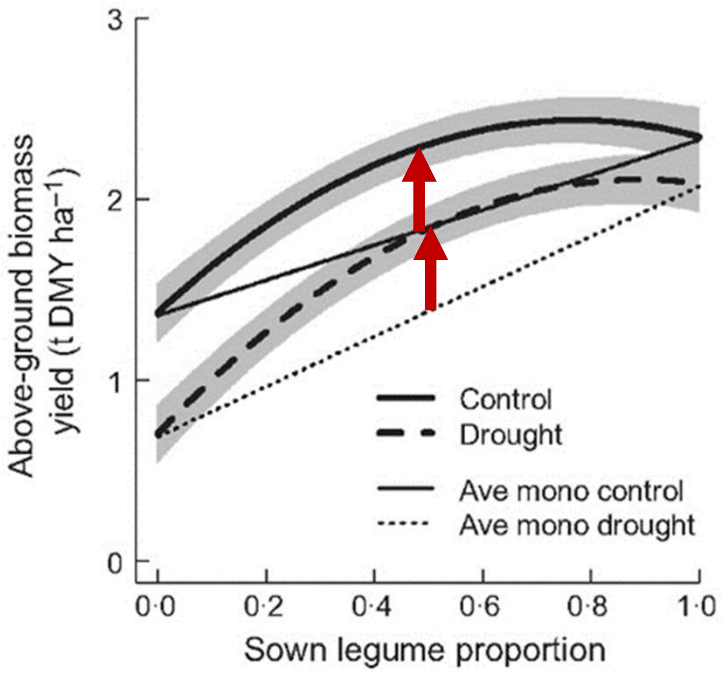
(semi-natural & Agrodiversity Experiment)



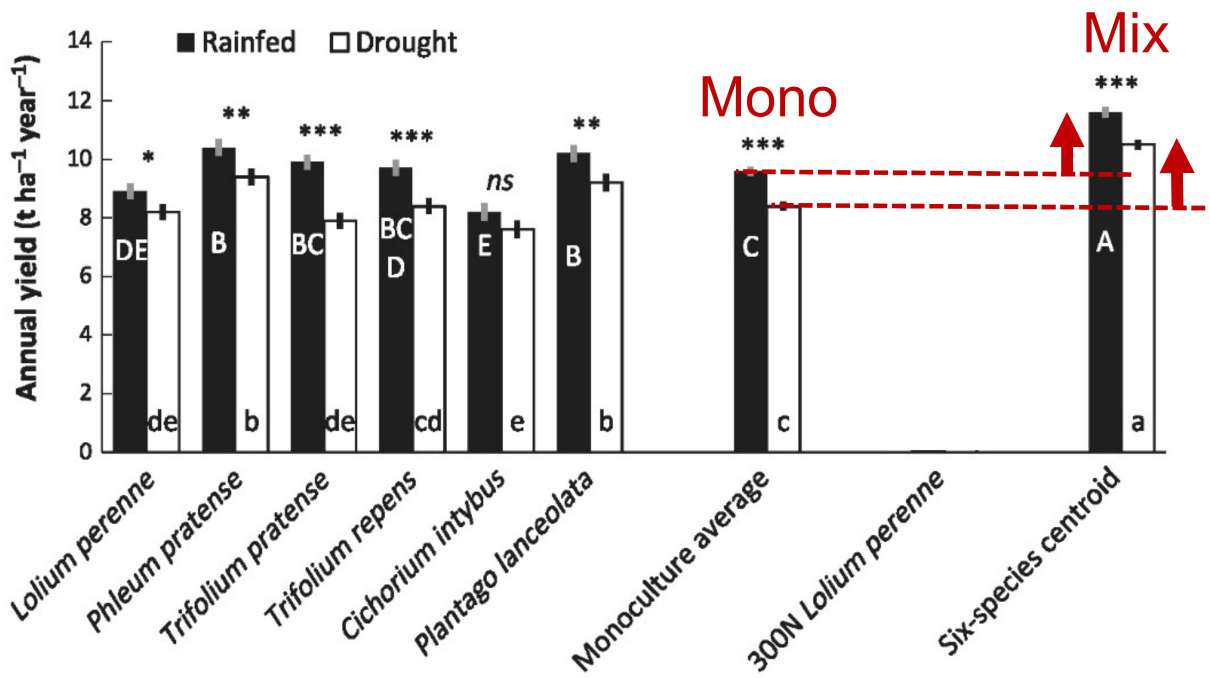
Isbell *et al.* (2015)

Stability = mean / standard deviation

Species diversity increases the mean of yield (through interactions)

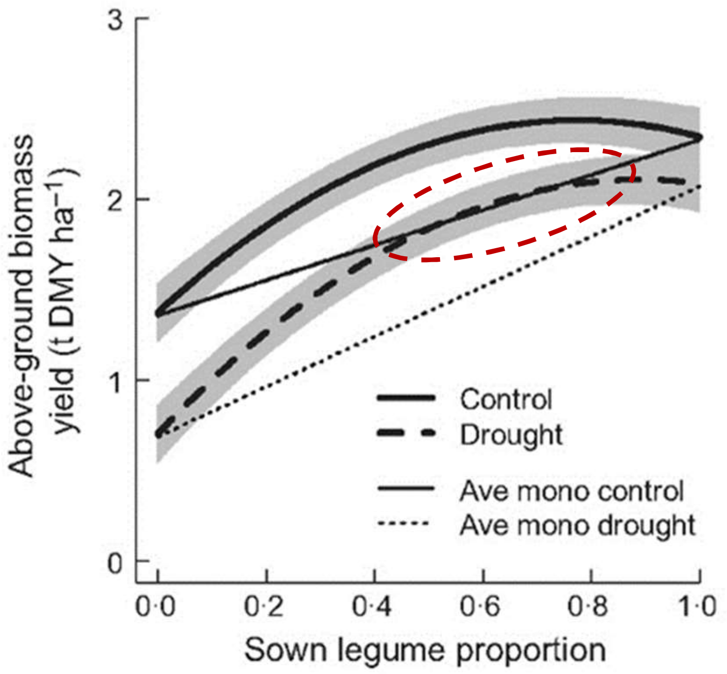


Hofer *et al*. (2016)

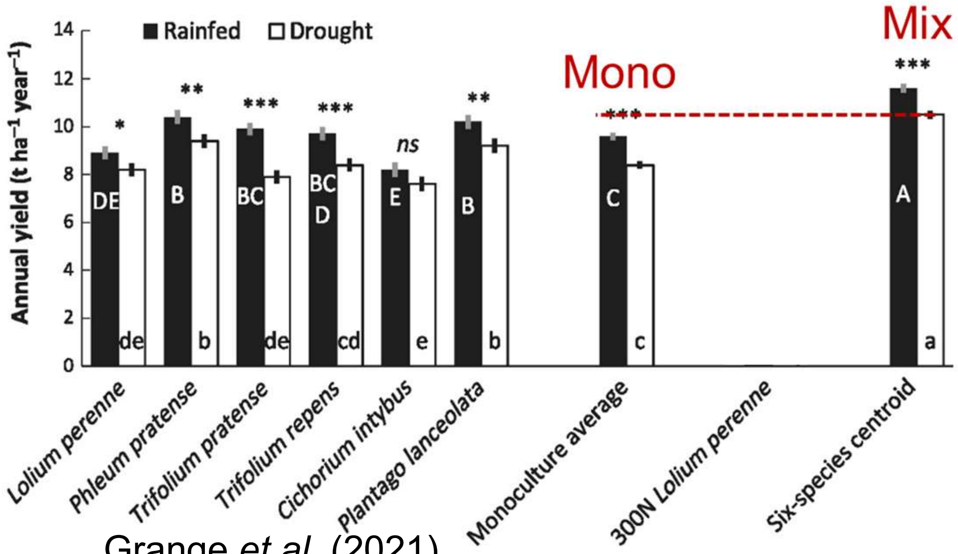


Grange *et al*. (2021)

Mixture yield under moderate drought can be as great as monoculture yield of rainfed control



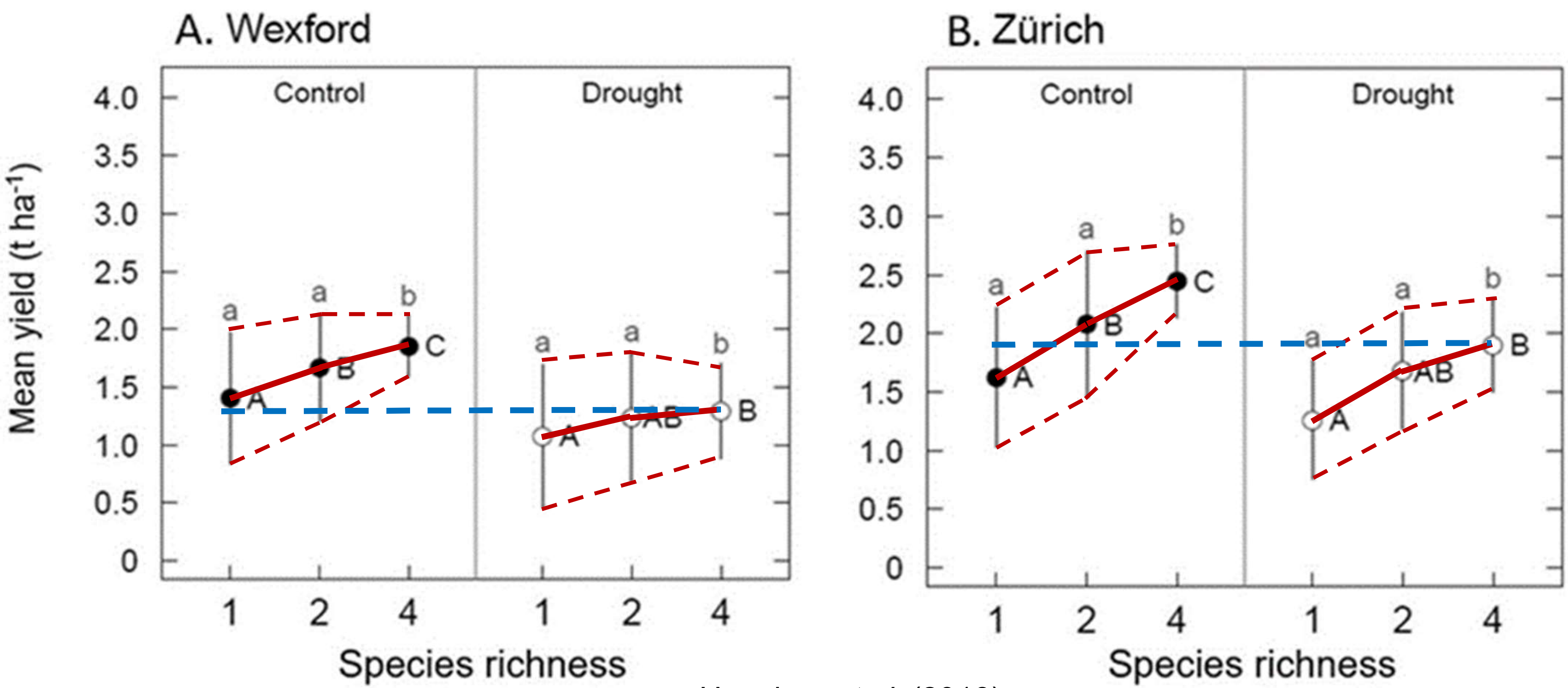
Hofer *et al*. (2016)



Grange *et al*. (2021)

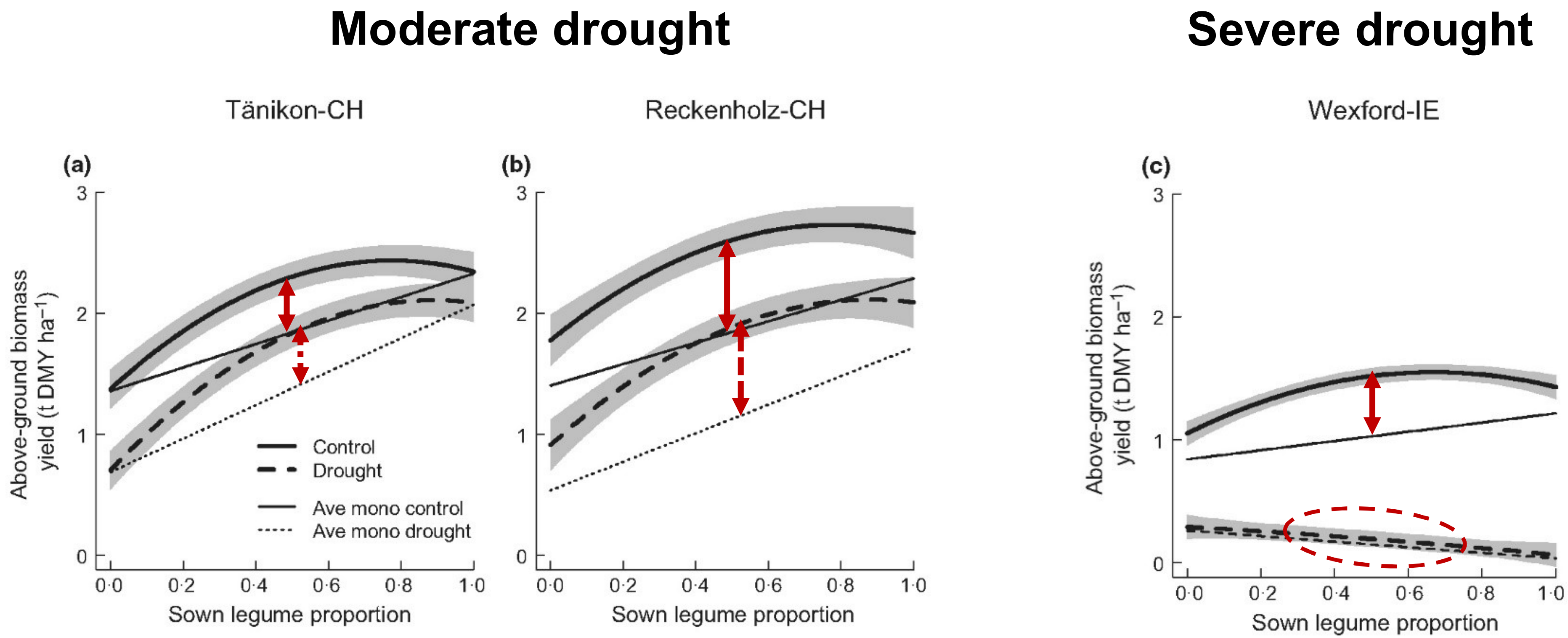
Same results: Mixtures with clover had higher yield under drought than mixtures without clover under control conditions
Komainda *et al*. (2020)

Summary: the mean, the stability, the drought
dedicated to Jean-Louis Peyraud



Haughey *et al*. (2018)

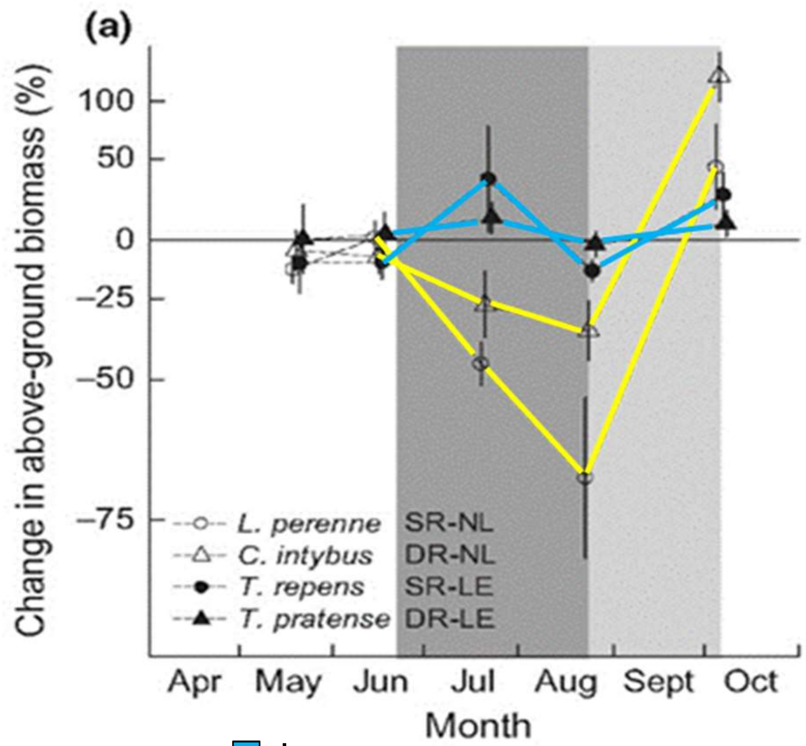
The strong interaction effects disappear under severe drought



Hofer *et al*. (2016)

Species identity independent of interactions

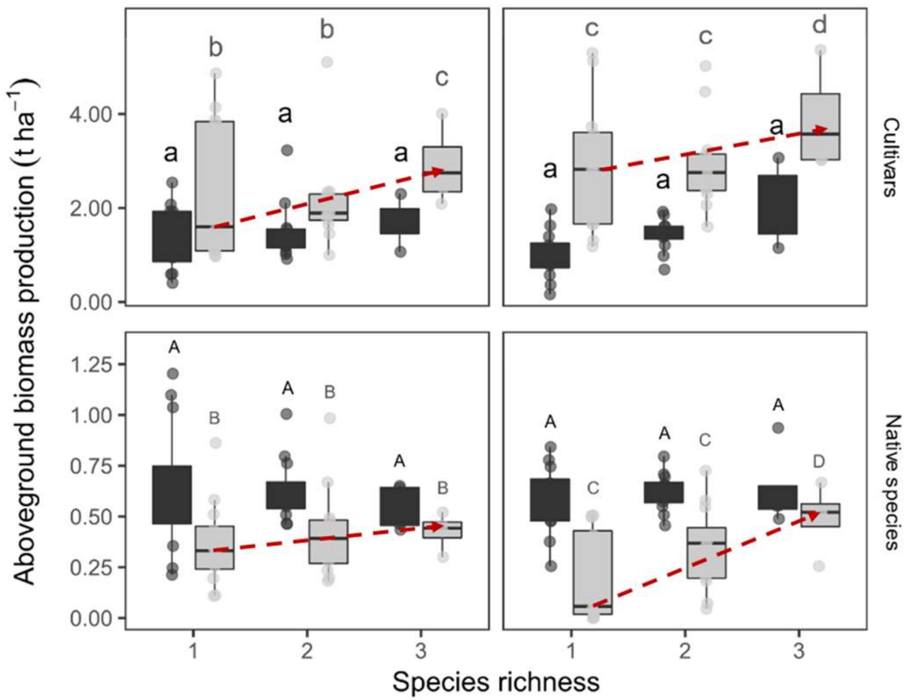
Monocultures fluctuations



Legume Non-Legume

Hofer *et al*. (2016)

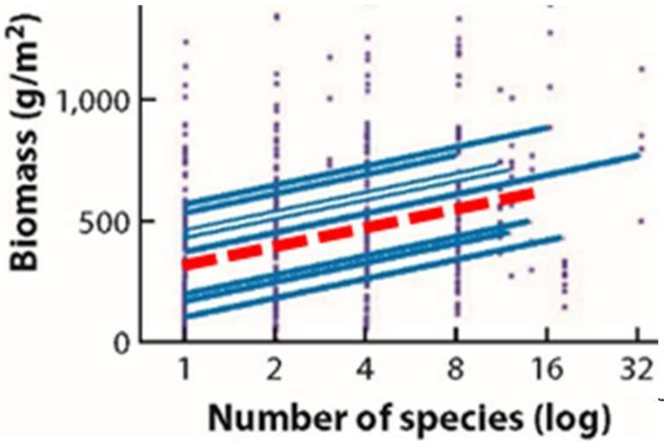
Survivors for strong recovery



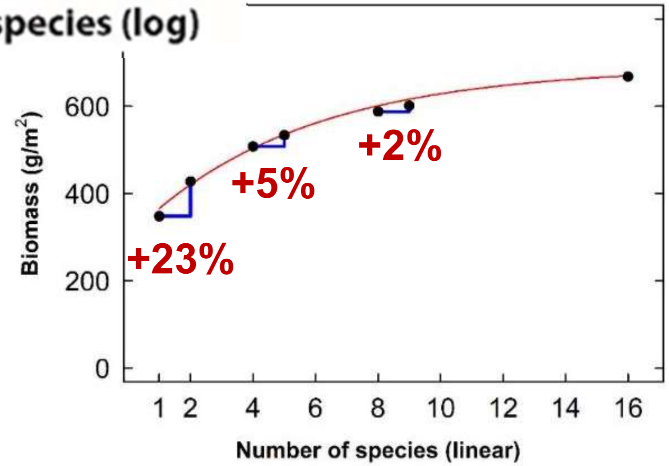
Pre-drought Post-drought

Calculated from Barkaoui *et al*. (2016)

Valuing inter-specific diversity: Low hanging fruits to start - *random* community assemblages



Hector *et al.* (1999)



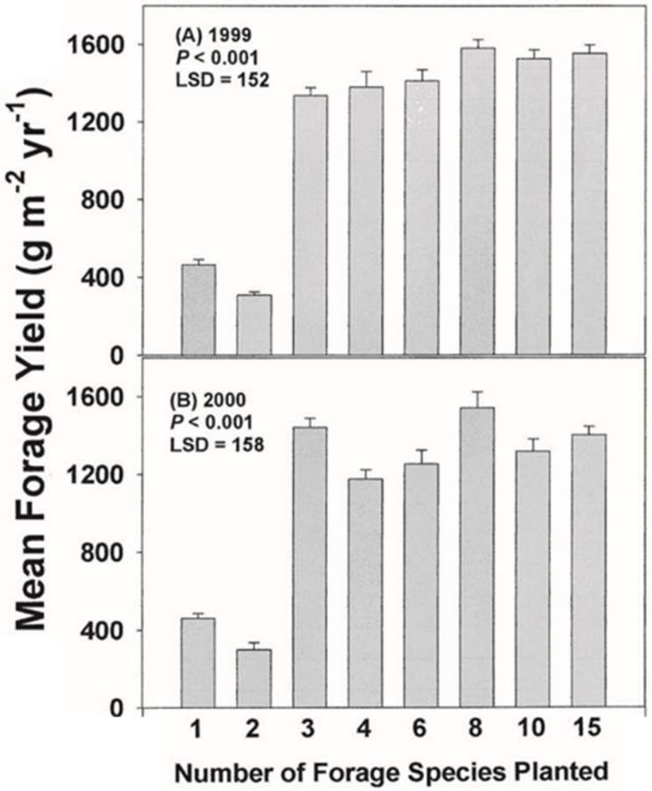
Same results from largest and longest-running biodiversity experiments

- Jena Scherber *et al*. (2020)
- Cedar Creek Tilman *et al*. (2001)

Same result for other ecosystem functions

- Community respiration, decomposition, nutrient retention, water retention
- Naeem *et al*. (1994), Tilman *et al*. (2014)

Even faster saturation in targeted mixture assemblages ⇨ very low hanging fruits to start



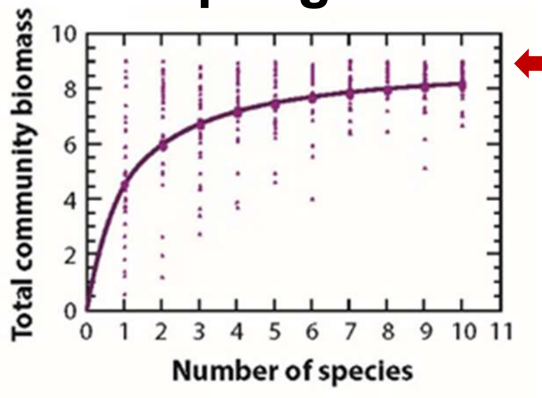
Tracy & Sanderson (2004)

Same results: no or marginal yield increase when comparing mixtures with:

- 2 and 9 species Grace *et al.* (2018)
- 3 and 8 species Lorenz *et al.* (2020)
- 3 and 9 species Sanderson (2010)
- 3 and 5 species Komainda *et al.* (2020)
- 4 and 6 species Grange *et al.* (2021)

Mechanisms to explain faster saturation

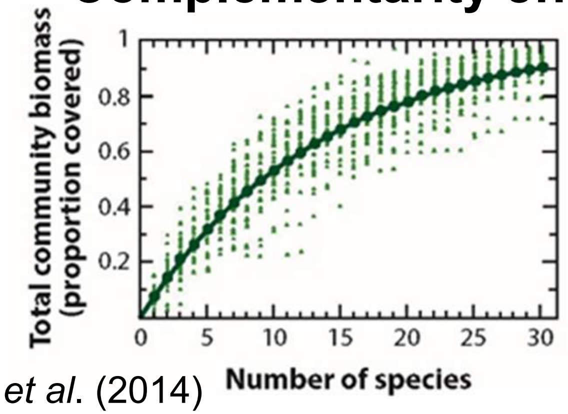
Sampling effect



The more species in a mixture, the larger the probability that it contains the highest yielding species

- Saturates for random combinations (Figure)
- Saturates quicker for targeted combinations because we start with highest yielding species (not *Bellis perennis*, *Ajuga reptans*, *Primula veris*)

Complementarity effect



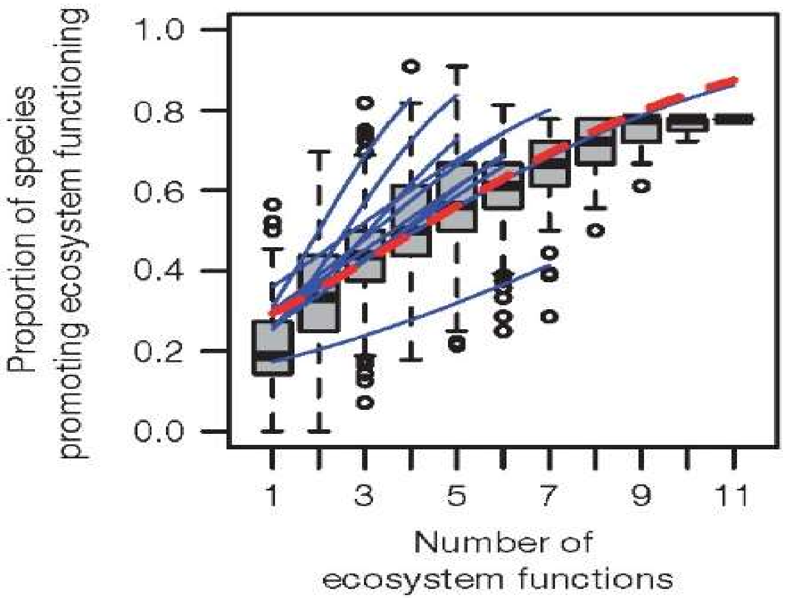
Tilman *et al*. (2014)

The more species in a mixture, the larger the probability that it contains highly complementary species

- Saturates for random combinations (Figure)
- Saturates quicker for targeted combinations because we start with most complementary species (e.g. grass x clover)

Slower saturation if more services

More species diversity is likely to be needed to simultaneously sustain *multiple* ecosystem functions



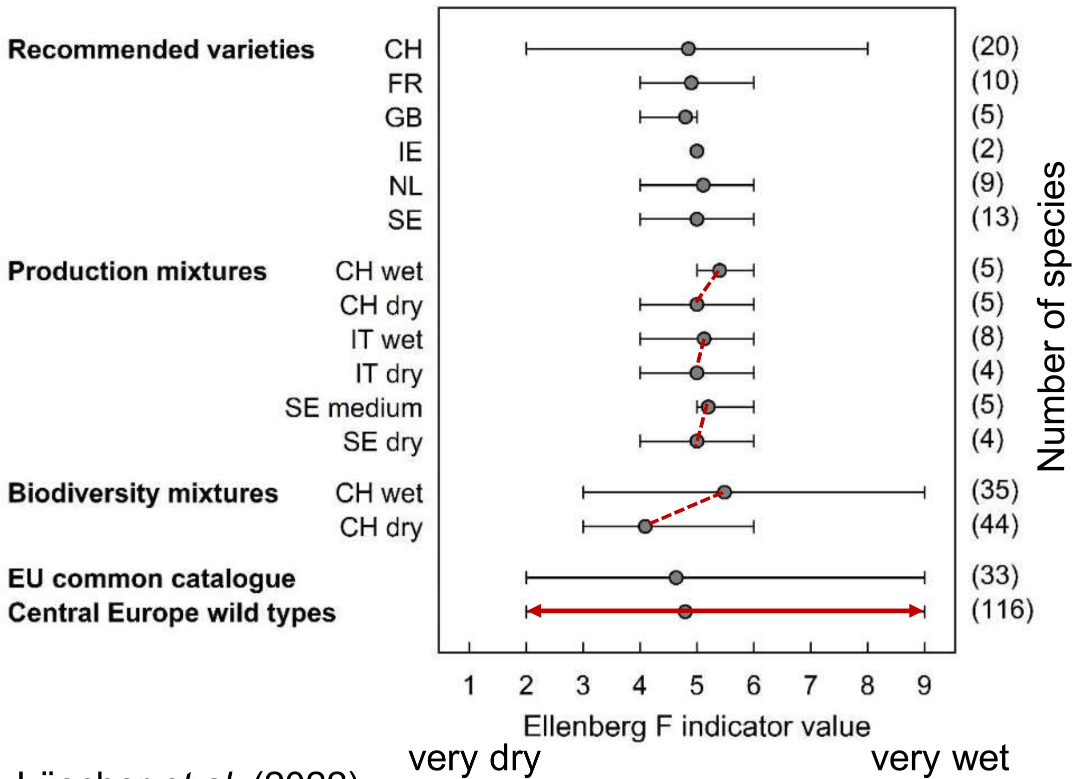
Isbell *et al*. (2011, 2015) Lefcheck *et al*. (2015)

Functional response similar or superior in higher diversity mixtures
(4-15 species compared to 1-3 species)

- resource availability to pollinators (mown)
  Cong *et al*. (2020)
- weed suppression (pasture)
  Tracy & Sanderson (2004)
- dry matter intake (grazed sward)
  Jaramillo *et al*. (2021)
- milk production (grazed)
  Jaramillo *et al*. (2021)
- soil C accumulation (grazed)
  Jaramillo *et al*. (2021)
- N retention (grazed)
  Jaramillo *et al*. (2021)

Valuing inter-specific variability: the present situation

Water requirements

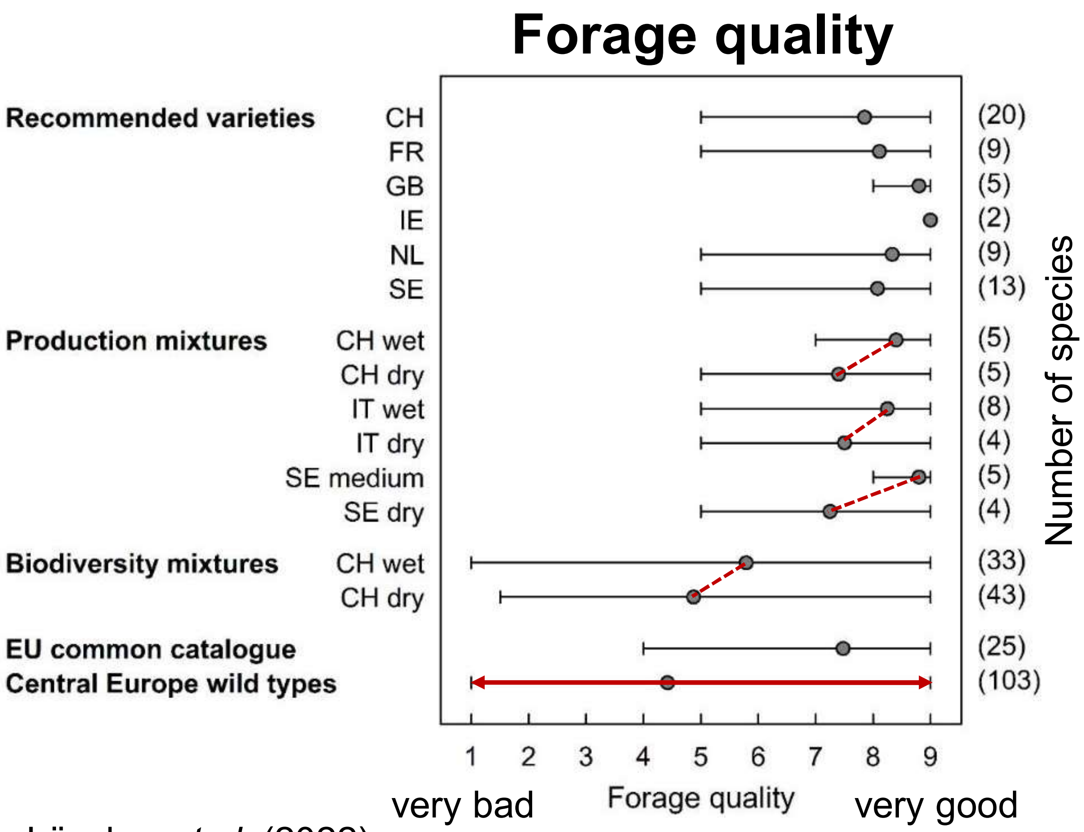


Lüscher *et al.* (2022)

Only a small fraction of the diversity potential is utilised

- small number of species on the recommended lists and in mixtures for production
- All of these in a small range of water requirements

Valuing inter-specific variability: trade-off with forage quality



Lüscher *et al*. (2022)

Possible reasons for small fraction of the potential utilised

- Trade-off
  (i) drought resistance *vs*. forage quality (Figure)
  (ii) growth under moderate drought *vs*. survival under severe drought
- Limited sub-set of species
  they need to be adapted to (very) high defoliation frequency
- No need?
  (i) diversity effects saturate at low species numbers
  (ii) drought pressure (still) too small
  (iii) other pressures more important?

Conclusions

Application

- Grasslands have a huge adaptation potential
- Both intra- and inter-specific diversity are important pillars for adaptation
- Both are insufficiently exploited
- Adaptation strategy depends on stress severity i.e. the region within Europe
  - For moderate, irregular stress
    (i) select ‘stay green’ plant strategy
    (ii) combine species for interactions
  - For severe, regular stress
    (i) select ‘dormant’ plant strategy
    (ii) combine species for identity

Research needs

- Interactions of drought stress with other environmental factors (other stresses, soil type, management)
- Effect of diversity on other ecosystem services than yield
- Effect of diversity on multiple ecosystem services (multifunctionality)

Agroscope


Thank you for your attention
29th GENERAL MEETING
JUNE 26-30, 2022 • CAEN, FRANCE
AGFF
cirad
AGRICULTURAL RESEARCH FOR DEVELOPMENT
ABSys
teagasc
AGRICULTURE AND FOOD DEVELOPMENT AUTHORITY
CENTRE D'ECOLOGIE FONCTIONNELLE & EVOLUTIVE
INRAE
la science pour la vie, l'humain, la terre

Agroscope