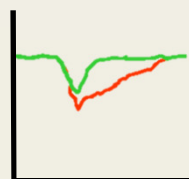
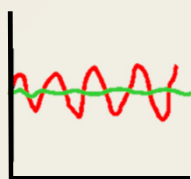
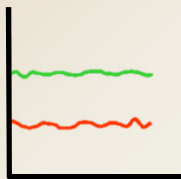


Resilience and adaptation of forage systems to climate change

Résilience et adaptation des systèmes fourragers aux changements climatiques



Valentin D. Picasso

Assistant Professor
Agronomy Department
University of Wisconsin – Madison

COLLOQUE SUR LES
PLANTES FOURRAGÈRES
20-02-20, Saint-Julie,
Québec, Canada



Native grasslands in Uruguay



Outline

- Sustainability, Resilience, and Stability
- Strategies for adaptation:
 - Resilient cultivars
 - Resilient species
 - Forage mixtures
 - Harvest and grazing management
 - Crop rotations with forages
 - Perennial forages and dual-use grain crops
- Climate change as an opportunity for forages

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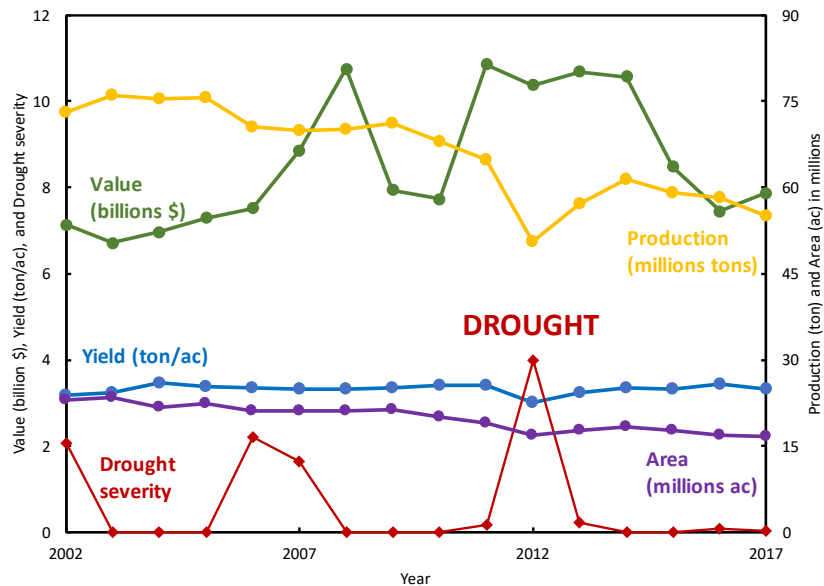


Sustainable agriculture attributes

- Productivity – high food yields
- Profitability – high income
- Efficiency – low inputs
- Stability – low variability
- Resilience – resist crisis
- Flexibility – adaptable
- Environmental services (soil, water, GHG, biodiversity) – protect and improve environment for future generations
- Fairness – socially acceptable

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Picasso et al. Data from NASS 2018, and NOAA 2018.

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**UNITÉ
INDIVISIBILITÉ
DE LA
DURABILITÉ:
PRODUCTIVITÉ
STABILITÉ
RÉSILIENCE
(OU LA
MORT)**

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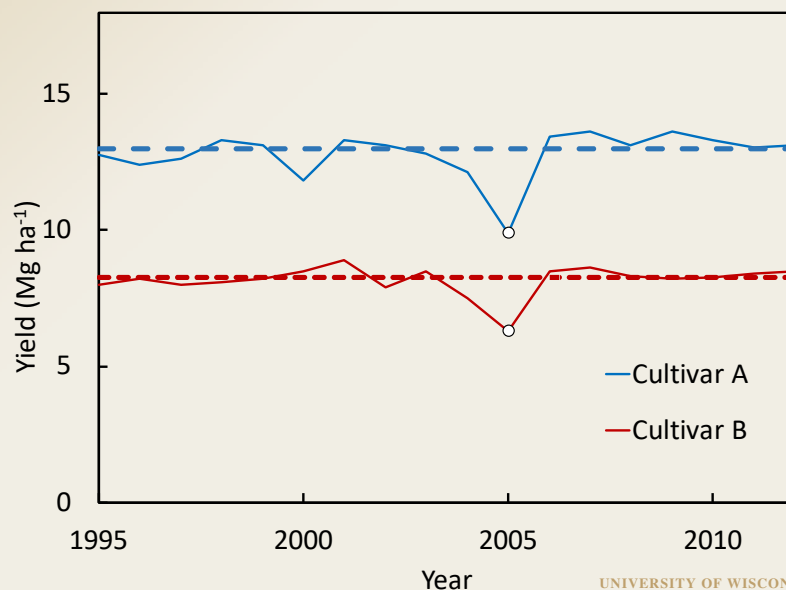
Productivity, Stability and Resilience

- **Productivity** is the mean yield over time.
- **Stability** is the minimal variability of yields over time under normal conditions.
- **Resilience** is the ability to withstand a short-term crisis, perturbation, or shock, like a drought.
It comprises two dimensions:
 - **Resistance**: the ability to not fall during the perturbation,
 - **Recovery**: the ability and speed of recovery afterwards.

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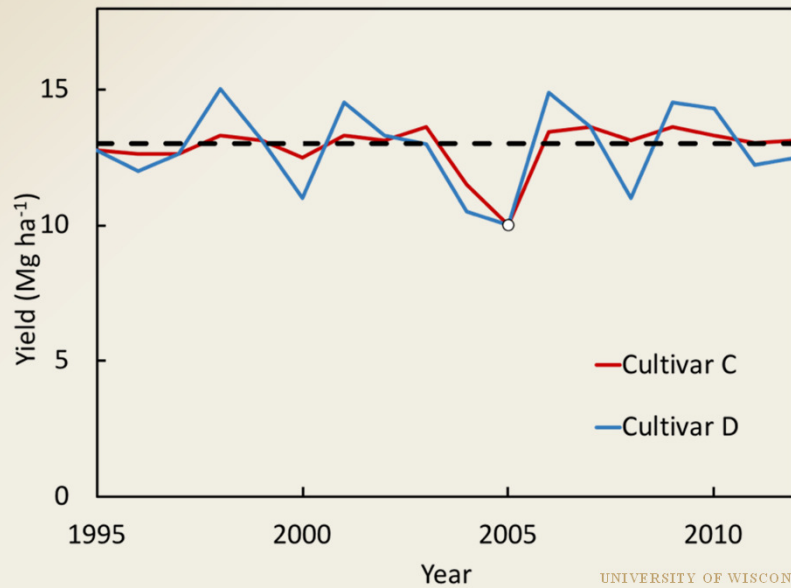
Productivity



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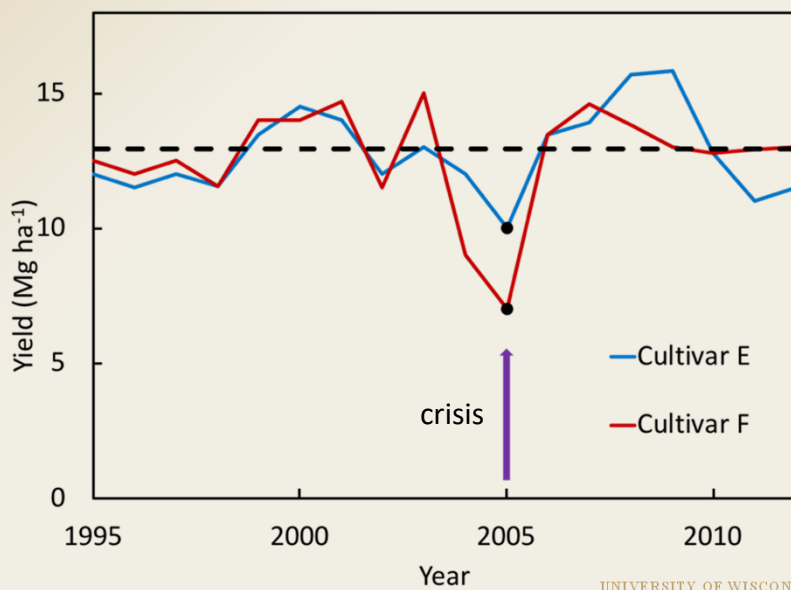


Stability



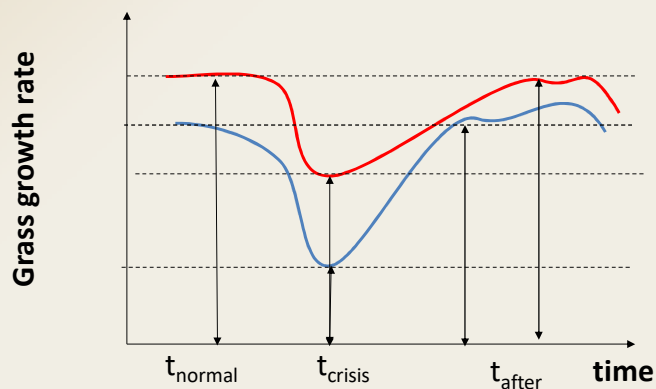
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Resilience



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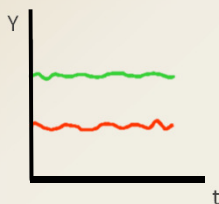
Resistance and recovery



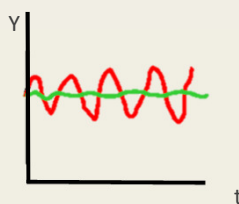
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Summary definitions

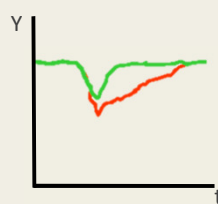
Productivity
= mean yield



Stability
= mean/std error



Resilience
= min/mean



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Strategies to increase resilience and stability in forage production

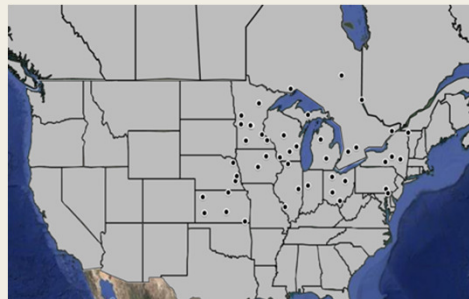
- Resilient cultivars
- Resilient species
- Forage mixtures
- Grazing management
- Crop rotations with forages
- Perennial forages and dual-use grain crops

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Are there more resilient cultivars in alfalfa?

- 679 alfalfa cultivars from 1060 public trials from 1995 – 2013, for 86 locations in 11 US states (IA, IL, IN, KS, MI, MN, NE, NY, OH, PA, WI) and Ontario (Canada).
- 25 locations with crises years evaluated in more than 11 consecutive years.
- 84 Cultivars evaluated in more than 3 locations.



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Crisis Year

- a year when yields were significantly reduced for most cultivars across the entire trial.
- weather data was then analyzed to identify the cause of the crisis (Palmer drought severity index)
- 80% of locations had drought crises years



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Are there differences between cultivars?

Cultivar	L	Productivity		Stability		Resilience	
		P<0.01		P<0.01		P<0.01	
		Mean	SE	Mean	SE	Mean	SE
631	4	14.2	0.7	40	5	<u>0.64</u>	0.04
5312	13	14.1	0.7	72	3	0.62	0.03
6415	8	<u>15.7</u>	0.7	46	4	0.57	0.03
ABUNDANCE	5	14.5	0.7	37	5	<u>0.62</u>	0.03
DK127	4	13.9	0.8	41	5	<u>0.64</u>	0.04
GENOA	5	15.3	0.7	39	5	0.55	0.03
ONEIDAVR	12	13.5	0.7	<u>75</u>	3	0.62	0.03
REBOUND50	5	<u>15.7</u>	0.7	41	5	0.56	0.03
STARBUCK	4	14.9	0.7	49	5	<u>0.63</u>	0.03
VERNAL	20	13.1	0.7	<u>69</u>	3	0.62	0.03
WL357HQ	9	<u>15.7</u>	0.7	32	4	0.57	0.03

Picasso et al. 2019

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Is resilience associated with productivity or stability?



	Stability	Resilience
Productivity	NS	-0.58
Stability		NS
Resilience		

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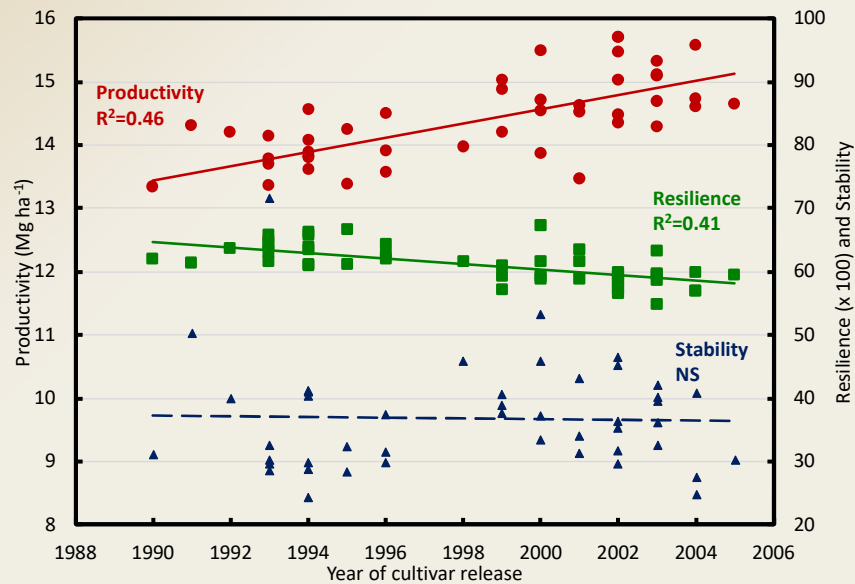
Is resilience associated with stress tolerance traits?



	Stability	Resilience	Winter Survival	Disease Resistance
Productivity	NS	-0.58	NS	0.30
Stability		NS	NS	-0.56
Resilience			NS	NS

Picasso et al. 2019

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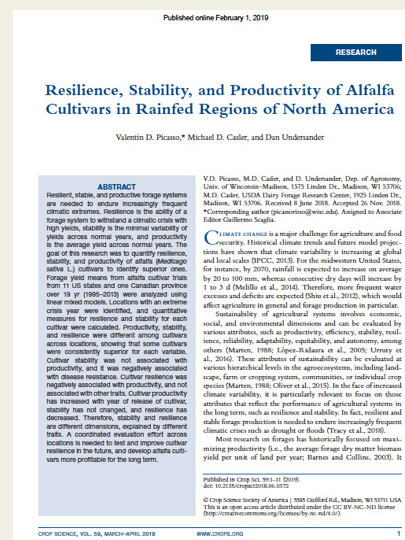


Picasso et al. 2019

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Conclusions

- Alfalfa cultivars differ in stability and resilience; it is possible to identify superior cultivars for each variable.
- Resilience and stability represent two different dimensions of the long-term performance of cultivars, and are associated with different traits.
- A coordinated testing approach across many locations is proposed to improve alfalfa resilience in the future.



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Ongoing research

- USDA-NIFA-AFRP grant 2018-2021 (WI, MN, CA, FL)
 - Expand and update North American alfalfa variety trials database with new cultivars.
 - Experiments to measure resilience of alfalfa cultivars to water and cold stresses in field, and identify plant traits associated with resilience.
 - Modeling yield of alfalfa cultivars under a wide range of climatic scenarios.
- International Alfalfa Resilience database (Uruguay, Argentina, Chile, ...)
- Other forage/crop species (Tall Fescue, Switchgrass, Oats, ...)



Relevant traits

- Winter hardiness
- Heat tolerance
- Drought tolerance
- Flood resistance

- Resistance to insects and diseases

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Breeding forages in North America

Quebec, Canada

- Alfalfa and red clover: cold tolerance and disease resistance
- Timothy: heat tolerance

Kentville, Canada

- alfalfa: drought and flood resistance

Cornell, New York USA

- Alfalfa resistance to insects and diseases

Wisconsin, USA

- Meadow fescue - yield
- Orchardgrass - non-flowering in cold-winter climates
- Red clover - yield, seedling vigor, disease resistance

California, UC Davis, USA

- alfalfa: tolerance to heat, deficit irrigation, and salinity, and persistence in dryland range environments
- Tall fescue summer active and summer dormant ecotypes, with and without endophytes

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Choice of species

Tolerance to subfreezing temperatures and anoxia caused by presence of ice on fields.



Suffocating effects of ice can lead to alfalfa stand losses. (photo courtesy of Greg Andrews)



Choice of species – winter tolerance

Legumes:

red clover < alfalfa < Birdsfoot trefoil < Kura clover



Grasses:

ryegrasses < orchardgrass < tall fescue <

reed canarygrass < smooth brome grass < timothy



Balasko and Nelson, 2003

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Choice of species – winter tolerance

BÉLANGER ET AL. — WINTER DAMAGE TO PERENNIAL FORAGE CROPS IN EASTERN CANADA 37

Table 1. Relative shoot regrowth, relative total non-structural carbohydrates (TNC), and ethanol concentration in shoot bases and crowns of oxygen deficiency-treated plants of four forage species following 100 d of treatment. Relative shoot regrowth and relative total non-structural carbohydrates (TNC) were calculated as values from oxygen deficiency-treated plants divided by values from plants maintained under normal atmospheric conditions. Adapted from Bertrand et al. (2001, 2003)

	Timothy	Orchardgrass	Alfalfa	Red Clover
Relative shoot regrowth	0.69	0.49	0.30	0.04
Relative TNC	1.24	0.95	0.46	0.62
Ethanol (mg g ⁻¹ DM)	3.07	11.04	10.41	14.28

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Choice of species – drought tolerance

Legumes:

white clover < Birdsfoot trefoil < red clover < Kura clover < alfalfa

Grasses:

Ryegrasses < timothy < orchardgrass < reed canarygrass
< tall fescue < smooth brome



McGraw and Nelson, 2003

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Perennials

- Ecosystem services:
 - Erosion control
 - Nutrient leaching reduction
 - Carbon fixation
- Multiple agricultural uses:
 - Pastures for grazing
 - Forages for feed
 - Biomass for energy
 - Perennial grains

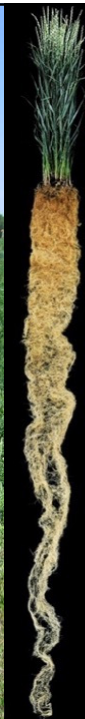


TABLE 1 Productivity, stability, and resilience values for biomass and ground cover measured on 13 perennial cool-season grass species at six Intermountain and northern Great Plains rangeland sites from 2000 to 2003

Species	Biomass kg ha ⁻¹			Ground cover %		
	P	S	R	P	S	R
Intermediate wheatgrass	5595 ^{a†}	28.5 ^a	0.3	98 ^a	58.3 ^a	0.6 ^{abcde}
Tall wheatgrass	5043 ^a	17.8 ^b	0.3	95 ^{ab}	36.0 ^{cd}	0.5 ^{bcd}
Crested wheatgrass	3818 ^b	19.6 ^b	0.4	86 ^{abcd}	49.9 ^{ab}	0.9 ^{ab}
Western wheatgrass	3781 ^b	12.7 ^c	0.4	97 ^a	37.1 ^{cd}	0.8 ^{abc}
RS Hybrid wheatgrass	3634 ^{bc}	10.6 ^{cde}	0.4	86 ^{abcd}	27.9 ^{def}	0.5 ^{bcd}
Meadow brome	3379 ^{bcd}	11.6 ^{cd}	0.4	90 ^{abc}	34.7 ^{cde}	0.7 ^{abcd}
Smooth brome	3193 ^{bcd}	9.3 ^{cdef}	0.5	86 ^{abcd}	27.9 ^{def}	0.7 ^{abcd}
Siberian wheatgrass	3112 ^{bcd}	11.2 ^{cd}	0.4	84 ^{abcd}	32.1 ^{cdef}	0.8 ^{abc}
Altai wildrye	2812 ^{bcd}	8.0 ^{def}	0.5	75 ^{bcd}	23.4 ^{efg}	0.4 ^{cde}
Russian wildrye	2658 ^{cdef}	10.4 ^{cde}	0.8	87 ^{abc}	41.6 ^{bc}	1.0 ^a
Basin wildrye	2339 ^{def}	6.7 ^{ef}	0.8	66 ^d	21.2 ^{fg}	0.4 ^{cde}
Thickspike wheatgrass	2206 ^{ef}	7.7 ^{def}	0.5	72 ^{cd}	26.9 ^{defg}	0.3 ^{de}
Bluebunch wheatgrass	1630 ^f	5.9 ^f	0.5	40 ^e	15.1 ^g	0.2 ^e
P value	<.0001	<.0001	>.30	<.0001	<.0001	<.05

Note. P, productivity; S, stability; R, resilience. Species: intermediate wheatgrass, *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey; tall wheatgrass, *Thinopyrum elongatum* (Host) D.R. Dewey; crested wheatgrass, *Agropyron cristatum* (L.) Gaertn. and A. *desertorum* (Fisch. ex Link) Schult.; western wheatgrass, *Pascopyrum smithii* Rydb.; RS Hybrid wheatgrass, *Elymus hoffmannii* K.B. Jensen & K.H. Asay; meadow brome, *Bromus biebersteinii* Roem. & Schult.; smooth brome, *Bromus inermis* Leyss.; Siberian wheatgrass, *Agropyron fragile* (Roth) P. Candargy; Altai wildrye, *Leymus angustus* (Trin.) Pilg.; Russian wildrye, *Psathyrostachys juncea* (Fisch.) Nevski; basin wildrye, *Leymus cinereus* (Scribn. & Merr.) Á. Löve; thickspike wheatgrass, *Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould; bluebunch wheatgrass, *Pseudoroegneria spicata* (Pursh) Á. Löve.

[†]Column values followed by different superscript letters differ significantly.

Robins et al., 2020

Kernza intermediate wheatgrass



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Choice of species

- There is no best species for every situation
- Consider multiple traits
- Look for recent data
- Perennials vs annuals
- Forage mixtures!

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Strategies to increase resilience and stability in forage production

- Resilient cultivars
- Resilient species
- Forage mixtures
- Grazing management
- Crop rotations with forages
- Perennial forages and dual-use grain crops

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Forage mixtures - advantages

- Insurance against climate if any single species fails.
- Increased yield
- Increased forage quality
- Grasses reduce heaving in alfalfa
- Extend growing season
- Reduce Nitrogen fertilizer requirements
- Increased soil benefits
- Reduced weed invasion

Picasso et al., 2008; Sanderson et al., 2005; Tracy et al., 2004

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How much forage species diversity is needed?

- 52 combinations of 8 perennial species
 - All monocultures
 - Some polycultures of 2, 3, 4, 6 and 8 species
 - For each level of species richness there were plots with and without each species
- 2 locations in Iowa
- 2 harvest regimes (1 vs 3 cuts)
- 3 years of data collection (2003-2006)
- Measured forage biomass per species

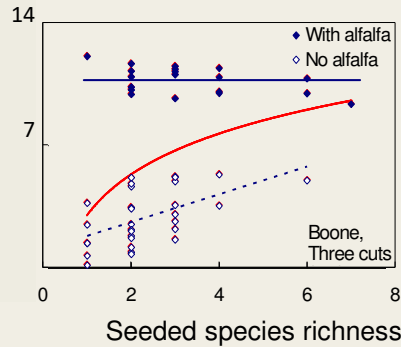
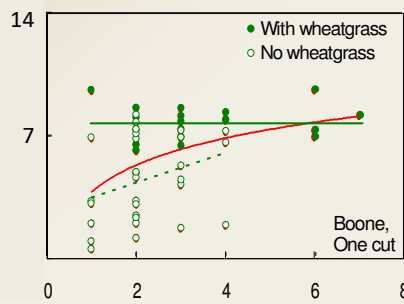


Picasso et al. (2008) Crop Sci.

Both Diversity and Species matter!



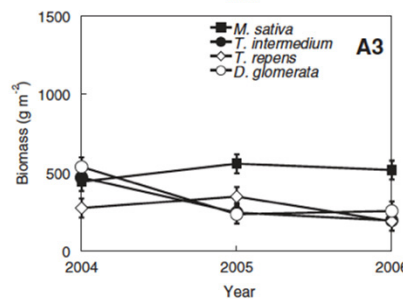
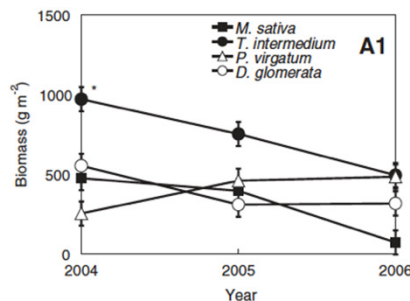
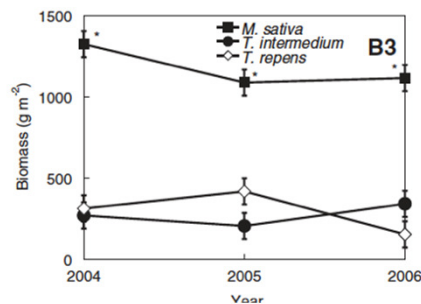
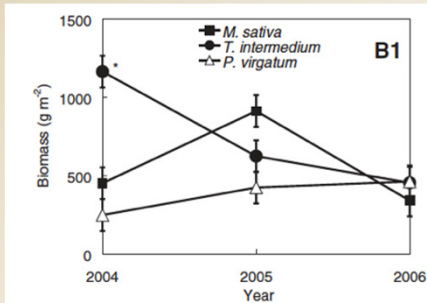
Biomass yield (tons ha⁻¹)



- Best monoculture: **Int. wheatgrass (1 cut)** vs. **alfalfa (3 cuts)**
- Weed biomass was reduced with diversity.

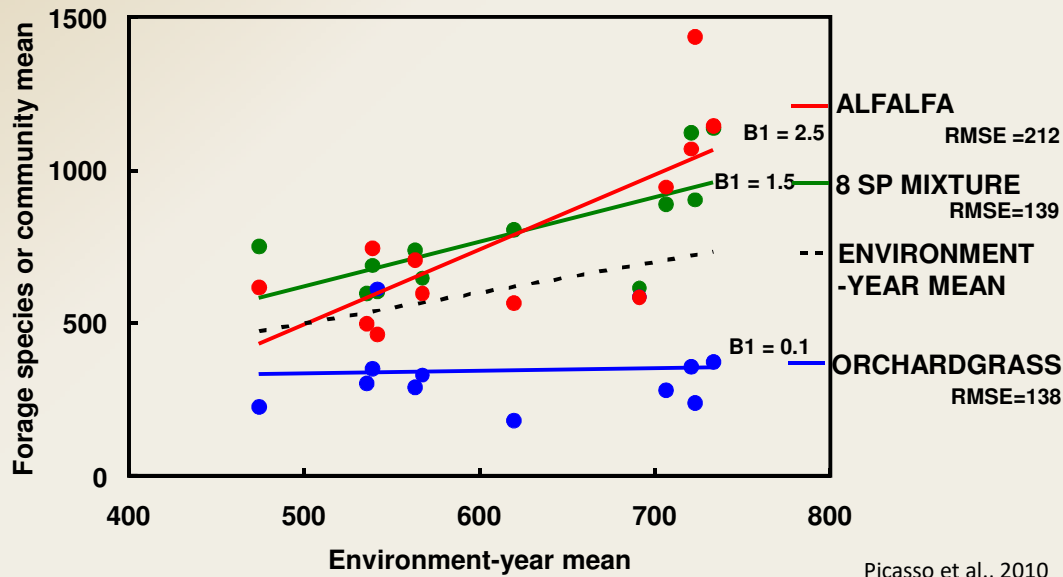
Picasso et al. (2008) Crop Sci.
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Species x Management x Site x Year

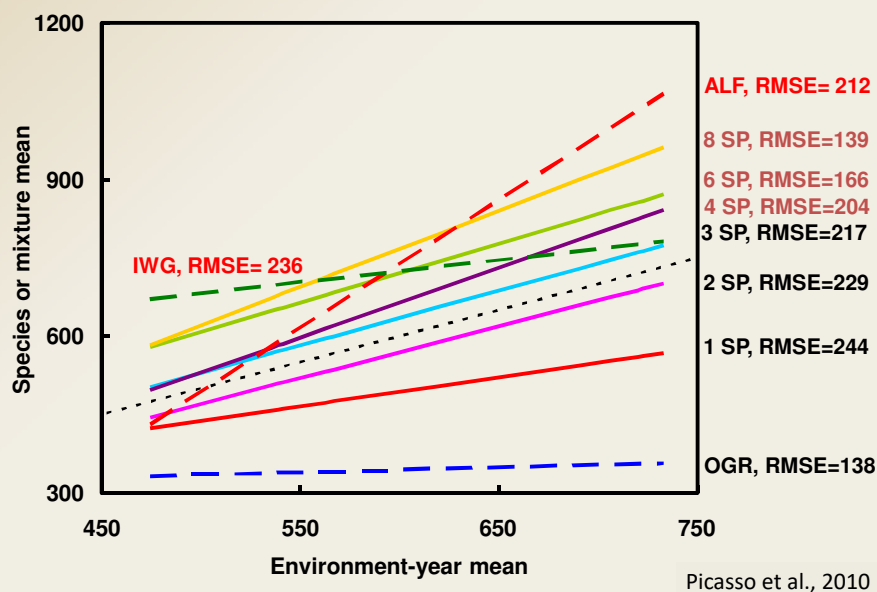


Picasso et al. (2011) RAFS

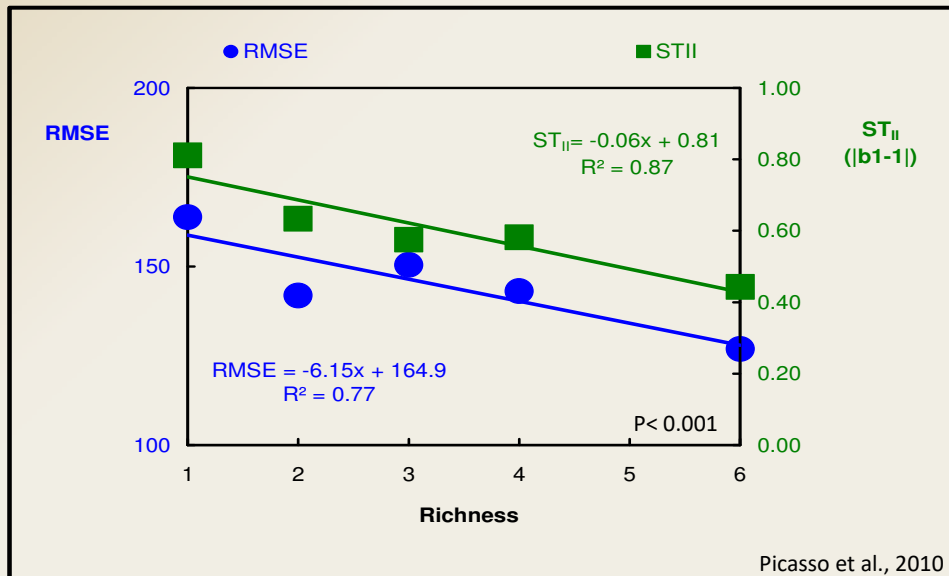
Type I, II, and III stability (Finlay & Wilkinson, 1963)



Stability type II (consistency) and III (reliability)



Reliability (type III) and Consistency (type II)



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Forage mixtures

- Species matter – choose well
- Diversity matters – 2-3 species (grass + legume)
- Forage mixtures are more stable
- Forage mixtures are more consistent and reliable

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Strategies to increase resilience and stability in forage production

- Resilient cultivars
- Resilient species
- Forage mixtures
- Grazing management
- Crop rotations with forages
- Perennial forages and dual-use grain crops

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Grazing

Forage harvest under wet conditions in spring is more challenging, and grazing provides expanded opportunities for forage utilization, therefore, grazing is likely to grow in livestock systems.

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Grazing management and resilience

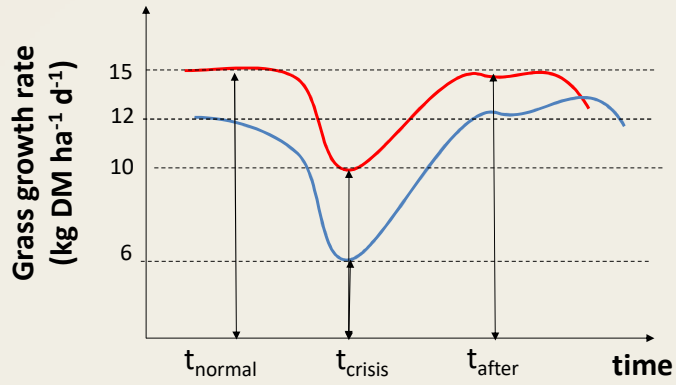
Normal (before drought)



Crisis (during drought)



— High herbage allowance: $R_s=0.66$, $r_c=3.1$
 — Low herbage allowance: $R_s=0.46$, $r_c=3.7$

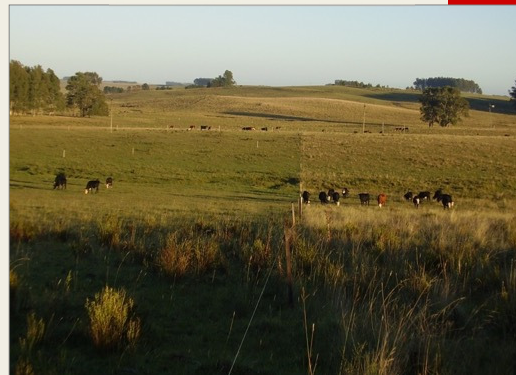
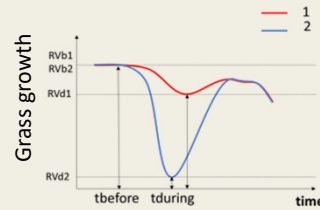
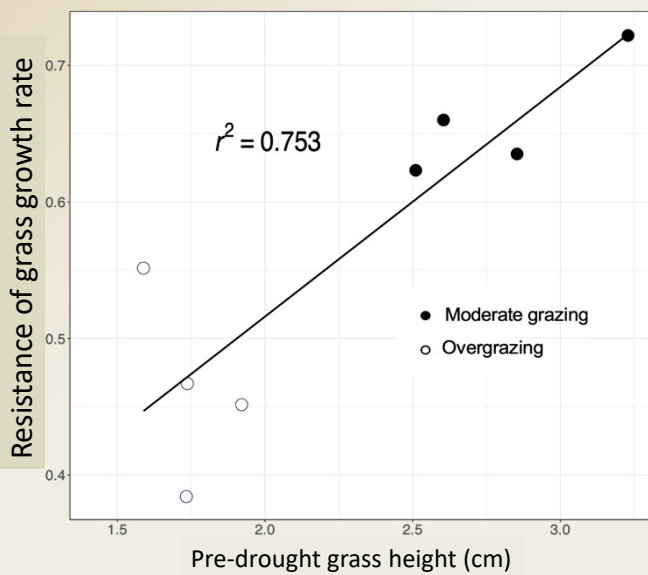


$$\text{Resistance} = \frac{Y_{\text{crisis}}}{Y_{\text{normal}}}$$

$$\text{Recovery} = \frac{Y_a - Y_c}{t_a - t_c}$$

Modernel et al., 2019. GFS

Resistance at paddock level: grass growth rate



Modernel et al., 2019. GFS

Crop rotation and resilience

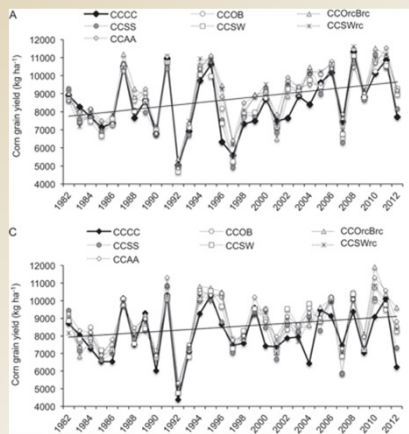
**Elora Research Station,
Ontario, Canada:**
1625 acres, silt loam soil,
900 mm annual rainfall,
2700-2800 CHU



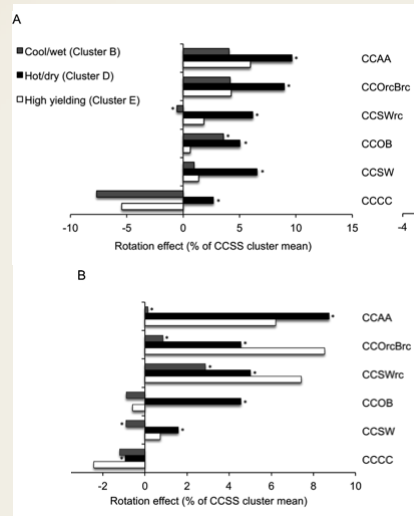
- Initiated in 1980
- Rotations – CCCC, AAAA, CCAA, CCSS, CCSW, CCSW(rc), CCOB, CCO(rc)B(rc)
- Conventional tillage and no-till

Bill Dean, Univ. Guelph

Diversified crop rotations are more stable and resilient



Soil Water Content (%)					Temperatures (°C)				
Cluster	Veg	Flow	Gr. Fill	Mat	Veg	Flow	Gr. Fill	Mat	
A	79.9	60.0	51.6	46.0	17.5	24.8	15.7	10.5	High
B	75.1	61.6	51.0	46.0	17.5	24.8	15.7	10.5	High-Average
C	77.3	60.0	50.0	39.9	17.4	25.1	15.2	10.5	Average
D	71.9	53.8	43.8	35.4	19.4	26.9	16.7	10.5	Average-Low
E	79.9	64.6	44.7	31.4	18.3	25.1	15.9	10.5	Low



Yield stability increased when corn and soybean were integrated into more diverse rotations with small grains, red clover, alfalfa, in a 31-year long term rotation trial in Ontario, Canada.

Crop diversification strategies increased the probability of harnessing favorable growing conditions while decreasing the risk of crop failure.

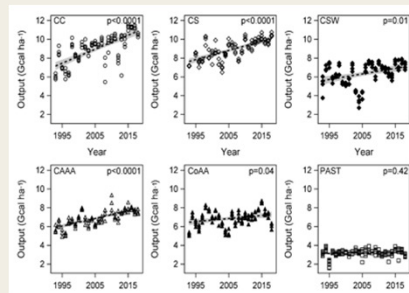
Gaudin et al., 2015

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Wisconsin Integrated Cropping Systems Trial

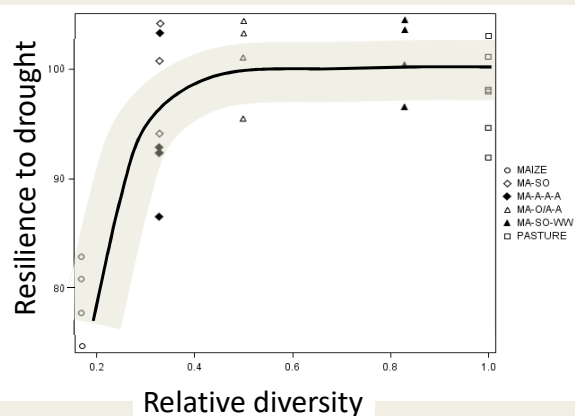
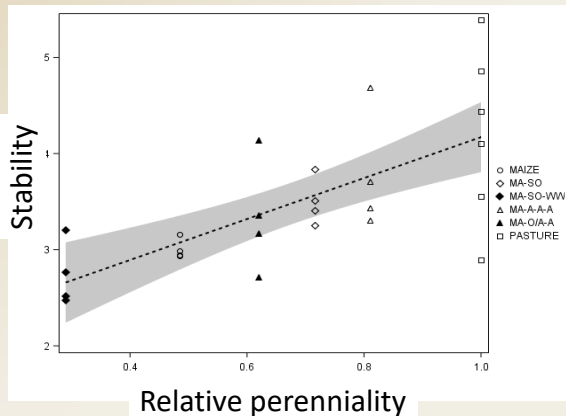


- Established in 1989, 30 years of continuous data.
- Cropping systems representative of Midwestern practices:
 - cash grain (Corn, Corn-Soy, Corn-Soy-Wheat)
 - dairy forage (C-Alfalfa 3yr, C-Oat-Alfalfa 2yr, Pasture)
- All fieldwork is performed with production-scale equipment.
- Randomized complete block design with four blocks.
- Every phase of every system in every block every year.



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Diversity and perenniality in crop rotations



Sanford et al., Wisconsin Integrated Cropping Systems Trial (in prep.)

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Need for more perennials

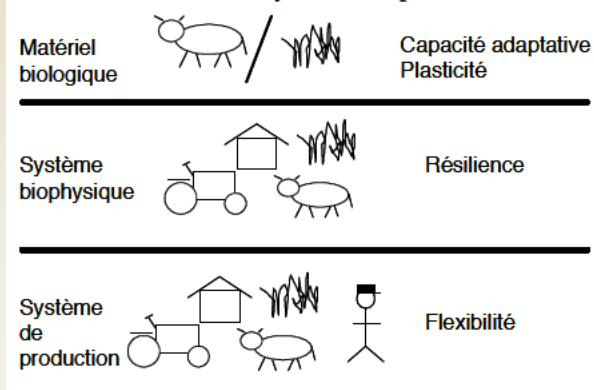
- Increased intensity of rains and storms demands expanding the area in pastures and perennial forages.
- To minimize area to plant each year longer rotations are needed.
- More years of perennial forages reduces the area to plant increasing the harvestable forage area on the farm.
- Perennial forages and pastures increase soil organic matter, water infiltration, and ability to withstand summer droughts.
- Required by conservation and regulatory agencies.

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Flexibility of production systems for adaptation

Figure 5. Désignation des propriétés d'adaptation selon le niveau d'organisation considéré dans l'analyse du fonctionnement des systèmes de production.



Ingrand et al., 2009

Same principles for different crises:

- Drought
- Floods
- Cold
- Climate change
- Market crisis
- Policy changes

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Strategies to increase resilience and stability in forage production

- Resilient cultivars – plant breeding
- Resilient species – adaptation and agronomy
- Forage mixtures – compatibility and management
- Harvest and grazing management – major impacts
- Crop rotations with forages – more perennials and diversity
- Perennial forages and dual-use grain crops – future expansion

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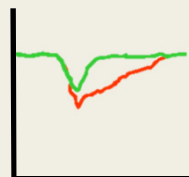
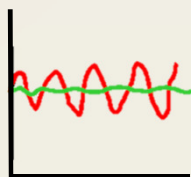
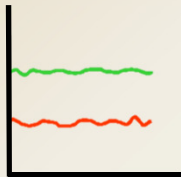
Conclusion

- Present climate variability and future climate trends provide significant opportunities to increase perennial forages and pasture area and production in North America.
- Higher forage production would be realized if both researchers and farmers focus on increasing tolerance to cold, heat, and disease stresses.
- More farm area in perennial forages and pasture can enhance farmers' resilience and stability of production, as well as reduce the environmental impacts of extreme climatic events.

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Thank you very much!
Merci beaucoup!



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