



# Co-operative Research Programme:

Biological Resource Management for Sustainable Agricultural Systems OECD Trade and Agriculture



# Making Science Useful to Agriculture

Dr. Primal Silva (OECD)

Adelaide, South Australia

November 26-29, 2018

#### **OECD**

- 36 Member Countries
- Committed to Democracy and the market economy
- A setting where governments:
  - Compare policy experiences
  - Seek answers to common problems
  - Identify good practice
  - Co-ordinate domestic and international policies

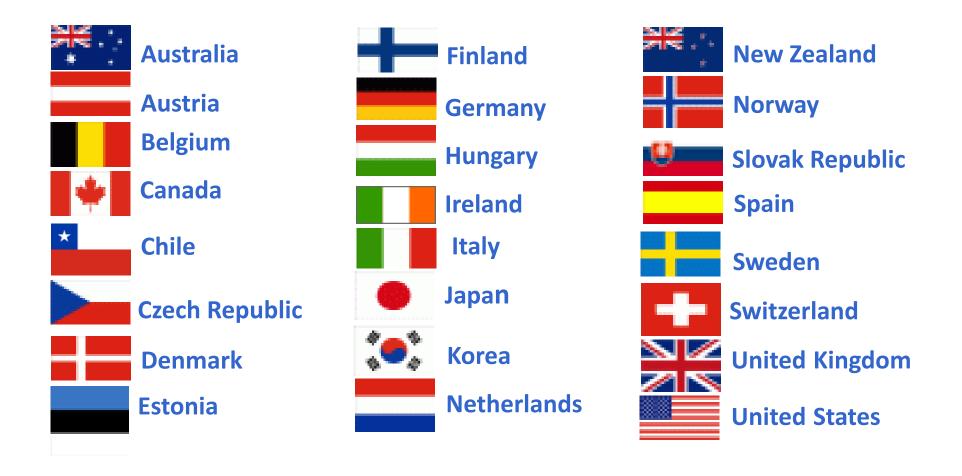
## **Co-operative Research Programme**

- Established in 1979 by a group of countries who saw the need for a body which would:
  - Provide a sound scientific knowledge base to agricultural policy-making
  - Contribute to an informed public debate on current and emerging agri-food issues
  - Promote scientific understanding and standards between major regions of OECD

## Co-operative Research Programme (CRP)

- Research and Innovation in Agriculture, Food, Fisheries and Forestry are leading global priorities.
- CRP provides valuable information to policy makers by facilitating international cooperation among scientists and institutions on global priorities with science underpinning policy emphasis.
- The key outcomes sought by the CRP are Sustainability, Food Security and Nutrition.

# Co-operative Research Programme Member Countries



### **Programme Activities**

#### Sponsorship of Conferences & Workshops

Provide a stage for informed debate on current & emerging issues in agriculture

#### Research Fellowships

Enhance knowledge base and promote scientific understanding between major regions of OECD

#### Research Themes for 2016-2020

#### **Theme 1: Managing Natural Capital for the Future**

 Managing natural capital by making secure the availability and managing the quality of natural resources

#### Theme 2: Managing Risks in a Connected World

 Research with anticipating, pre-empting, coping with and managing risks that impact on the potential of agricultural systems to achieve food security

#### Theme 3: Transformational Technologies and Innovation

Novel and innovative technologies that achieve a step change

## **2018 Conferences**

Conference Title	Dates	Location
(1) TERRAenVISION: Science for Society,	29 January - 2 February 2018	Barcelona, Spain
(2) 2018 Circular Economy for Agri-Food Resource Management	13-15 June 2018	Seoul, Japan
(3) OECD Conference on Genome Editing: Applications in Agriculture - Implications for Health, Environment and Regulation,	28-29 June 2018	OECD, Paris, France
(4) CRISPRing - a new begin for genetic improvement of plants and microbes	3-5 September 2018	Budapest, Hungary
(5) Natural products in pest management: Innovative approaches for increasing their use	25-29 September 2018	Bellagio, Italy
(6) Preparing Europe for invasion by the beetles emerald ash borer and bronze birch borer, two major tree-killing pests	1-4 October 2018	Vienna, Austria

## **2018 Conferences**

Conference Title	Dates	Location
(7) Risk valuation and risk management tools in agri-food sector	17-18 October 2018	Bratislava, Slovak Republic
(8) Making science useful to agriculture	26-29 November 2018	Adelaide, Australia

### **Information on Fellowship and Conferences**

#### **Fellowships:**

- From a Member Country to another Member Country
- PhD + Permanent or fixed-term post
- Up to 26 weeks
- Travel expenses + weekly living allowance
- Multidisciplinary research
- Travel out between March 1, 2020 to December 15, 2020
- Call for applications for 2020 opens April 2019 to September 10, 2019

#### **Conferences:**

 Call for applications for 2020 – opens April 2019 to September 10, 2019

### **Selection Criteria for Fellowships and Conferences**

- Relevance to the OECD themes & potential contributions
- Scientific Excellence; focused objectives, innovative outcomes etc.
- Scientific Record of Applicant
- Crossing Disciplines
- Impact including dissemination
- Policy relevance
- For Conference only: organization & planned participation

#### **Selection Process**

#### The Scientific Advisory Body (SAB)

- Six scientists and research administrators
- Examines all applications for scientific quality
- Recommends the conferences and fellowships for sponsorship

#### The Governing Body

- Delegates from each Member country
- Final approval of sponsorships according to SAB's recommendations and policy relevance of the applications

## **Outputs required by CRP**

#### **Conferences:**

- Publication of Proceedings
- Conference report to OECD
- Evaluation Questionnaires from all Conference partnerships

#### **Fellowships:**

- Report on substantive outputs of research done
- Evaluation Questionnaires from Research Fellows and their Host Laboratories
- Copy of any subsequent publication resulting from the research

# Importance of the Conference 'Making Science Useful to Agriculture' from the OECD Perspective

#### **Value Proposition:**

- This conference was approved under the "Transformational Technologies and Innovation" theme of the CRP.
- Speakers include experts from Australia, USA, Finland, Canada, Sweden, United Kingdom, Spain and Denmark which provides a forum for a valuable exchange of ideas.
- The conference will:
  - Pose key questions to probe fundamental assumptions regarding Research and Development investments in agriculture,
  - Examine what evidence do we have to support the impact of Research and Development
  - Consider how might we improve the usefulness of Science to Agriculture?

#### **OECD Trade and Agriculture**



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Canadian Food Inspection Agency
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# Making science useful to agriculture

Adelaide, 26-29 November 2018











## Challenges for global agriculture in the next two decades

- (1) for all at all times, abundant, affordable, healthy and nutritious food;
- (2) for farmers, comfortable stable incomes, in line with the rest of society, from sustainable farming with less drudgery;
- (3) for the non-farm environment, absence of encroachment and of contamination by farming;
- (4) for the rural communities, viable support and attractive landscapes;
- (5) for the world, maintenance of non-agricultural biodiversity.

Fischer RA, Connor DJ (2018) Issues for cropping and agricultural science in the next 20 years. Field Crops Research 222:121–142

# **Themes**

Day 1

focused investment of scarce R&D resources.

Days 2 (breeding), Day 3 (agronomy)

avoid misconstructed science that compromises returns on investment; patterns underlying success and failure.

# Beyond cliché...

...chemists be enlisted to understand plant nutrition; mechanics in order to devise more efficient farm implements; naturalists to perfect stockbreeding; and botanists to identify and select the most promising cultivars...

Auguste Broussonet, secretary of the Société Royale d'Agriculture, 1786

# Research style

interdisciplinarity multidisciplinarity transdisciplinarity post-normal science systemic intervention integrated assessment sustainability science team science mode 2<sup>10</sup> action research integration and implementation science (I2S)

Bammer G (2013) Disciplining interdisciplinarity. Integration and implementation sciences for researching complex real-world problems. ANU Press

Technology is combinatory, unavoidable, directional, disruptive, explainable and unpredictable.



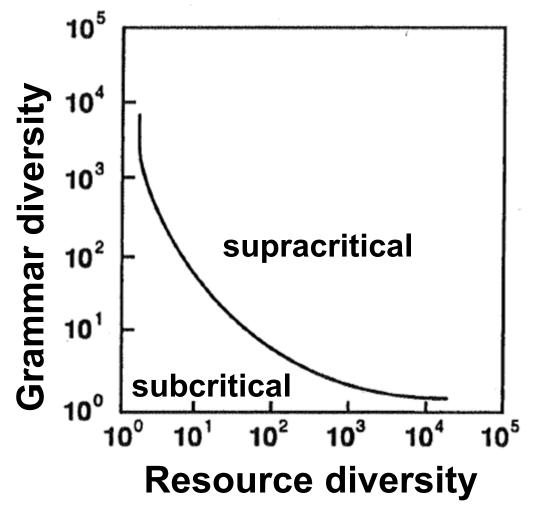


Technology Carrying capacity (billion)

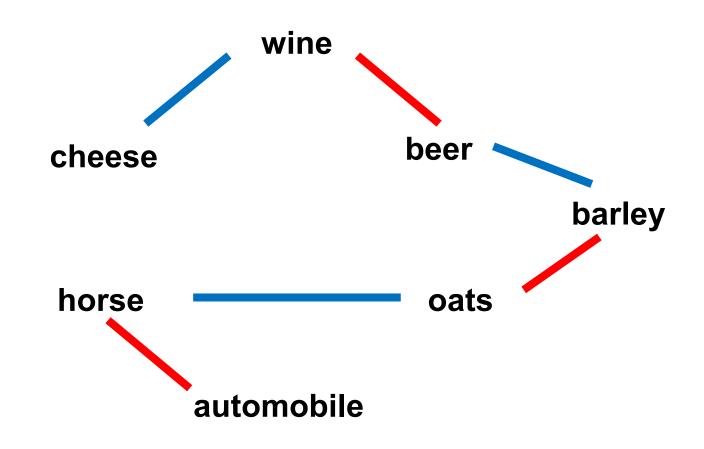
actual 6

organic 3-4

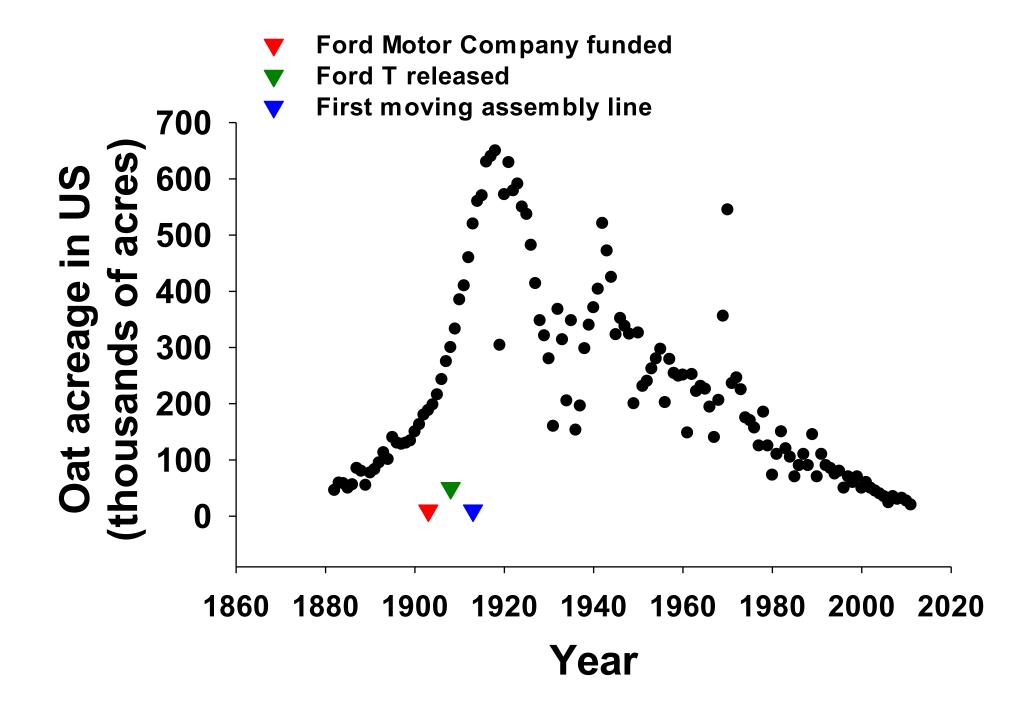
The concept that elements of a set act on other elements of the same set to produce new elements which then become part of this set is ubiquitous

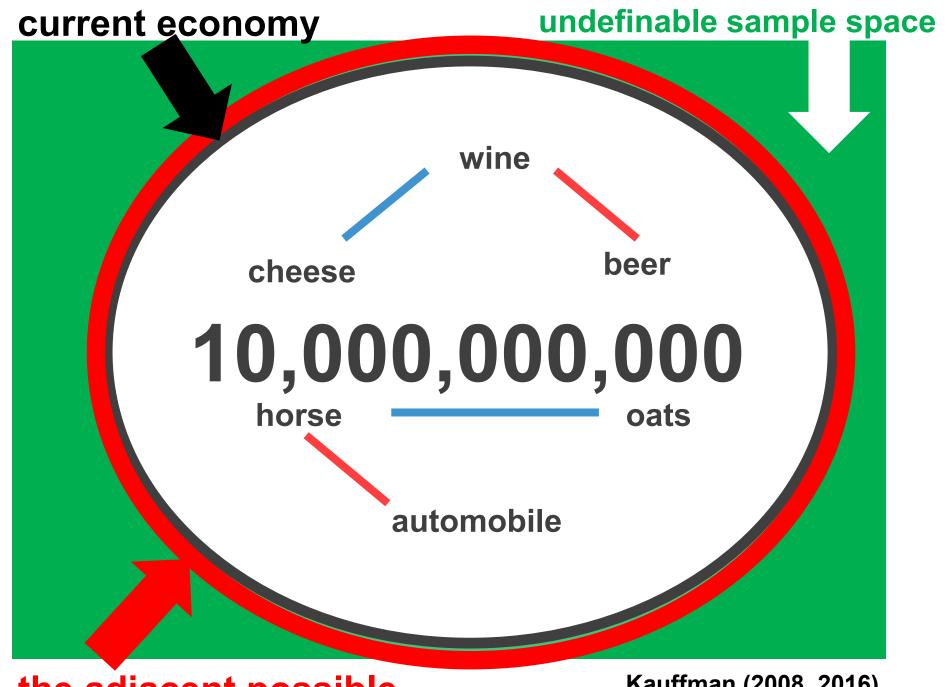


Hanel, Kauffman, Thurner 2005. Phase transition in random catalytic networks. Physical Review E 72. Kauffman SA 2008 Reinventing the Sacred: A New View of Science, Reason, and Religion



synergy —— antagonism ——





the adjacent possible

Kauffman (2008, 2016)

Owing to Darwinian pre-adaptations, the trajectories of the economy and biosphere are unpredictable Kauffman (2008)

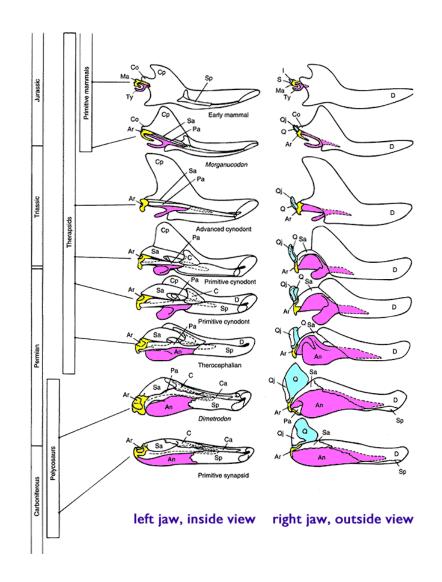
pre-adaptation in technology



# pre-adaptation in the biosphere

new function: ear (mammal)

original function: jaw (fish)



The managers of research still carp about strategic plans and milestones. They seem unable to understand that one cannot manage the discovery of the unknown.

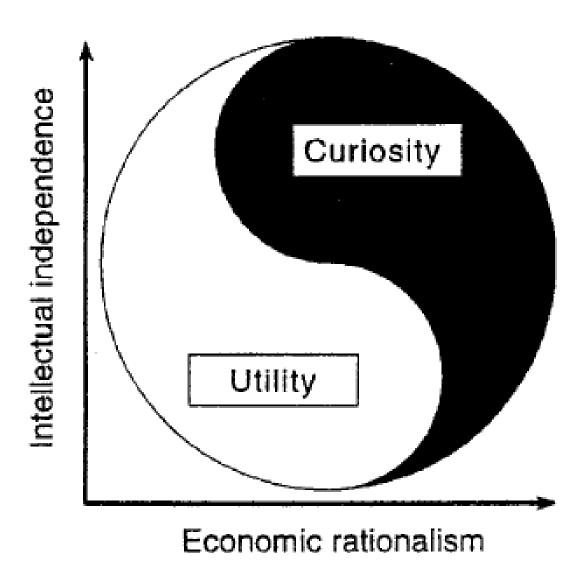
Osmond CB (1995) Quintessential inefficiencies of plant bioenergetics: Tales of two cultures. Australian Journal of Plant Physiology 22: 123-129

...one cannot manage the discovery of the unknown...

...but we cannot afford expensive distractions in agricultural research\*.

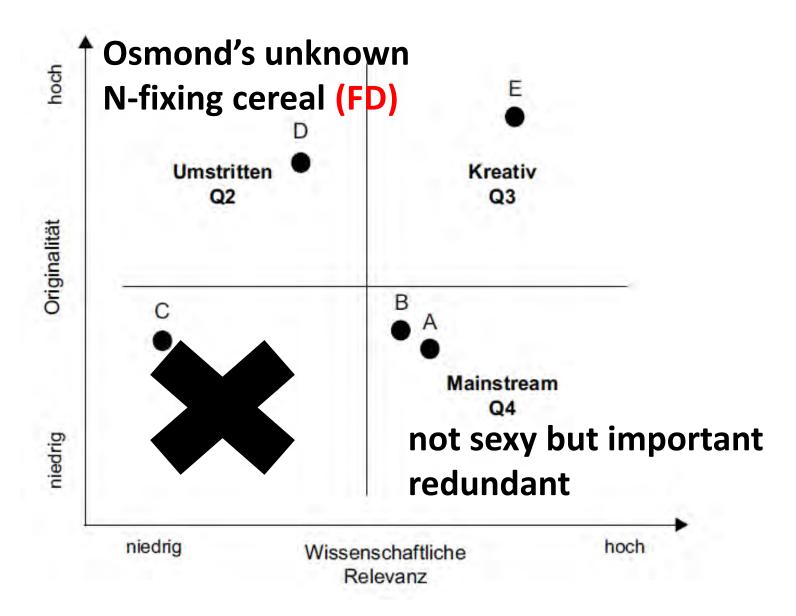
<sup>\*</sup>Fischer RA, Connor DJ (2018) Issues for cropping and agricultural science in the next 20 years. Field Crops Research 222:121–142

The Tao of research achievement

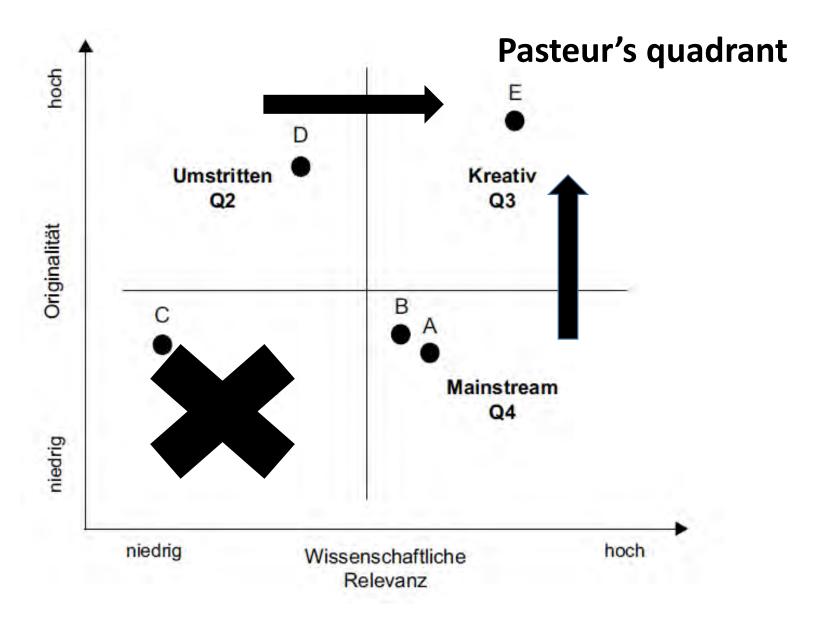


PH

Osmond CB (1995) Quintessential inefficiencies of plant bioenergetics: Tales of two cultures. Australian Journal of Plant Physiology 22: 123-129



Heinze T (2012) What are creative accomplishments in science? Kolner Zeitschrift Fur Soziologie Und Sozialpsychologie 64:583



Heinze T (2012) Was sind kreative Forschungsleistungen? Kolner Zeitschrift Fur Soziologie Und Sozialpsychologie 64:583-599

...focused investment of limited R&D resources needs formal economic evaluation of alternative investments and priority-setting procedures...

...formal evaluation and priority-setting procedures should not be used as a basis for replacing ingenuity, serendipity and scientific entrepreneurship with bureaucratic procedures...

Alston JM, Norton GW, Pardey PG (1995) Science under scarcity: principles and practice for agricultural research evaluation and priority setting. Cornell University Press, Ithaca. Cited by > 1393

#### Day 1. Investing in R&D

**Julian Alston** 

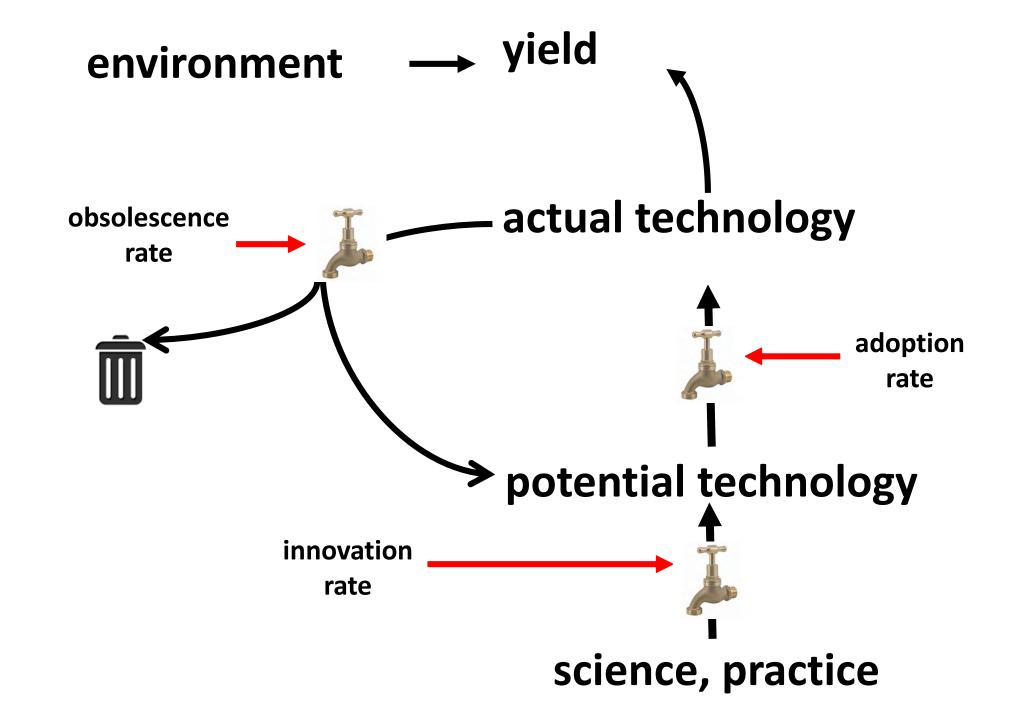
Francis Ogbonnaya, Stephen Loss

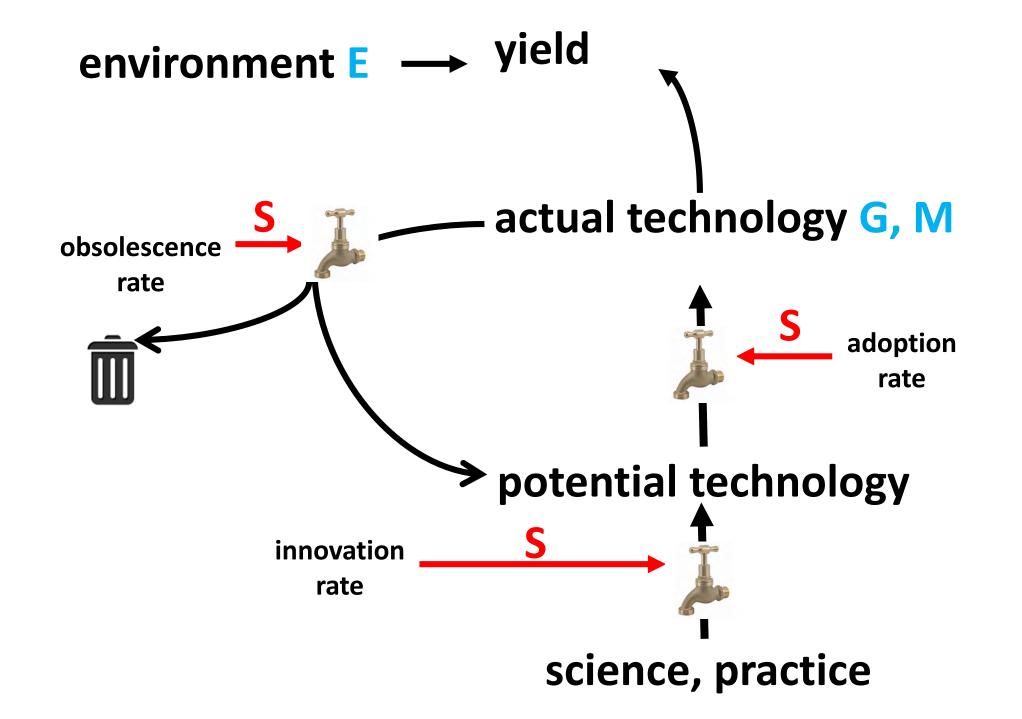
Allan Mayfield, Malcom Buckby

**Peter Appleford** 

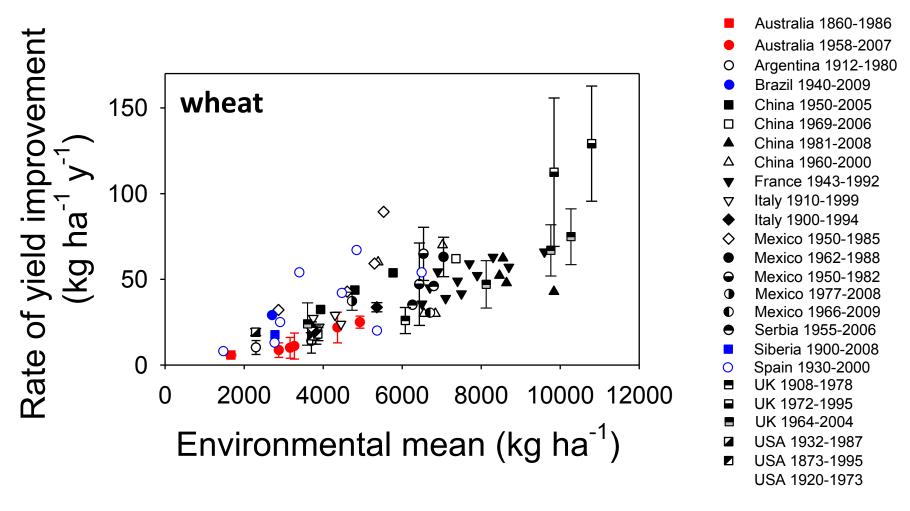
**Richard Gray** 

**Bill Long** 



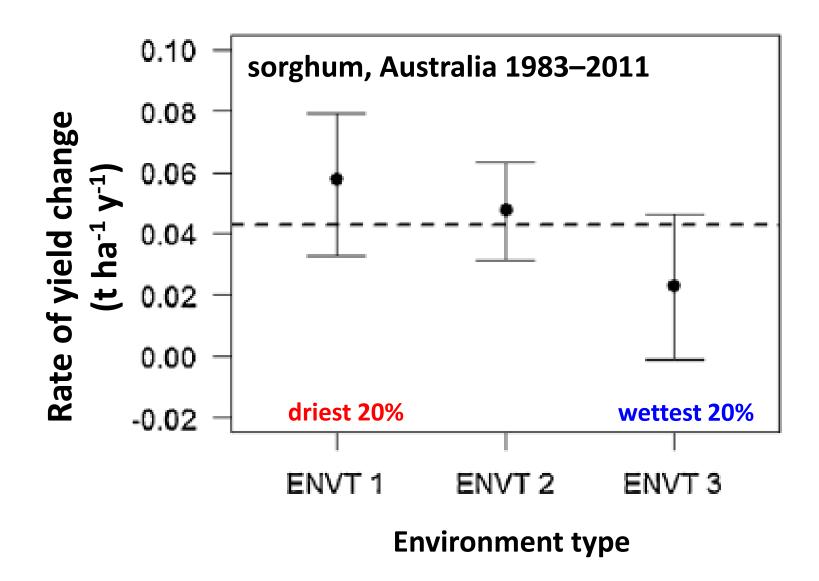


#### technology x environment interaction



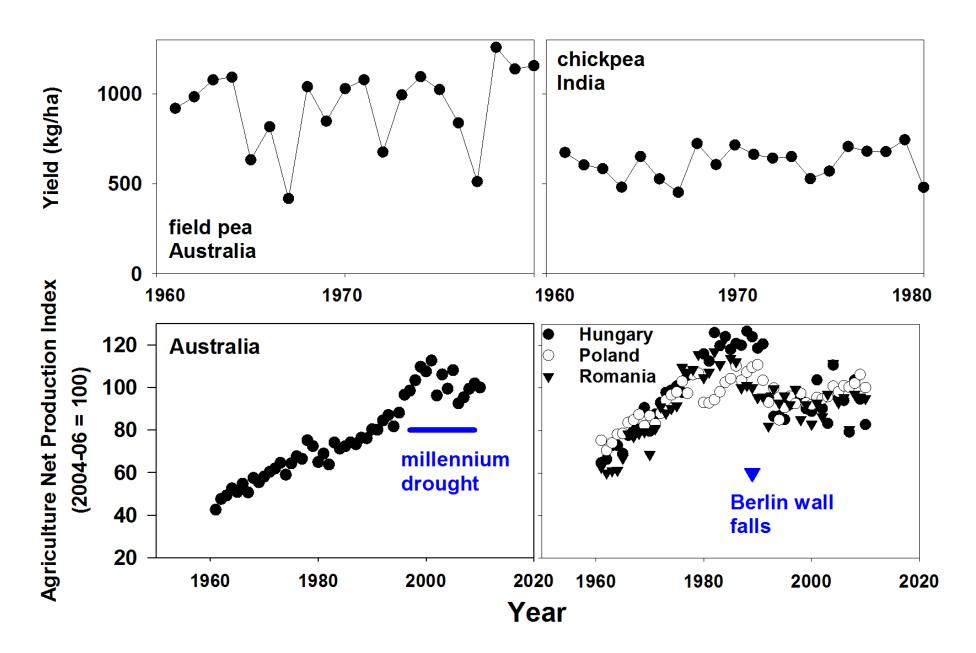
Sadras et al. (2016) Interactions between water and nitrogen in Australian cropping systems: physiological, agronomic, economic, breeding and modelling perspectives. Crop and Pasture Science 67:1019-1053

#### technology x environment interaction



39

#### impact of environment & technology depends on aggregation and scale

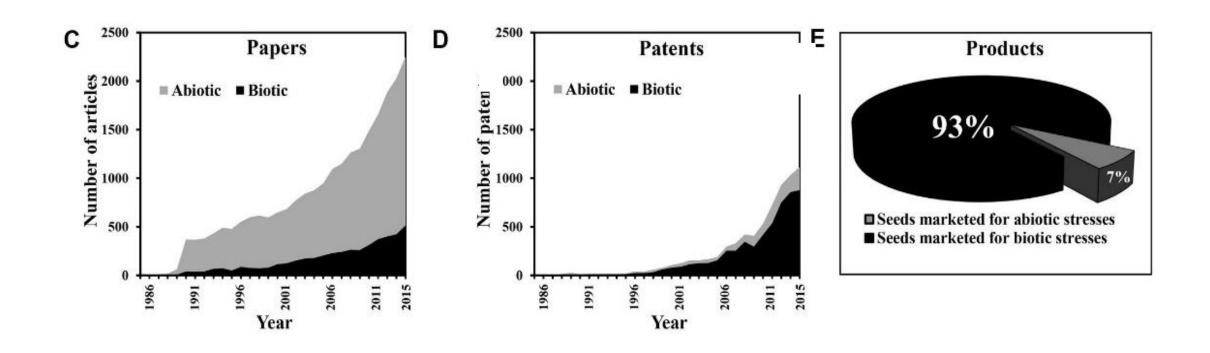


# investment decisions assume science is sound

# ...we cannot afford misconstrued science (days 2 and 3).

human endeavor nit picking patterns

### paper-to-patent-to-product



Dalal A, Attia Z, Moshelion M (2017) To produce or to survive: how plastic is your crop stress physiology? Frontiers in Plant Science 8

# Underperformance in improvement of yield potential and adaptation to drought

"yield is complex"

"my approach is naïve to capture the complexity of yield"

We're in a maze, not a highway; there is nowhere that speed alone can take us.

Julie Dehghani

From molecules to landscapes, we're generating more, better, cheaper data

We're in a maze, not a highway...I'm not being held back by the university's computers...I'm being held back by my own lack of insight into the problems I'm addressing...

Julie Dehghani

Findability
Accessibility
Interoperability
Reusability

cf Gabriele Bammer

Wilkinson et al. (2016) The FAIR guiding principles for scientific data management and stewardship. Scientific Data 3:160018

### implications for investment

#### **GLOBAL TECHNOLOGICAL TRENDS – GRDC 2018-23**

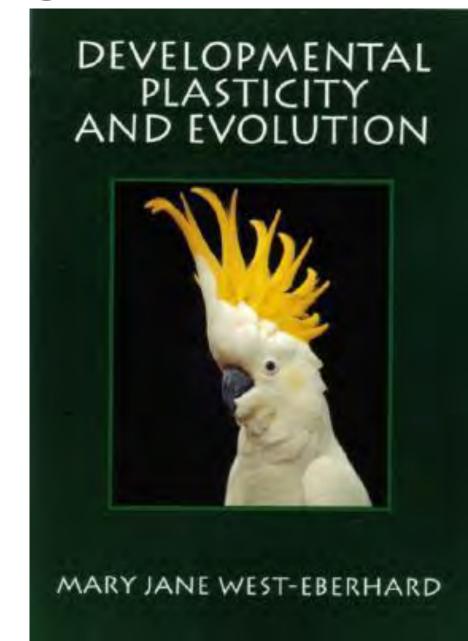
- 1.Large data sets will require ongoing management and curation to support ongoing analysis.
- 2. Data analysis will be driven by improvements in artificial intelligence, modelling and forecasting.
- 3. Greater use of data in decision-making will drive required improvements in connectivity ...
- 4. Labour shortages will drive automation of farm practices.
- 5. Demonstrated intellectual property management ...
- 6. Existing supply chains and incumbent business models will be disrupted by digital ... artificial intelligence... machine learning...

## lagging theory is a growing bottleneck

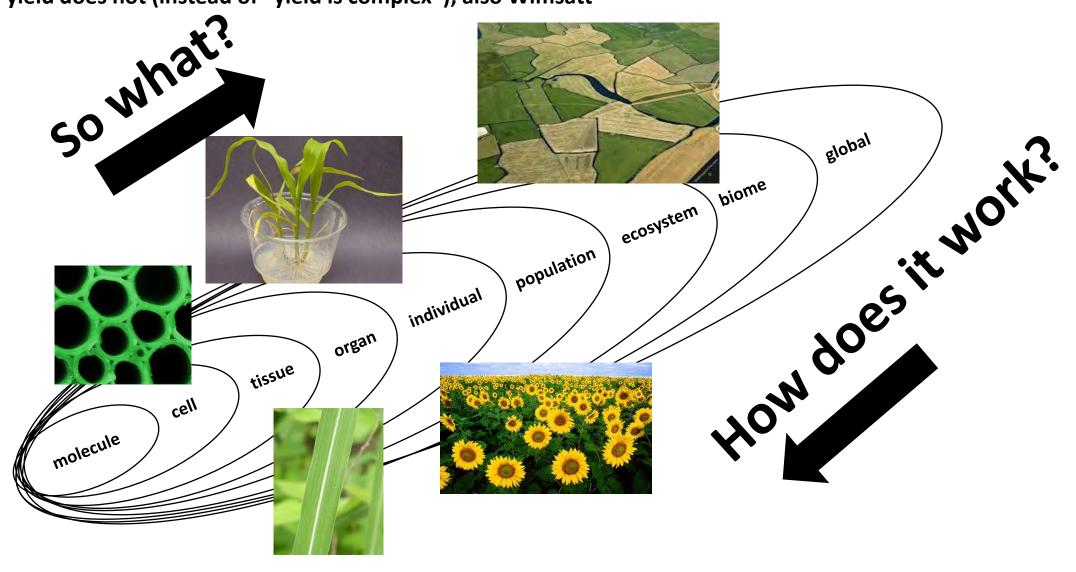
unjustified G → P

genes "...do not construct nor control phenotypes on their own; instead, they show an intricate relationship with the cell, the organism, and the external environment"

Félix MA (2016) Phenotypic evolution with and beyond genome evolution. Current Topics in Developmental Biology 119:291-347

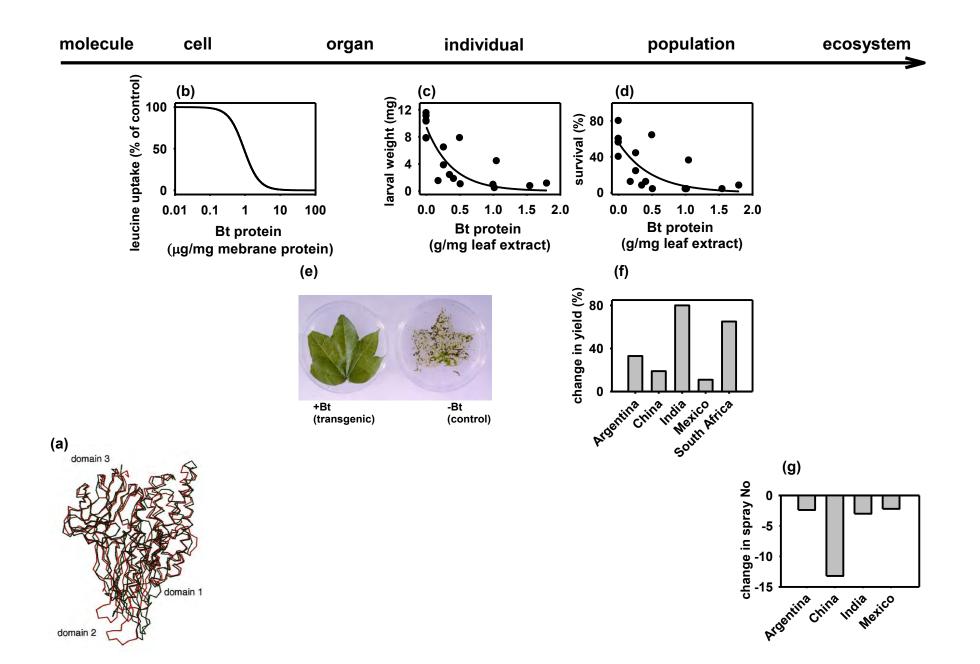


Bt scales, yield does not (instead of "yield is complex"); also Wimsatt



Sadras VO & Richards RA (2014) Improvement of crop yield in dry environments: benchmarks, levels of organisation and the role of nitrogen. J. Exp. Bot. 65:1981

Wimsatt WC (1994) The ontology of complex systems: levels of organization, perspectives and causal thickets. Can J Philosophy 20, 20749



# Yield (kg/ha) is a population-level trait plant-plant interactions, driven by the principles population ecology, are important



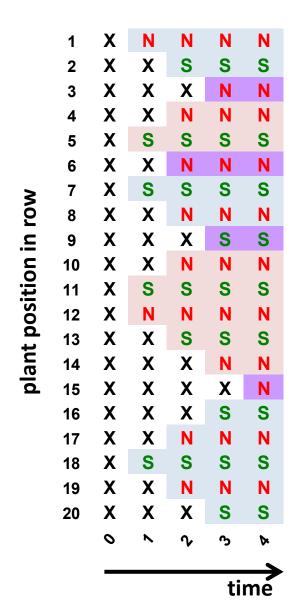
John L. Harper

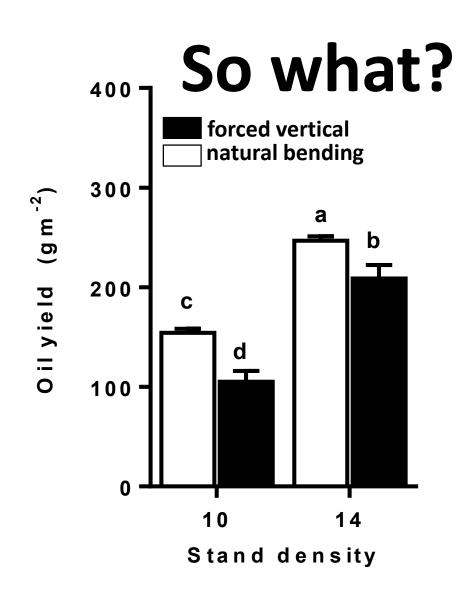
# Hall's effect 14 plants per m<sup>2</sup> 5 plants per m<sup>2</sup>

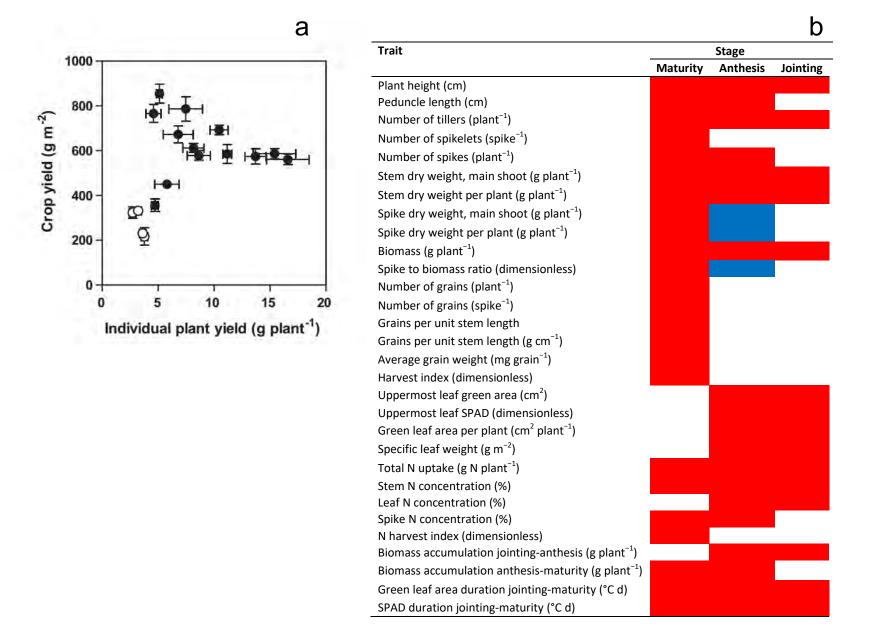
López Pereira et al (2017) Light-mediated self-organization of sunflower stands increases oil yield in the field. PNAS 114:7975-7980

#### Stand self-organisation increased yield

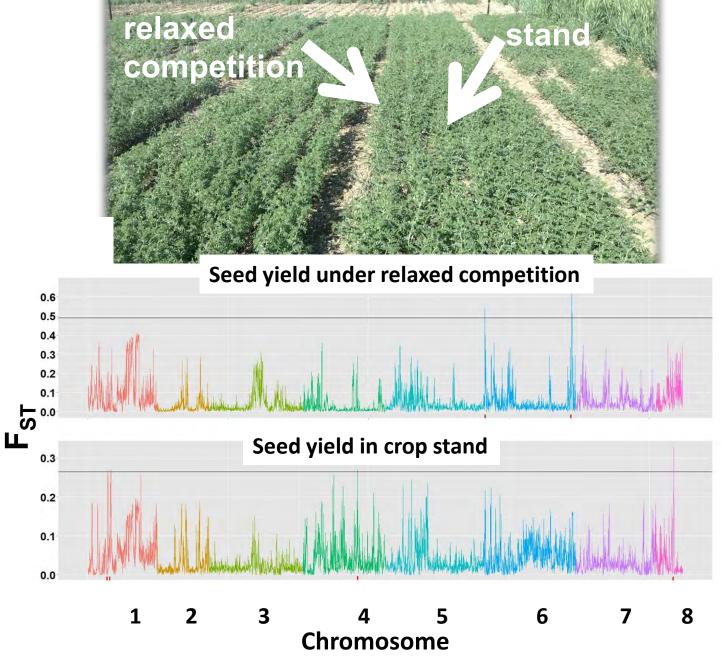
cellular automata simulations reproduced the actual pattern of stem inclination



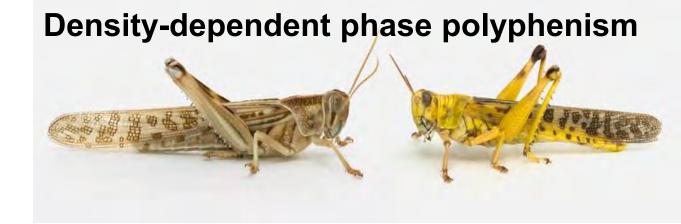




Pedró A, Savin R, Slafer GA (2012) Crop productivity as related to single-plant traits at key phenological stages in durum wheat. Field Crops Research 138:42-51

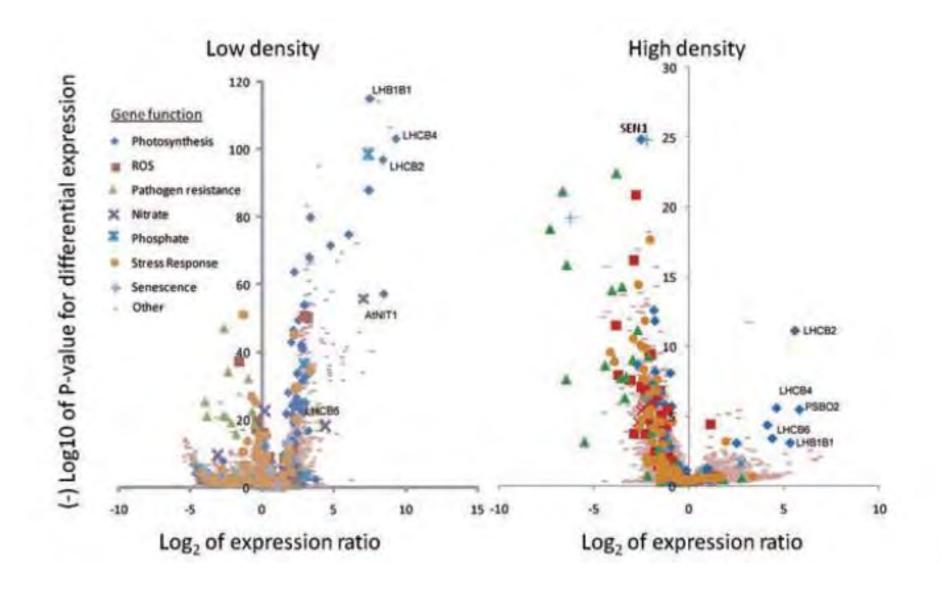


Lake L, Li Y, Casal JJ, Sadras VO (2016) Negative association between chickpea response to competition and crop yield: phenotypic and genetic analysis. Field Crops Research 196:409–417



## density-dependent gene expression

In the midgut, genes involved in morphogenesis, cell growth, nucleic acid metabolism and cell communication were downregulated in gregarious nymphs, whereas genes for carbohydrate metabolism were upregulated. In the hindlegs, genes involved in morphogenesis, muscle development, cell growth, metabolism, cell motility and muscle contraction were all downregulated in gregarious nymphs; whereas in the head, genes involved in responding to external stimuli were upregulated in gregarious nymphs, and metabolic genes and those involved in protein and nucleic acid biosynthesis were downregulated relative



Geisler et al 2012 Upregulation of photosynthesis genes, and down-regulation of stress defense genes, is the response of Arabidopsis thaliana shoots to intraspecific competition. Botanical Studies 53:85-96

...focus on just a few model organisms can lead us astray, partly by making us think biology is more homogenous than it is, with all mammals like rats, all insects like Drosophila...

#### taxonomic bias

> 25% research on sexual conflict in *D. melanogaster* 

Zuk M & Travisano M (2018) Models on the Runway: How Do We Make Replicas of the World? *The American Naturalist*.

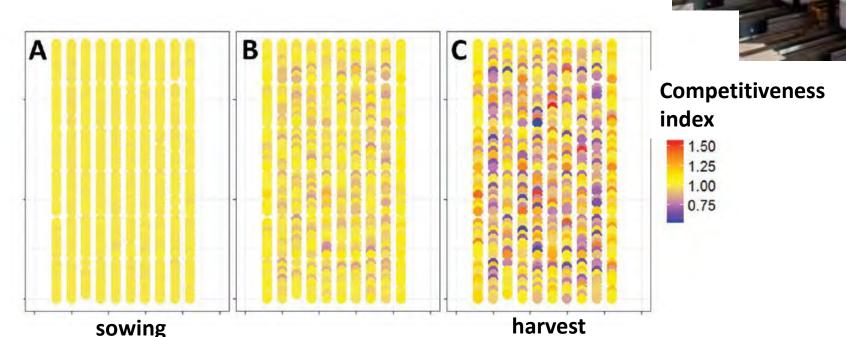
### Two-fold bias: taxonomic + setting

number of papers in Web of Science searching TITLE for [(wheat OR Arabidopsis) AND drought]

Period	Wheat	Arabidopsis	
1950-1980	51	0	
1980-2018	1250	624 (50%)	

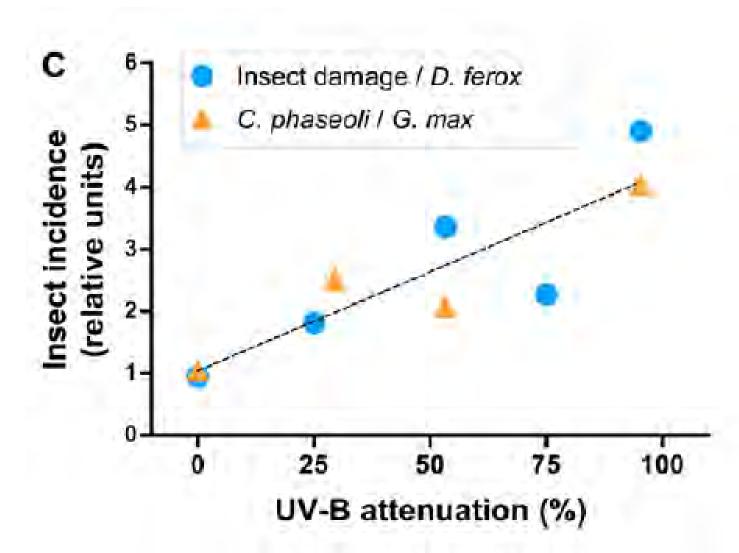
# Setting bias hierarchies are bound to emerge in plant-based settings

(statistical paradigm)



Chen T-W, Cabrera-Bosquet L, Alvarez Prado S, Perez R, Artzet S, Pradal C, Coupel-Ledru A, Fournier C, Tardieu F (2018) Genetic and environmental dissection of biomass accumulation in multi-genotype maize canopies. Journal of Experimental Botany:ery309-ery309

#### Setting bias - stress intensity (salt, UV, temperature)



Ballaré CL, Mazza CA, Austin AT, Pierik R (2012) Canopy light and plant health. Plant Physiology 160:145-155

#### Day 2. Failure and success in plant breeding

**Peter Langridge** 

**Pedro Aphalo** 

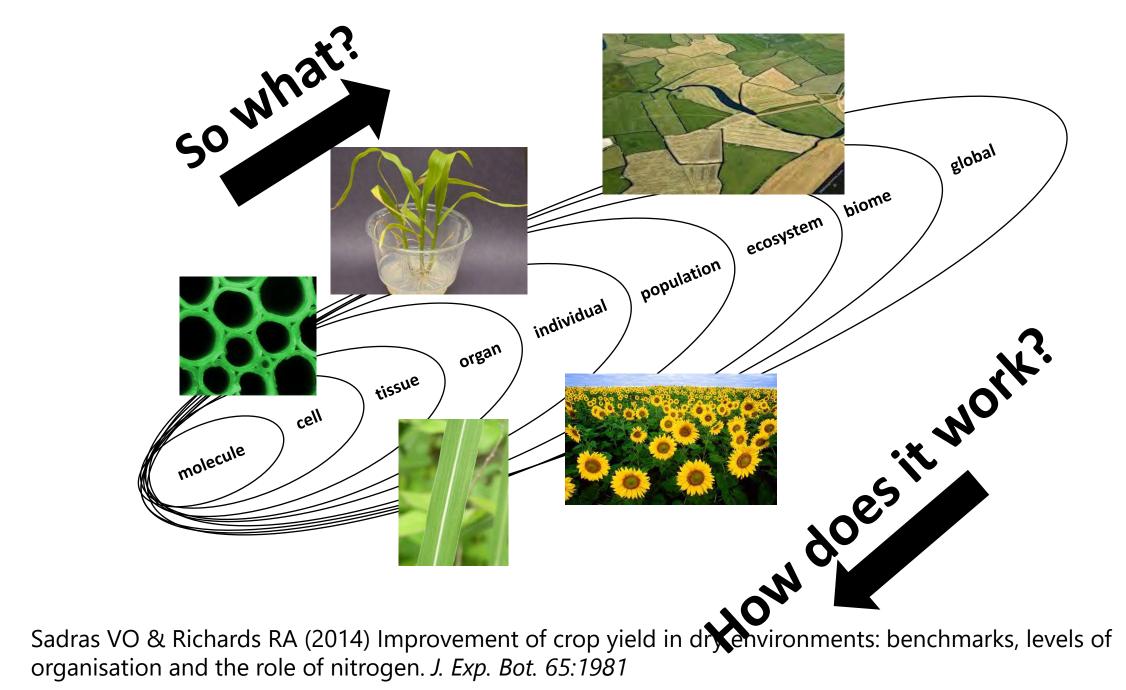
**Ford Denison** 

Jill Lenne

Renée Lafitte

**Tony Fischer** 

**Martin Kropff** 



organisation and the role of nitrogen. J. Exp. Bot. 65:1981

"under certain conditions ... organic systems can nearly match conventional yields ... organic agriculture as an important tool in sustainable food production ... (Seufert et al. 2012).

Seufert V, Ramankutty N, Foley JA (2012) Comparing the yields of organic and conventional agriculture. Nature 485:229-232 **861 Citations** 

# This conclusion is misleading because it fails to account for the supply of organic nutrients required to replace inorganic fertilizers, and hence confuses yield of <u>individual crops</u> with that of <u>production systems</u>

Connor DJ (2013) Organically grown crops do not a cropping system make and nor can organic agriculture nearly feed the world. Field Crops Research 144:145-147 **44 Citations** 

Kirchmann et al. (2016) Flaws and criteria for design and evaluation of comparative organic and conventional cropping systems. Field Crops Research 186:99-106

#### Arburscular mycorrhizal fungi...

"....could reduce up to 50% usage of chemical fertilisers..."

"...sustainable saviours..."

Ryan MH, Graham JH Little evidence that farmers should consider abundance or diversity of arbuscular mycorrhizal fungi when managing crops. New Phytologist

Irrigation is complex and is not amenable to be characterised by a single indicator.

The water foot print oversimplifies processes using colourful language – grey, green, blue - that is both influential (policy making) and misleading.

Fereres E, Villalobos FJ, Orgaz F, Minguez MI, van Halsema G, Perry CJ (2017) Commentary: On the water footprint as an indicator of water use in food production. Irrigation Science 35:83-85

# Day 3. Failure and success in agronomy Holger Kirchmann

Megan Ryan

Inés Mínguez

**Peter Hayman** 

**John Passioura** 

John Kierkegaard

**John Porter** 

**Daniel Rodríguez** 

#### Day 4. Outputs

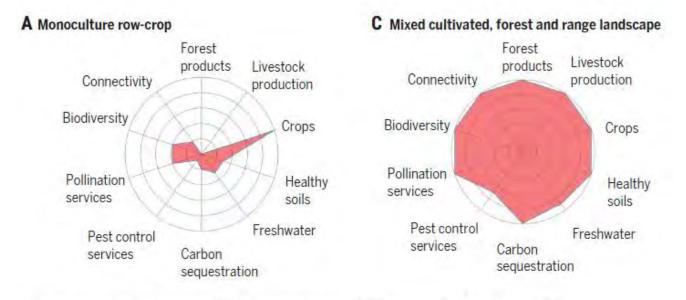
- Survey (please return by midday Thursday 29)
- Proceedings papers + presentations
- Single summary paper "Making science more useful to agriculture"
- Target journal Nature Plants, JXB, FCR

#### Current 35,000 words → 3,000–4,000 words + 4–6 display items (Nature Plants)

Section	ı	Lead author	words
	1 Intro	VS	200
	2 Science under scarcity: principles and practice for agricultural research evaluation and priority setting	JA	300
	3 The role of producer controlled research organizations in making science useful to agriculture	RG (+ FO, SL, MB, AM)	300
	4 Reductionism, oversimplification and lack of rigour can compromise return on investment		
	4.1 Organic ag	HK, DC	300
	4.2 Water foot print	IM, FV	300
	4.3 Genetic Resources	JL	300
	4.4 Mychorrizas, soil microbiology	MR	300
	4.5 Biotech, phenotype model, PA	VS	600
	5 Incremental transformation: science and agriculture learning together	JK +DR	500
	6 Conclusions	TF, DC	300
Box			
	1 trade-off	FD	400
	2 scales	J Pa (+VS)	400
	3 context	PA	400
	4 data, theory, fragmentation (radiation, water, nitrogen)	J Po (+J Pa, TF)	400
	5 searching for transgenes that improve yield: promise and reality	RL + PL	400

## Making science useful to agriculture

Adelaide, 26-29 November 2018



Kremen et al., Science 362, eaau6020 (2018)

19 October 2018











## Science under Scarcity:

Principles and Practice for Agricultural Research Evaluation and Priority Setting

Julian M. Alston

University of California, Davis

Making Science Useful to Agriculture
University of Adelaide
November 26–29, 2018



Principles and Practice for Agricultural Research Evaluation

and Priority Setting

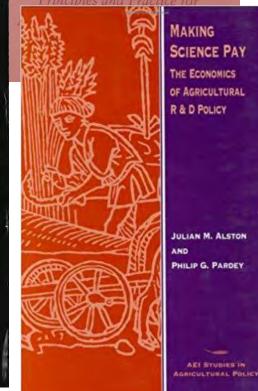
JULIAN M. ALSTON GEORGE W. NORTON

PHILIP G. PARDEY

Philip G. Pardey

#### SCIENCE UNDER **SCARCITY**







Fisheries Research and Development Corporation Rural Industries Research and Development Corporation Sugar Research and Development Corporation Grape and Wine Research and **Development Corporation** Forest Wood
Products Australia Dairy Australia AWI ALEKSTER Wood mla

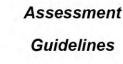




Cotton Research and

Grains Research and

Development Corporatio



Impact

**COUNCIL OF** 

RURAL RESEARCH

AND DEVELOPMENT

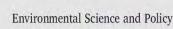
CORPORATIONS





May 2014





journal homepage: www.elsevier.com/locate/envsci

Policy-oriented environmental research: What is it worth?

David J. Pannell<sup>a,\*</sup>, Julian M. Alston<sup>b</sup>, Scott Jeffrey<sup>c</sup>, Yvonne M. Buckley<sup>d</sup>, Peter Vesk<sup>e</sup>, Jonathan R. Rhodes<sup>f</sup>, Eve McDonald-Madden<sup>f</sup>, Simon Nally<sup>g</sup>, Garry Goucher<sup>h</sup>, Tas Thamo<sup>a</sup>

- University of Western Australia, Perth, Australia
- University of California Davis, Davis, United States
- University of Alberta, Canada
- d School of Natural Sciences, Zoology, Trinity College Dublin, Dublin 2, Ireland University of Melbourne, Australia
- University of Queensland, School of Earth and Environmental Sciences, Brisbane, Australia
- 8 Department of the Environment and Energy, Canberra, Australia
- Garry Goucher and Associates, Sydney, Australia

ARTICLEINFO

Applied research conomics Research evaluation Research impact esearch prioritization ABSTRACT

Environmental and conservation scientists are increasingly being asked to justify their work in terms of benefits to society. This article describes economic theory for conceptualizing the benefits from environmental research, and provides a framework for estimating those benefits. In particular we discuss the evaluation of environmental science that is intended to benefit society through informing policy decisions. The chain between environmental research and its benefits through policy change includes at least four links; the research itself, policy change, behavior change and environmental change. Each of these four stages presents challenges and entails time lags. If any link fails, the chain breaks. The standard economic model of supply and demand, which is used to quantify



Perhaps the major benefit from a process of research program review, evaluation, and priority setting is that the participants gain a clearer view of what they are trying to achieve—and how best to get there.

Scientists and policymakers will make better decisions as they develop an economic way of thinking about research investment choices.

Alston, Norton, and Pardey (1995, p. 512)

### Outline

- Logic of choice
- Concepts and measures
- Heuristics and rules of thumb

- Example—*Vitis*Gen
- Financing angles

### Outline

Logic of choice

Concepts and measures

Heuristics and rules of thumb

• Example—VitisGen

Financing angles

### Logic of Choice

### Constrained maximization of an objective function

- Single-valued objective for public agricultural science
  - Maximize net benefits (broadly defined) to society
  - Applied (or applicable) research
- Implementation
  - Maximize net benefits per unit of constrained resource (research funds?)
  - Allocate funds across projects ranked according to benefit-cost ratio
- Money metric measures of (conceptually) tangible benefits
  - Even for non-monetized consequences (e.g., wilderness conservation)

### Logic of Choice

### R&D as an Investment....

- Investment today streams of benefits over potentially many future years
  - Uncertainty about whether and when benefits will flow
- Money metric measures allow benefits to be quantified and compared
- Requires a conceptual model of the mechanism by which benefits are generated
- Capital budgeting (and discounting)
  - deals with timing issues and makes benefits and costs comparable
  - summary statistics such as benefit-cost ratio or internal rate of return

### Logic of Choice

### Money <u>metric</u> (\$) measures ≠ only monetized benefits matter

- Conceptual approach (investment, cost-benefit analysis) applies as a way
  of thinking about all types of research investments
  - even if consequences are not easily quantifiable
  - even if quantifiable consequences are non-monetary
- Particularly natural in the context of commodity-oriented agricultural R&D, for which competitive supply and demand model applies
  - use this to illustrate concepts

### Outline

Logic of choice

Concepts and measures

Heuristics and rules of thumb

• Example—VitisGen

Financing angles

### **Elements of Evaluation**

### **Firm-Level Impact of Adoption**

varies among producers and over time (relative to a counterfactual that varies among producers and over time)



#### **Adoption Pattern**

varies among producers and over time



combine and aggregate across firms



Measure of aggregate impact of adoption on quantities of inputs and outputs over time



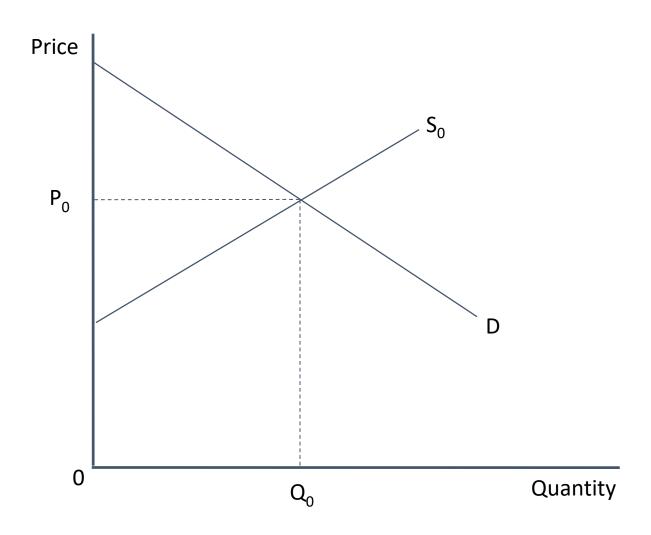
combine with other information, models, various transformations

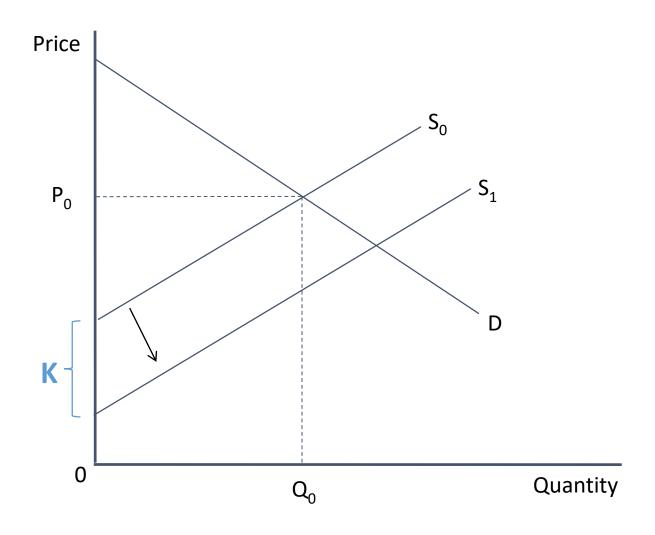
Measures of impacts on prices of inputs and outputs, gross benefits and their distribution, etc.

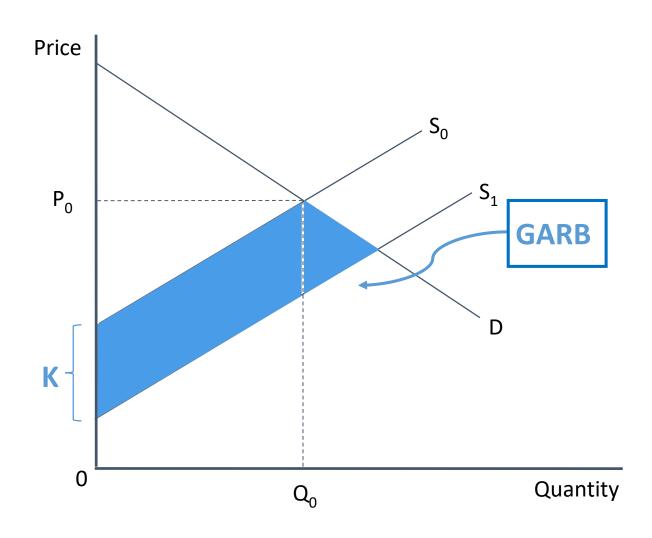


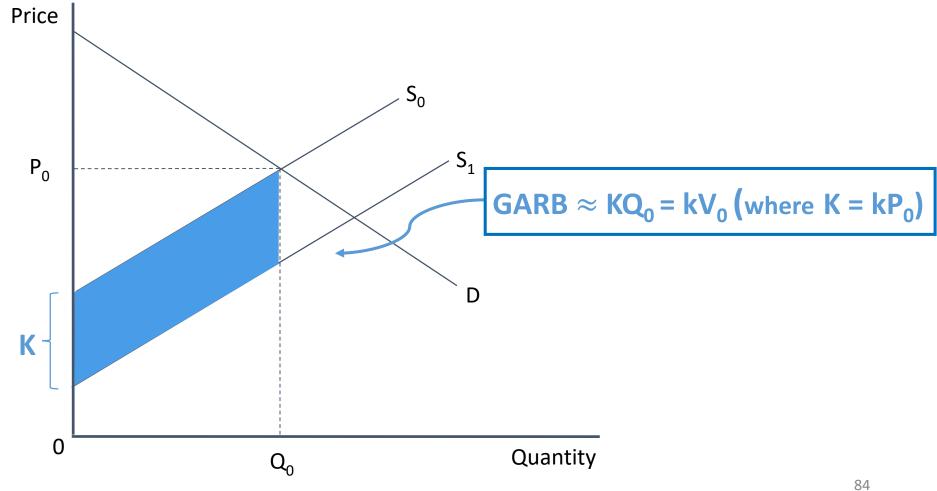
combine with other information, various transformations

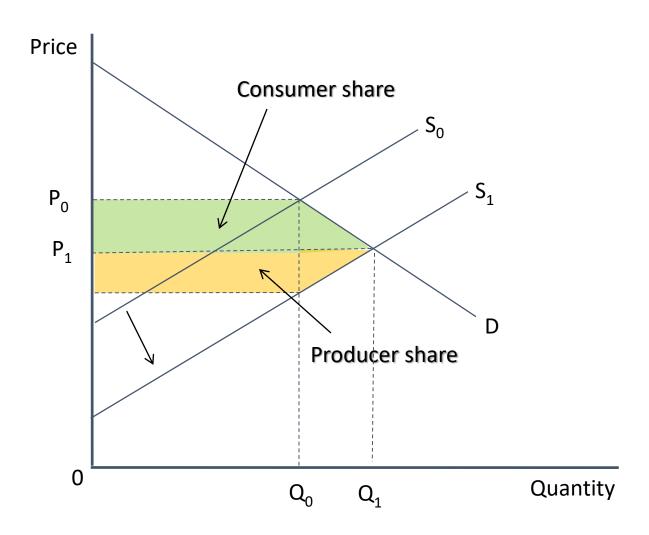
Measures of net benefits and their distribution, etc.











# IVIUITIMARKET IMPACTS (from Science under Scarcity)

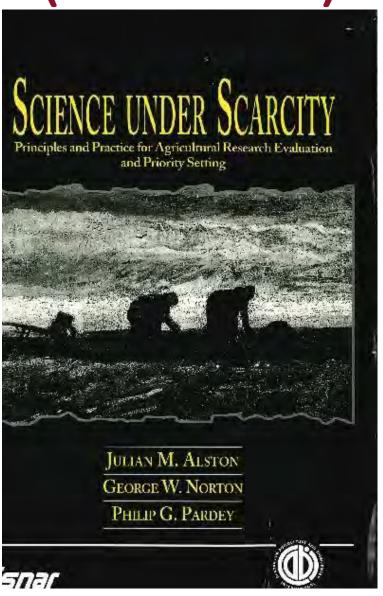
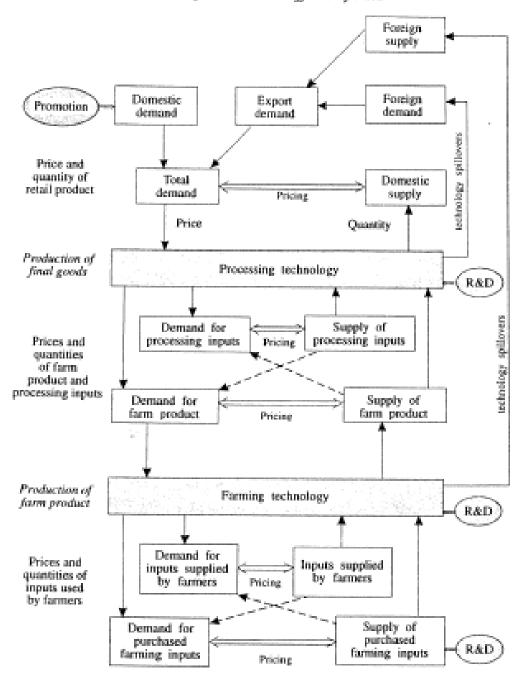


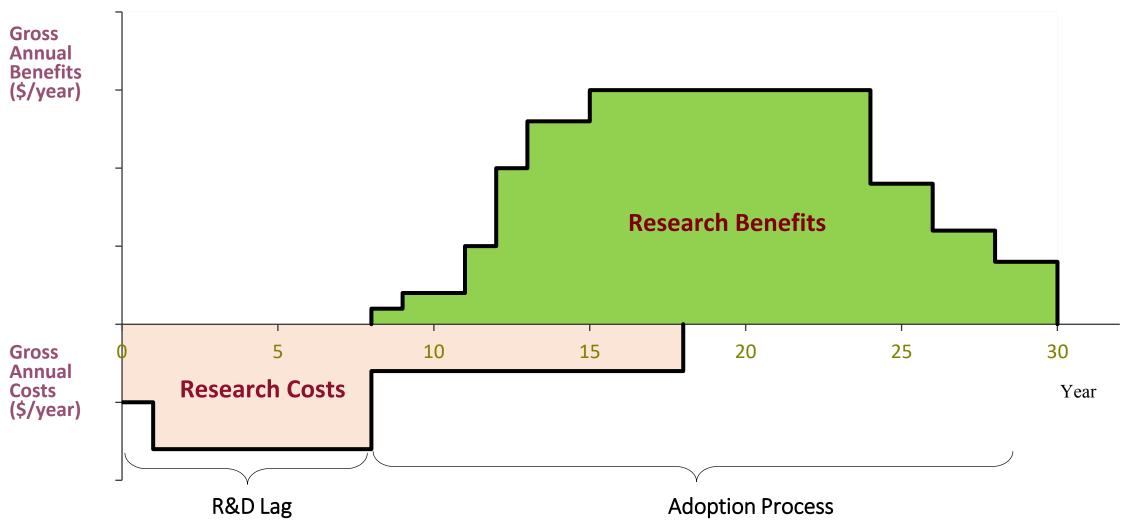
Figure 2.10: Schematics of multimarket effects of R&D



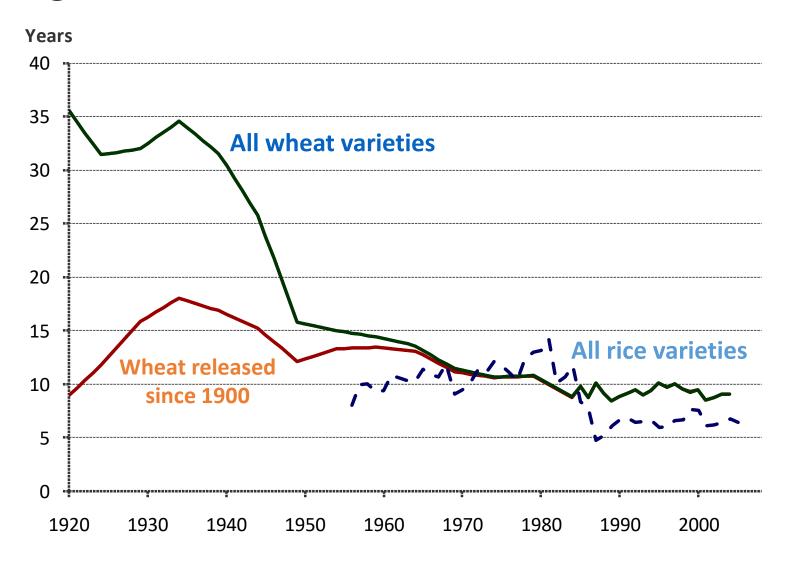
### Conceptual and Measurement Issues (1)

- GARB = kPQ = gross annual research benefits (i.e., for given year)
  - *k* = proportional reduction in unit costs (or productivity gain)
  - *P* = product price
  - *Q* = annual production
- GARB = kV
  - *V* = value of production or size of the industry
  - *k* = proportional benefit (e.g., productivity gain)
- Basic measurement issues
  - Measure GARB over time (many years)
  - Quantifying basic parameters (k, adoption => P, Q) is not trivial
  - Credible estimates?

### Flows of Research Benefits and Costs Over Time



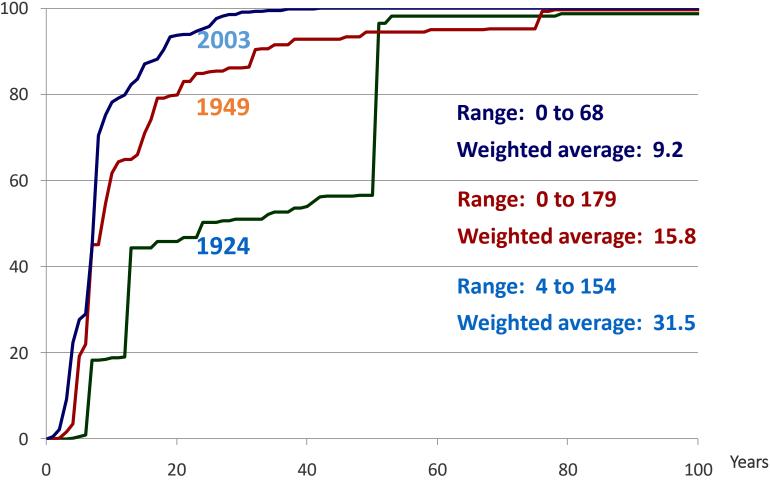
### Average Age of U.S. Wheat and Rice Varieties



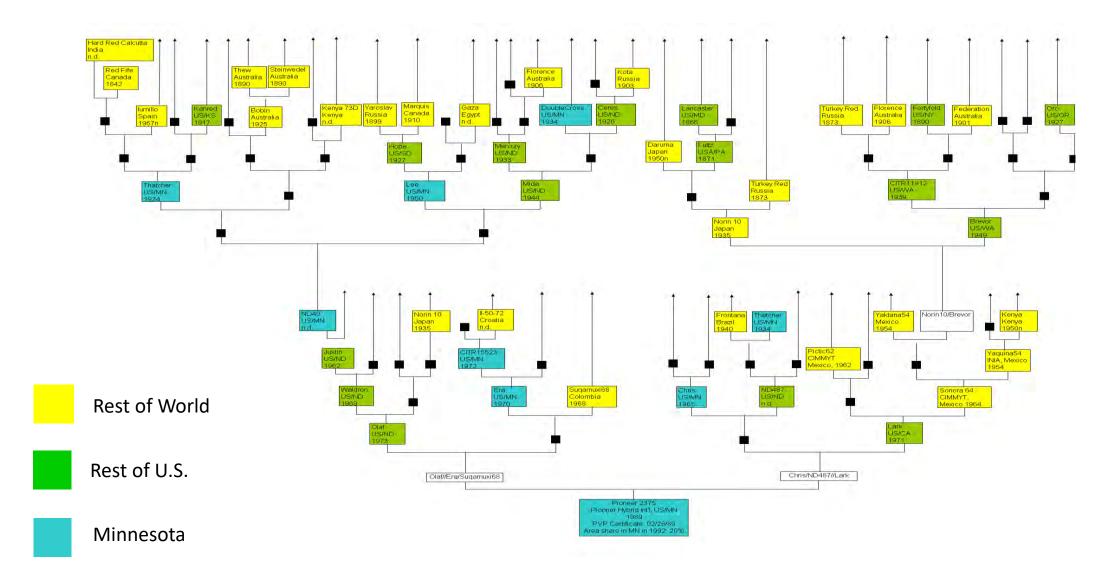
### **Cumulative Distribution Function**

Percent of wheat acreage planted to varieties, by age





### Pioneer 2375 by origin of its Ancestors



### Cost-Benefit Analysis

Present value of future streams of benefits and costs

$$PVB_{t} = B_{t} + \frac{B_{t+1}}{(1+r)} + \frac{B_{t+2}}{(1+r)^{2}} + \frac{B_{t+2}}{(1+r)^{2}} + \dots + \frac{B_{t+n}}{(1+r)^{n}} + \dots$$

- $B_t$  = benefits in year t in nominal \$
- r = discount rate (like an interest rate), % per year
- Discount rate and timing of flows of benefits (and costs) both matter
  - at r = 0.05 \$1 received in 30 years has a present value of \$0.23
  - at r = 0.02 \$1 received in 30 years has a present value of \$0.55
- Summary statistics
  - NPV = PVB PVC
  - BCR = PVB/PVC
  - IRR = discount rate such that NPV = 0

### Conceptual and Measurement Issues (2)

- Market distortions (can we use market prices)?
  - government policies (taxes, subsidies, regulations)
  - trade barriers
  - environmental and other externalities
  - other market failures
- Appropriate counterparts for non-commodity specific R&D
  - disembodied knowledge
  - more-basic
  - environmental
  - social science
- Translation from "functional" to "personal" distribution
  - we'll skip this!

### INTERMISSION

### Outline

Logic of choice

Concepts and measures

Heuristics and rules of thumb

• Example—VitisGen

Financing angles

### **Decision Criterion**

### Considering any public policy....

- Prima facie evidence of market failure?
  - Necessary condition?
  - Not sufficient!
- Do (expected) benefits exceed costs (BCR > 1)?
  - Necessary and sufficient ?
  - Constrained budget?
- Do (expected) benefits exceed opportunity costs?
  - Necessary and sufficient!

### Net Benefits to Society Depend on...

- Cost of investment in R&D over time
  - Including adoption phase
- Dynamic path of gross annual research benefits (GARB)
  - R&D lags
  - Adoption lags
  - Benefits from adoption per unit
  - Total adoption
    - Which depends on benefits from adoption
  - Disadoption process
    - Economic or technological obsolescence

### Valuing Varietal Innovations

Variable profit per hectare  $(\pi)$ :

$$\pi_0 = PY - VC$$

P= output price; Y = yield/hectare; VC = variable cost/hectare

After adopting innovation:

proportional yield gain

proportional v. cost saving

$$\pi_1 = P(1 + p)Y(1 + v) - VC(1 - v)$$

proportional price premium

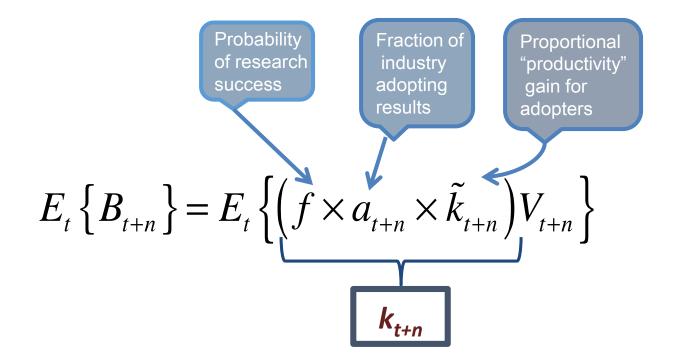
$$\pi_1 - \pi_0 \approx PY(\mathbf{p} + \mathbf{y} + \mathbf{s}_{\mathbf{v}})$$

variable cost as a share of total cost

$$\tilde{k} \approx (\boldsymbol{p} + \boldsymbol{y} + \boldsymbol{s}_{\boldsymbol{v}} \boldsymbol{v})$$

### Essential Determinants of $GARB_{t+n}$

- B = GARB = kV
  - *V* = value of production or size of the industry
  - *k* = proportional benefit (e.g., productivity gain)
- Expectations in year t of benefits in year t+n, ex ante



### Rules of Thumb and Heuristic Devices

### Intuitive implications!

- Expected total <u>future</u> benefits are greater if we have LARGER
  - Odds of successful research (leading to useful results)
  - Proportional gains for those who adopt
  - Proportion of the sector adopting (at any given time)
    - Higher maximum adoption
    - Faster achievement of maximum adoption
    - More enduring maximum adoption
  - Size of sector to which the research applies

### Rules of Thumb and Heuristic Devices

### Intuitive implications!

- Expected <u>present value</u> is greater if future benefits
  - Arise sooner (i.e., faster adoption; higher ceiling adoption)
  - Apply for longer time (more durable technology)
- Approximate estimation of benefits is better than "scoring" based on characteristics identified here

$$E_{t}\left\{B_{t+n}\right\} = E_{t}\left\{\left(f \times a_{t+n} \times \tilde{k}_{t+n}\right)V_{t+n}\right\}$$

### Rules of Thumb and Heuristic Devices

### Intuitive implications!

- Same principle applies for more difficult cases such as policy-oriented environmental R&D or policy oriented social science
  - e.g., pertaining to climate policy or endangered species preservation
  - "adopter" is government or public agency
- Expected present value of benefits is greater if
  - odds of research success are greater
  - odds of policy change are greater
  - maximum potential benefits are greater (larger "scale" issue)
    - larger benefits per unit, and larger number of units affected
  - future benefits arise sooner (i.e., faster & more widespread adoption of policy change)
  - future benefits apply for longer time (more durable policy change)

### Conclusion

- It seems reasonable to ask agricultural scientists, as part of any research proposal, to state a "value proposition" in terms of
  - a pathway to benefits arising from the research if it succeeds
  - the odds of success
  - who will adopt the results, beginning when, and for how long
  - what form the benefits will take and to whom they will accrue
  - the likely scale of the resulting benefits
  - what will happen if the proposed research project is not funded

### Outline

- Logic of choice
- Concepts and measures
- Heuristics and rules of thumb

- Example—VitisGen
- Financing angles

# Resistance in California Vineyards

### Methods:

- Aggregate analysis of pecuniary and non-pecuniary costs of PM management in California
- Budgets for representative vineyards to show benefits of transition from established to resistant varieties for
  - Wine grape growers
  - Table grape growers
  - Raisin grape growers
- Aggregation to measures of regional benefits based on assumptions about adoption rates and timing



# Aggregate Costs of PM Management in Grapes in California (2011)

### **Total Pecuniary Costs**

Product: \$71 million

Application: \$118 million

Total Cost = \$189 million (4.9% of industry revenue)



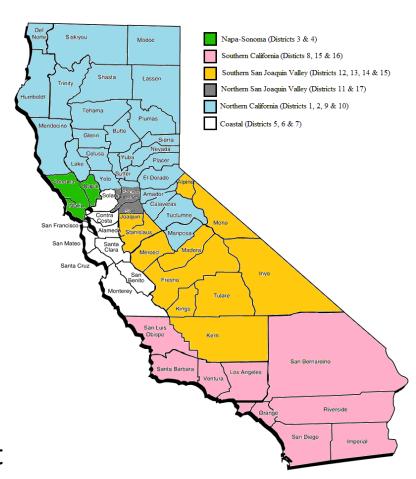


## Grower Value of Resistant Varieties in Representative Production Systems

- Wine grapes (Central Coast Chardonnay)
  - Conventionally bred non-vinifera varieties
  - Transgenic varieties with *vinifera* names
    - → Significant market resistance

- Raisin and table grapes (San Joaquin Valley)
  - Not usually marketed by varietal name
  - Berry quality and harvesting methods more important







## Total Present Value from Adoption of PM-Resistant Grape Varieties

Maximum Adoption Rate	Adoption Lag (L+3, Years)			
%	10	20	30	40
Raisins: all	\$ Millions			
20	37.8	28.1	20.9	15.6
60	113.4	84.4	62.8	46.7
100	189.0	140.6	104.6	77.9
Wine Grapes: Central Coast Chardonnay				
20	7.8	5.8	4.3	3.2
60	23.4	17.4	12.9	9.6
100	38.9	29.0	21.6	16.0
Table Grapes: Crimson Seedless				
20	3.9	2.9	2.1	1.6
60	11.6	8.6	6.4	4.8
100	19.3	14.4	10.7	7.9



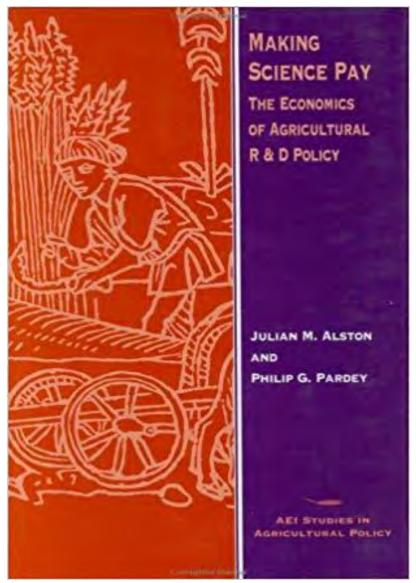
## Non-Pecuniary Costs of PM Management

- Environmental and human health effects
- Pesticide risk indicators
  - Ranking or an index based on
    - toxicological and physiochemical properties of the pesticides
       X site-specific environmental conditions
  - Environmental Impact Quotient (EIQ)
  - Pesticide Use Risk Evaluation (PURE) system

### Outline

- Logic of choice
- Concepts and measures
- Heuristics and rules of thumb

- Example—VitisGen
- Financing angles



# Financing Angles

- Block grants versus competitive grants
  - Information costs
  - Opportunity costs of inefficient allocation
  - Costs of competing for funds
- Who decides priorities? How are they implemented?
  - e.g., USDA NIFA
    - farm productivity-oriented R&D losing ground
    - expertise versus ?????
- Agricultural R&D as an instrument of social policy?
  - Public health
  - Income distribution
  - Animal welfare
  - Environmental objectives

# Financing Angles

- Division of labor for funding and performing R&D
  - Private? Public (crowding out)? Public-private partnerships (crowding in)?
  - Commonwealth? State government? RDCs? International organizations?
- Sources of funds aligned with beneficiaries?
  - Efficient jurisdictions ⇔ incentives
  - Fairness ⇔ Incentives
- How does the research evaluation and priority-setting process affect
  - Total funding available?
  - Efficiency and effectiveness with which it is used?
  - Opportunity costs, transaction costs, & information costs
  - Morale?

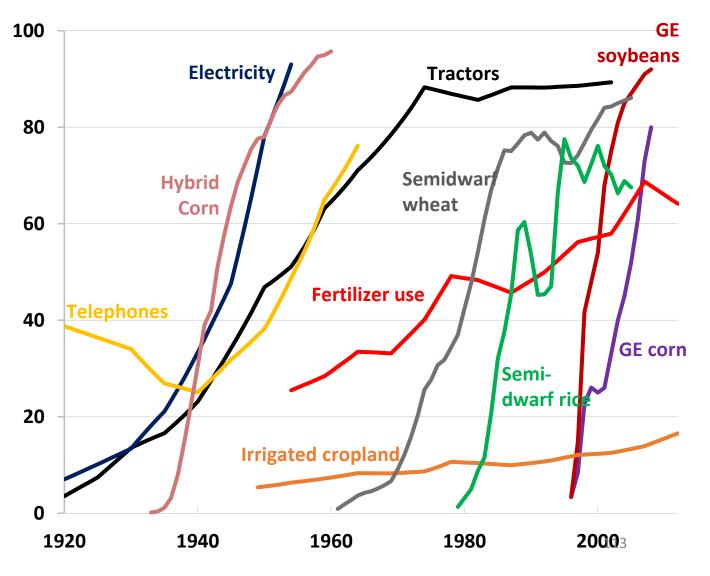
Perhaps the major benefit from a process of research program review, evaluation, and priority setting is that the participants gain a clearer view of what they are trying to achieve—and how best to get there.

Scientists and policymakers will make better decisions as they develop an economic way of thinking about research investment choices.

Alston, Norton, and Pardey (1995, p. 512)

# Adoption Paths for Selected Major U.S. Farming Innovations, 1920–2012







## PRESENTATION OVERVIEW



About us – structure & governance, successes, need for change

Realignment – change since 2015

Strategic Plan 2018-2023

Pre-breeding & breeding

Other commercial successes

Water Use Initiative – participatory R&D

Extension & communication

Ongoing challenges



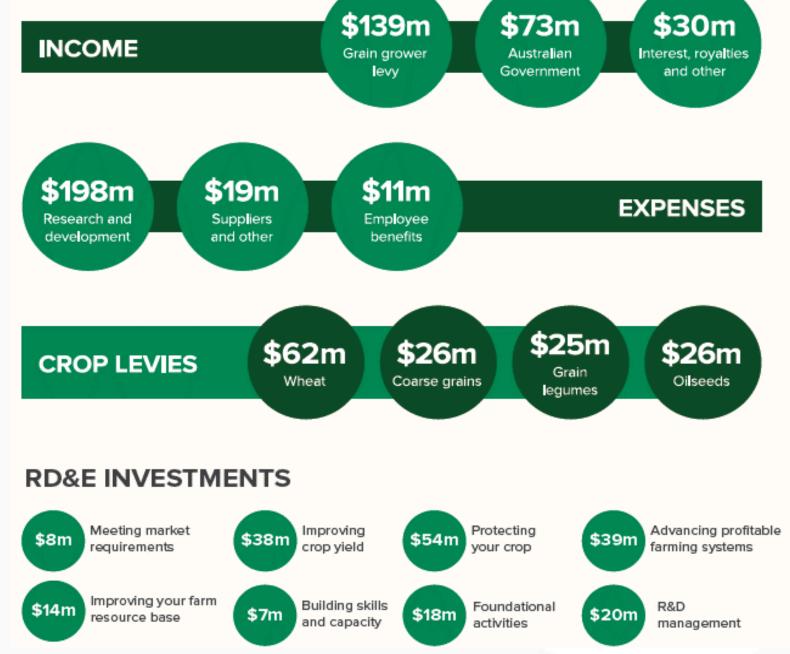
### **ABOUT GRDC**

Statutory body established in 1992 under the Primary Industries Research and Development Act (1989).

Governed by a Board, and informed by regional panels and grower networks.

- 25 leviable crops
- 900 projects

The model has worked well.



Figures from 2016/17 financial year

### STAKEHOLDER ENGAGEMENT



Regional panels: North, South & West

Growers, advisers, researchers & one GRDC executive

- identify and prioritise regional issues & investments,
- interact with stakeholders, and
- assist staff in monitoring the portfolio.



Regional Cropping Solution Networks/Grower Solution Groups

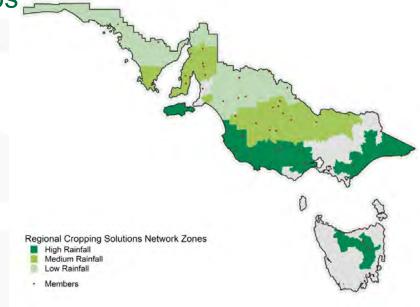
Local growers, advisers, researchers

identify and analyse local issues

#### **Industry Representative Groups**

- Grain Producers Australia
- Grain Growers Limited

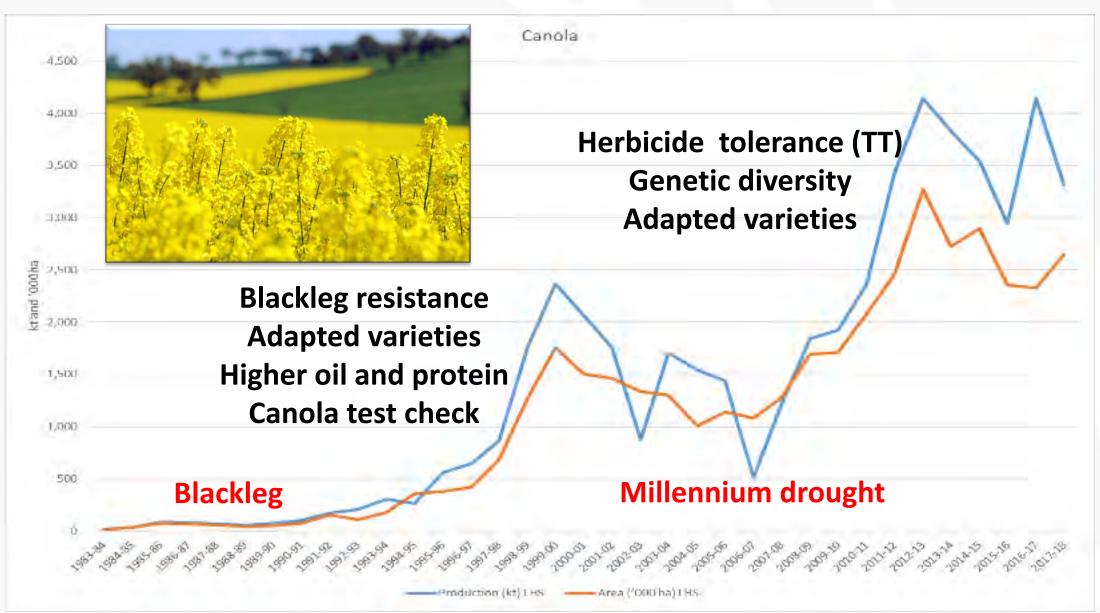




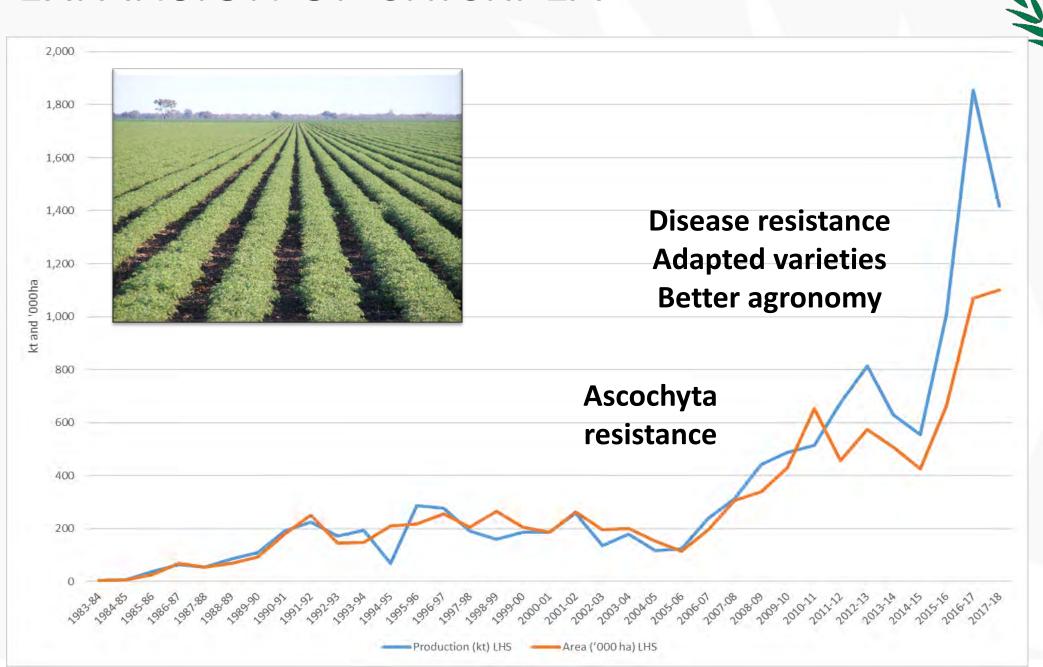
Altruism & passion for the industry fosters innovation and rapid adoption

### **EXPANSION OF CANOLA**





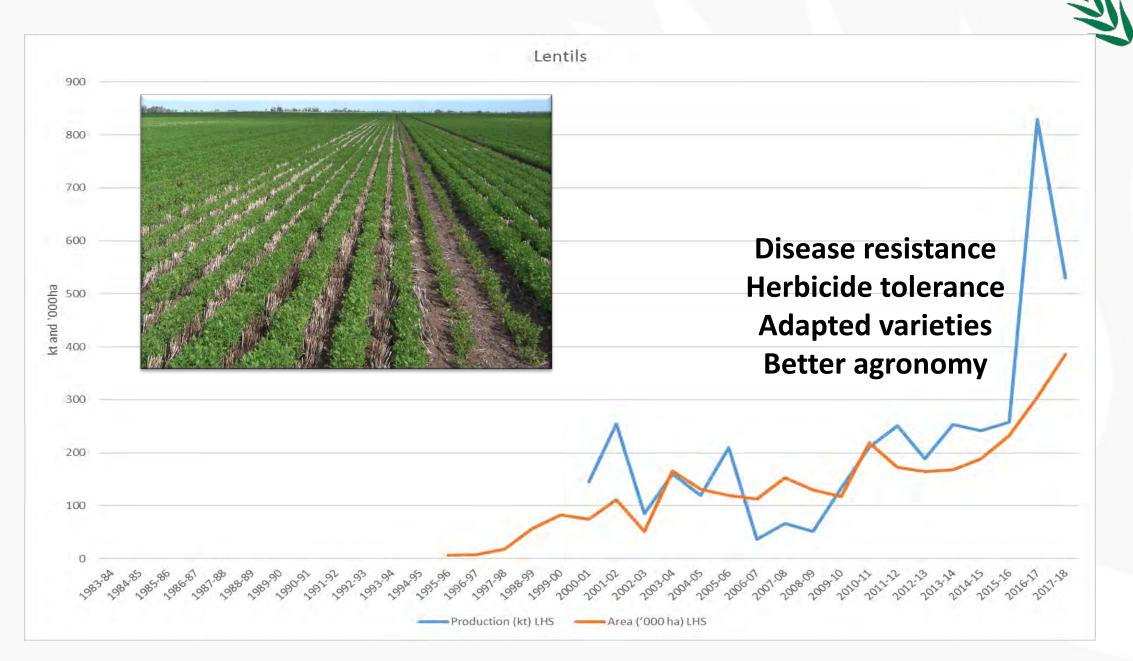
### **EXPANSION OF CHICKPEA**



GRDC

GRAINS RESEARC & DEVELOPMENT CORPORATION

### **EXPANSION OF LENTIL**

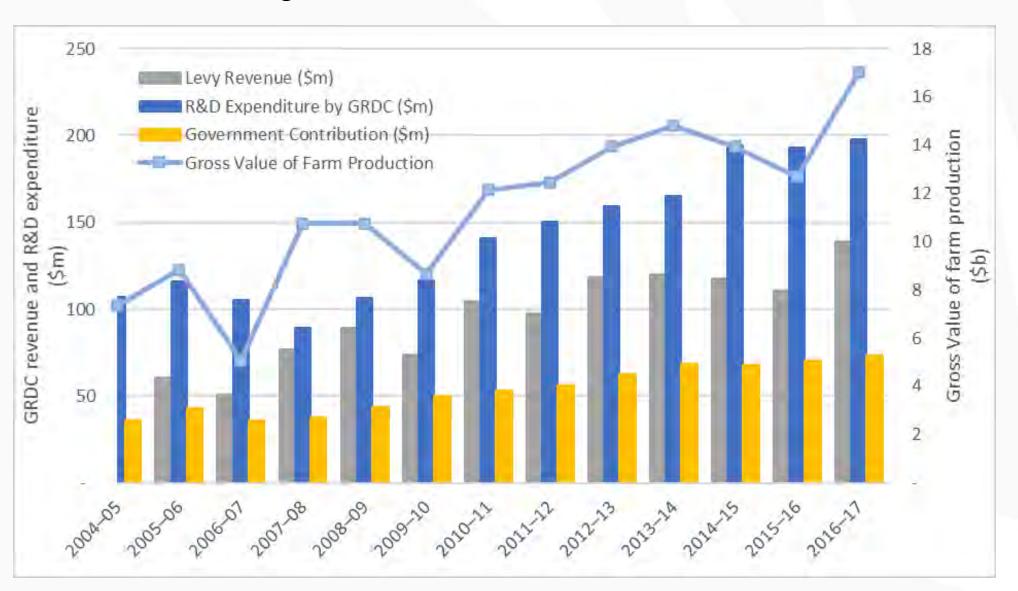


GRDC

# **INDUSTRY & RD&E GROWTH**



GRDC investments have grown from \$30M in 1990 to \$198M in 2018



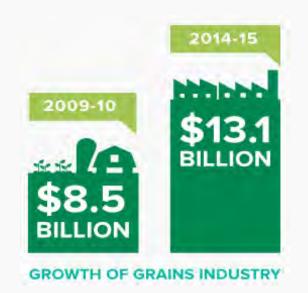
# EXTERNAL DRIVERS OF CHANGE



A lot has changed in the grains research landscape in 25 years

#### External drivers for change include:

- Significant growth in grains industry & GRDC investments
- Decline in public sector investment in grains R,D & E
- Globalisation of research activities
- Growth in private sector investment





# INTERNAL DRIVERS FOR CHANGE



Evolution required to continue to deliver maximum value

#### Internal drivers for change include:

- Need for improved investment process
- Outdated systems and processes
- Lack of transparency in decision making
- Perceived as bureaucratic and unresponsive
- Not as in touch with growers as it could be



### REBUILDING & REALIGNMENT

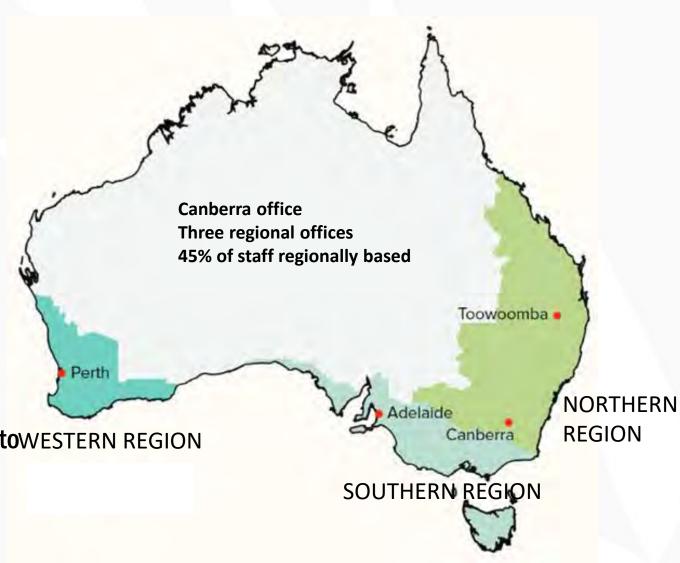


#### **Since 2015**

- Realignment of north/south regions
- New chairman & board, new MD
- Expanded staff in regional offices
- New business structure
- New management systems

#### **Regional Staff**

- Expertise in soils & nutrition, farming systems, agronomy & crop protection
- National Variety Testing transitioned in-house
- Grower relations & communications managers towestern region ensure effective extension
- Regional business support & commercial expertise



# GRDC STRATEGIC PLAN 2018-2023



Framework for investment in RD&E to deliver on purpose:

### **GRDC** Purpose:

To invest in RD&E to create enduring profitability for Australian grain growers.



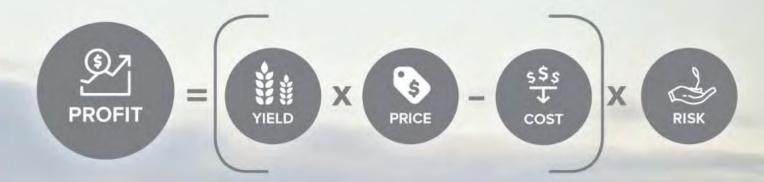
www.rdeplan.grdc.com.au

### **A NEW GRDC - FOCUSED ON GROWER PROFITABILITY**

Targeted investment in grains RD&E to ensure on-ground impact

#### Focus on key profit drivers:

- Yield
- Price
- Optimised costs
- Effective risk management
- Leveraged investments
- Nationally coordinated
- Regionally relevant
- Regionally delivered
- Locally adopted



#### **GRDC'S CORE OBJECTIVES**



**OBJECTIVE 1:** 

IMPROVE YIELD AND YIELD STABILITY



**OBJECTIVE 2:** 

MAINTAIN AND IMPROVE PRICE



**OBJECTIVE 3:** 

**OPTIMISE INPUT COSTS** 



**OBJECTIVE 4:** 

REDUCE POST-FARMGATE COSTS



**OBJECTIVE 5:** 

MANAGE RISK TO MAXIMISE PROFIT AND MINIMISE LOSSES

# KEY INVESTMENT TARGETS



**30 Key Investment Targets underpin the core objectives:** 

- KITS will enable targeted RD&E investment for maximum impact
- Provides a framework for prioritisation and a transparent and agreed rationale for investment



www.rdeplan.grdc.com.au



# WHOLE OF PORTFOLIO INVESTMENTS



Gotting the rick/roward balance right

**Research & Development Discovery New Traits Agronomy** Farming Systems Soils **Nutrition New Varieties** Weeds **New Actives** Pests **Research Support New Tools** Disease

**Regional Delivery** Extension Communication Capacity building

GRDC was too risk adverse? Increased appetite for higher risk transformational ideas.

### COMMERCIAL BREEDING

### Private/public comercialisation pathways



#### **Privatisation of Wheat Breeding**

GRDC changed plant breeders rights legislation to develop end point royalties (1998).

GRDC invested in establishment of private breeding companies.

Created impetus for global investment from Limagrain, Syngenta, Advanta, Bayer, Dow, Monsanto and BASF.

Since 2000, total investment in wheat breeding has increased \$11 – 160 million p.a.





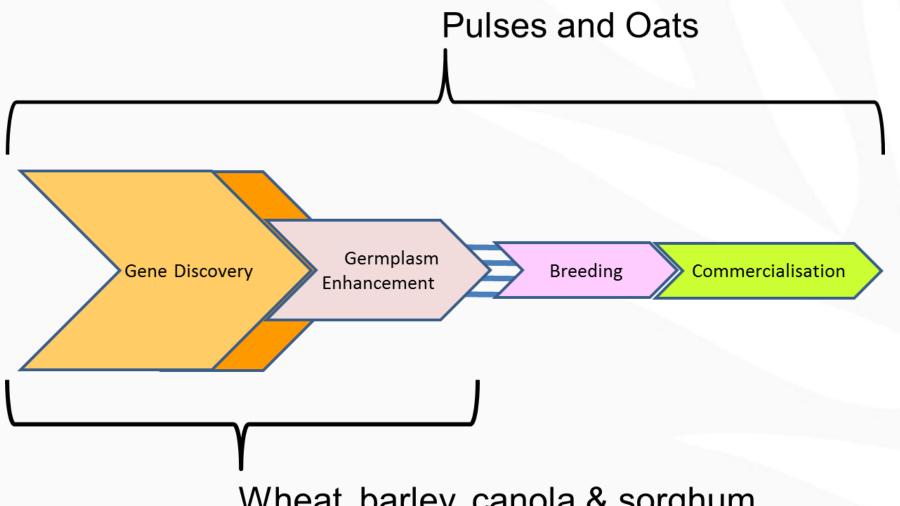




## PRE-BREEDING INVESTMENT

### **SCOPE** is crop dependent





Wheat, barley, canola & sorghum

# OPPORTUNITIES FOR PRE-BREEDING



Aspirational outcome	All GRDC investment in pre-breeding R&D is delivered to growers in the form of superior crop varieties  via commercial breeders		
Intermediate outcomes	All GRDC investment in pre- breeding projects have a clearly mapped pathway to market.	2. All GRDC investment in pre- breeding projects with public research partners involve collaboration with breeders.	3. GRDC direct engagement and investment with commercial breeders to deliver outcomes for growers.
Practice changes	<ul> <li>1.1 All GRDC investment in prebreeding research is designed to enable variety development.</li> <li>1.2 All GRDC investment in prebreeding investments have a business case prior to investment.</li> <li>1.3 All GRDC investment in prebreeding research has relevance and value to growers.</li> </ul>	<ul> <li>2.1 GRDC pre-breeding portfolio with clearly delineated investment categories for engagement with commercial breeders.</li> <li>2.2 GRDC pre-breeding investment portfolio managed to facilitate industry access.</li> <li>2.3 All GRDC investment in pre-breeding investments partnered to some degree with a breeding organisation.</li> </ul>	<ul> <li>3.1 GRDC management with strong direct linkages with industry.</li> <li>3.2 Commercial parties as research provider where they possess demonstrable capacity and capability to deliver investment goals.</li> <li>3.3 GRDC investments with access to intellectual property held by private sector to deliver project outputs.</li> </ul>



# BREEDING PARTNERSHIPS



# HOW CAN GRDC INVESTMENT BEST INFLUENCE BREEDER RATE OF GENETIC GAIN?

 $\Delta G = \frac{\text{Genetic Variance } x \text{ Selection Intensity } x \text{ Selection Accuracy}}{\text{Generation Time (Cross - Cross)}}$ 

# PRE-BREEDING CONSIDERATIONS



#### **Investment/business case**

- Constraint? Area/production? Value to growers?
- Options solutions/approaches
- How will the outcome impact growers profitability?
- Return on investment and cost: benefit across scenarios
- Breeder engagement = pathway to impact; Intellectual Property management
- Assumptions (review over lifetime of project)
- Transformational and/or incremental

#### **Grower focus – core principles**

- All investments must improve grower profitability and deliver a clear ROI
- All investments must have a defined grower customer for pre-breeding outputs
- The scope and quantum of investment must be consistent with value to be created
- Investment is not just subsidising core breeding activities, or creating market failure
- Joint breeder/GRDC management of investment

Open for business: regionally, nationally and internationally



# OTHER COMMERCIAL SUCCESSES

Private/public comercialisation pathways

#### Other commercial examples

DGT soil P test (Agronomy Solutions)
Harrington Seed Destructor (De Bruin Engineering)
Low gluten barley for malting (Radeberge)
Sporacle Blackleg Predictor (Bayer CropAlert)

High omega-3 canola (Nuseed)

Soil diagnostics and wetting agents (BASF)

High oleic safflower (Go Resources)

Low gluten barley (Healthy Grain)

High amylose wheat (Arista)

Late maturing alpha-amylase assay (Bayer)

Novozymes Biologicals (Monsanto).





GRDC works to ensure that IP is protected and relevant parties reap a fair financial reward from its commercialisation.

### INTERNATIONAL COLLABORATION



#### **Herbicide Innovation Partnership**

- GRDC and Bayer Crop Science
- \$45 million over 5 years
- Aims to develop new chemistry to help Australian grain growers manage difficult weeds
- Train the next generation of Australian scientists

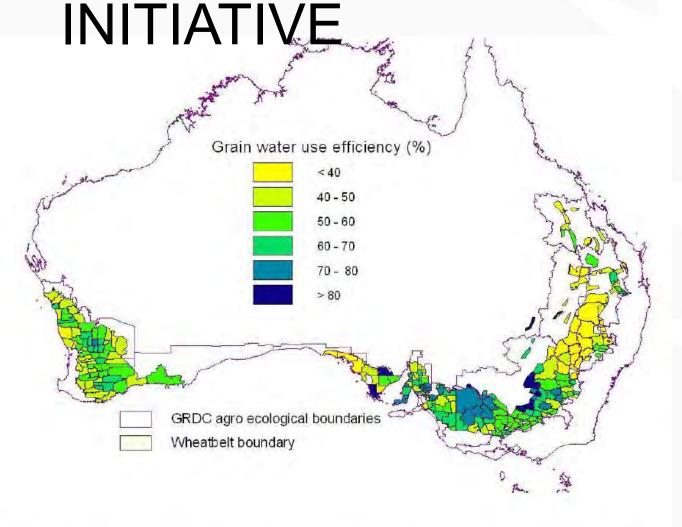






WATER USE EFFICIENCY





**Fig. 1.** National assessment of regional WUE achieved as a % of potential assessed using the French and Schultz (1984) approach as reported in the GRDC commissioned Beeston Report (Beeston *et al.* 2005) that stimulated GRDC Investment in a National WUE Initiative.

- \$17.5m RD&E aiming to increase WUE by 10% (2008-2013)
- 16 grower groups & consultants working alongside scientists in a participatory approach

### WUE INITIATIVE - OUTCOMES



<u>Practice</u>	Increase in WUE (%)
	· · · · · · · · · · · · · · · · · · ·

Better summer weed control 37 - 140

Matching N supply to yield potential 91 (on deep sands)

Inclusion of break crops 16 - 83

Earlier sowing of appropriate varieties 21 - 33

Management synergies 11 - 47

Estimated BCR 3.7 to 1

Internal ROI 18.5%



### WIDE ADOPTION



"The uptake of many of the aspects of this research program have been outstanding. Farmers no longer debate the benefits and costs of summer weed control."

Bill Long, Agricultural Consultant, SA

"A unique aspect of this project has been the speed of adoption by growers. After just three seasons there has been widespread practice change across the industry."

Tim Condon, Agricultural Consultant, NSW

Consultants
Scientists
Farmer groups
Farmers

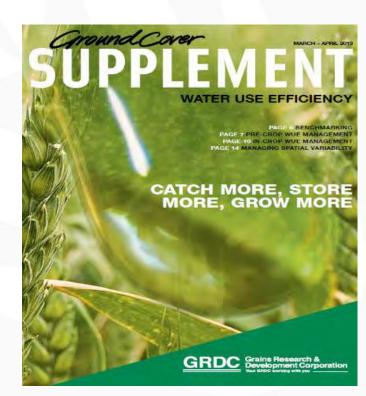


Collective enquiry.....

### **EXTENSION & COMMUNICATION**

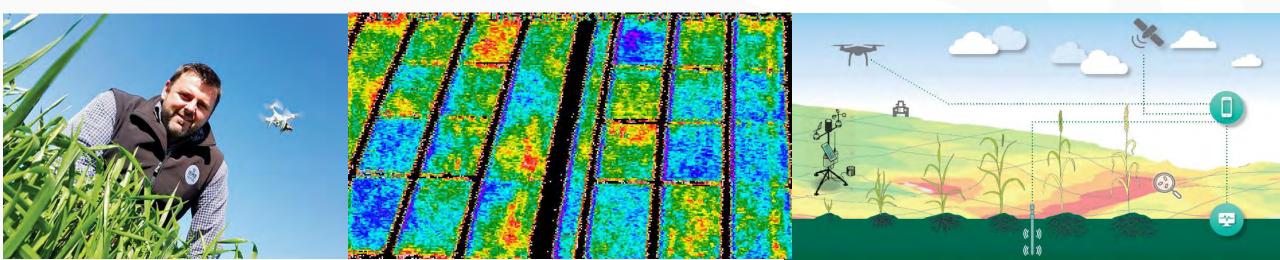


- While Groundcover magazine is highly regarded, GRDC communications have been not been well coordinated – in some cases 'quantity over quality'.
- GRDC website has been renewed but further work is required working on getting all final project reports accessible.
- Need to better understand growers and how they want information.
- Consultants and advisers are being increasingly targeted.
- Grower training and capacity building has been ad hoc.
- Grower Relations team is developing an extension & communications strategy.



# **CHALLENGES**

- Monitoring & Evaluation how to better demonstrate impact and value for individual projects and as an organisation?
- Cross RDC collaboration has improved with governments Rural RD for Profit but could improve further.
- How do we demonstrate 'clean and green' and ensure enduring profits, given increasing limitations from policy and regulation?
- Getting the balance right between regionally relevant & nationally coordinated.
- Harnessing value from 'big data', robotics, remote sensing, digital revolution.









SA grain growers funding research solutions

www.sagit.com.au







# SAGIT funding of agricultural research

• Origin

• Deed & Trustees

Source of funds







# Application categories

- Research
- Capital
- Travel
- Grower groups field day speakers & publication of trial results









# SAGIT funding application process

- Open call
- Once a year (early February)
- Applicants notified after project assessment meeting in mid-March
- Can have "Out-of-season" applications in special circumstances







# Role of scientific officer

- Advice on project applications
- Review of project applications (including liaison with GRDC)
- Project visits
- Communication with project officers







# Selection criteria for projects

- Issue of importance to SA grain growers
- Project plan
- Benefits to SA grain growers







# Funded projects

- In 2018 31 new research projects (out of 45 projects submitted) and 30 on-going projects.
  - This includes 5 conference sponsorships, 4 publications (including Gross Margin Guide) and 3 grower group extension workshops.
- Average term of projects is 1.7 years
- Average SAGIT funding/project for current projects is \$91,000





# Examples of SAGIT funded projects

- Pre-breeding salinity tolerance in cereals; Improving N-use efficiency in durum
- Plant breeding P250 medic; Studenica vetch; lentils for lower rainfall regions
- Crop agronomy, crop nutrition, soil water monitoring, control of weeds, diseases (including PREDICTA B test for soilborne diseases) & insects
- Internships
- Agricultural science awareness in high schools







# Soil moisture monitoring, Eyre Peninsula











# Nodulation of pulses where sown into dry soil









# Heat tolerance of wheat and barley lines











# Hart long term cropping systems









# SARDI & Hart interns, 2016 - 2019















SA grain growers funding research solutions







# **Allocating State Government Research Investment** The SARDI experience

**Dr Peter Appleford** 

**26 November 2018** 



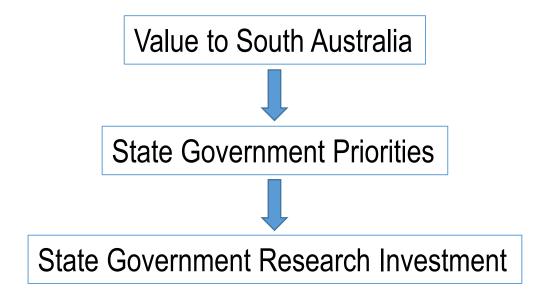


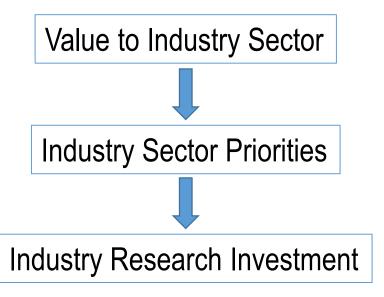


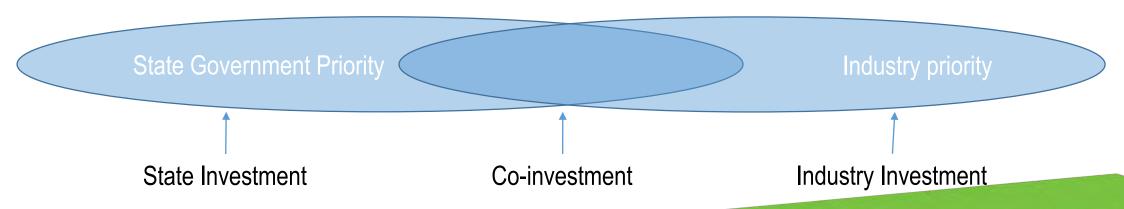




### The Overview

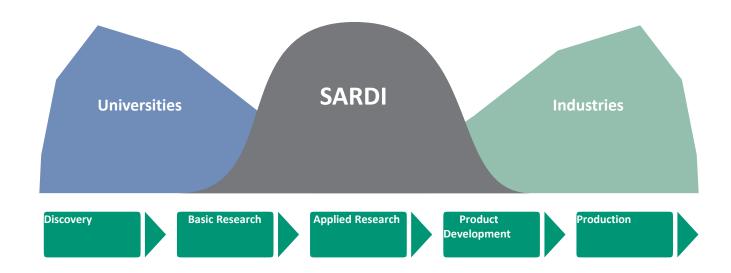






# **SARDI**

"Deliver applied science that grows South Australia's primary industries, food and wine."



# Roles of SARDI

- Growing the production and profitability
- Informing sustainable management of natural resources that underpin primary production,
- Protecting and enhancing market access for South Australian businesses and products,
- Driving food innovation, and
- Delivering impact from applied science.

# Science Divisions – Overview 2017-18

Division	State Allocation	Total Budget	FTE
Crop Sciences	\$2.535 Million	\$25.456 Million	137.6
Aquatic Sciences	\$2.718 Million	\$19.956 Million	86.2
Livestock Sciences	\$1.218 Million	\$5.795 Million	33.9
Food Sciences	\$0.802 Million	\$2.984 Million	11.36
Business Support	\$1.854 Million	\$8.937 Million	48.49
Total	\$9.128 Million	\$60.128 Million	317.55

# **Investment Allocation Process**

#### Three stages:

- 1. A Portfolio Balancing / Investment Decision Process
- 2. Project Assessment Process
- 3. Assessment of research outcomes / return on investment

# Portfolio balancing/allocation decision process

#### **Outcomes:**

- Determines the investment available for commitment
- A transparent mechanism for the allocation of investment across the SARDI programs/subprograms
- Provides decisions on split of investment across science programs and sub-programs for the next three years
- Provides decisions on investment into new programs (if any) and how those programs will be funded and fit into the overall RD&E program
- Provides for decisions on long term funding direction for the programs/sub-programs

# **Assessment of Research Outcomes/ROI**

- Step 1 Determine the funding available to invest.
- Step 2 Undertake an assessment against the investment criteria and policy priorities on a SARDI Division basis to identify the direction and quantum of research investment changes across the SARDI Program areas over the next 3 to 5 years. SARDI Program / Science Program leader engagement.
- Step 3 Undertake an assessment against the investment criteria and policy priorities within each SARDI Science Program, to identify the direction and quantum of research investment changes within the SARDI Program areas over the next 3 to 5 years.
- Step 4 Consult on the outcomes of the assessment and proposed investment changes across relevant PIRSA divisions and relevant SARDI Staff.
- Step 5 Communicate outcomes of process.
- Step 6 Finalise and implement investment changes.

# **Funds Available for Investment**



**Investment Criteria** 

#### **START**

Investment in:

- areas supported by government policy
- new/developing sector opportunities
- new industry/sector investment opportunities
- •areas where SA has/desires a comparative advantage

#### **MAINTAIN/INCREASE**

Investment in:

- •areas where government policy indicates a need to maintain/increase
- •large/significantly growing sectors
- areas attracting increased industry funding
- •areas where SA has/desires a comparative advantage

#### **DECREASE**

Investment in:

- areas where government policy indicates a reduction
- declining sectors
- areas with reduced industry funding
- areas where SA does not have a comparative advantage

#### **STOP**

Investment in:

- areas not aligned with government policy
- significantly declining sectors
- •areas attracting no/low levels of industry funding
- •areas where SA does not have/desire a comparative advantage



# **Investment Criteria – cont.**

- the maintenance of capability to support legislative decision making
- succession planning requirements for core science capability
- Government policy priorities sector plans

# **Sector Plans**

#### Inputs

- RDC Strategies
- Industry plans, strategies, blueprints
- Policy drivers
- Economic analysis REM
- Role of current and past work
- SWOT analysis
- Sector vs commodity analysis
- Industry production
- Industry funding direction current and future
- Scenario analysis of investment changes

#### **Sector Plans:**

Grains/Cropping

Livestock including

wool

Wine

Horticulture

Fishing and

Aquaculture

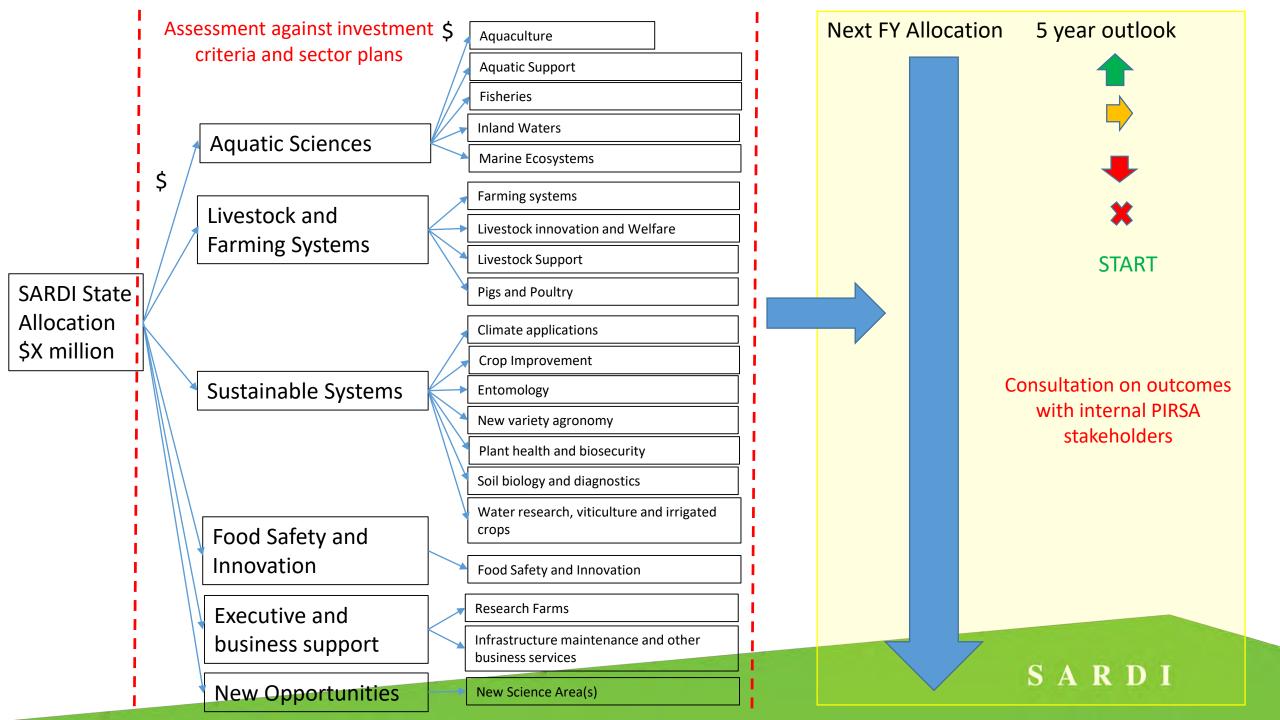
**Poultry** 

Pigs

Food

#### **Contents**

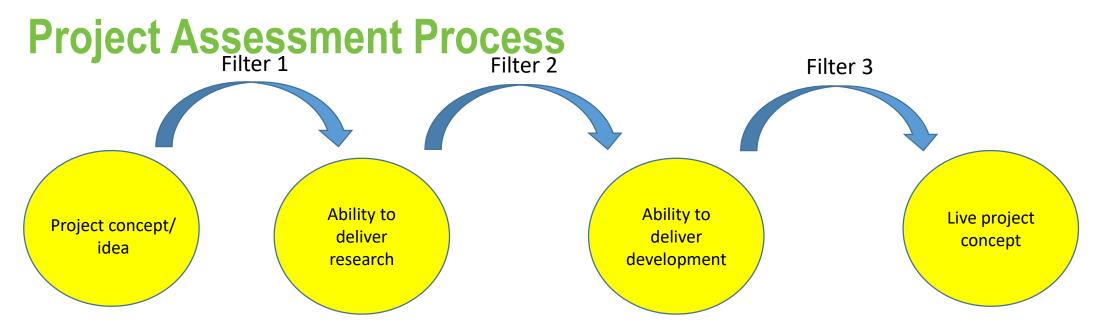
- Sector outcomes and goals
  - - prod, efficiency, jobs?
- Industry growth path
- Value chain investment
- Key opportunities
- Assessment against investment criteria
- Long term investment direction – 5 to 10 year
- Constraints
- Monitoring and evaluation framework



# **Project Assessment Process**

#### Outcomes:

- A transparent mechanism for selection of projects for investment
- Determines if the project aligns with policy
- Determines if the project is realistic and deliverable
- Determines if then outputs/outcomes of the research can be translated into impact



- Step 1 does the project idea/concept align with the PIRSA Corporate Plan, SARDI Strategic Plan and or sector plans. If yes progress to step 2, if no rejected.
- Step 2 can SARDI deliver the project idea/concept. Does SARDI have access to the correct capability/infrastructure. Is the funding likely to be available internally or externally. If yes progress to step 3, if no rejected.
- Step 3 can the research outputs/outcomes be translated into impact (logic map). If yes progress to step 4, if no rejected.
- Step 4 live project option available to seek funding from unallocated SARDI investment pool (cash and in-kind) or external sources.

  SARDI

# **Logic Map/Theory of Action Example – Bennet's Hierarchy**



# **Assessment of Research Outcomes/ROI**

- Monitoring and evaluation of research investment is an important component of any investment framework.
- Requires a research and investment monitoring and evaluation framework. The framework will include measures to determine the quality of research and development delivery, and impact.
- A selection of SARDI Science-programs and or projects will be assessed to determine the return on investment from the research and development investment.

# The Role Of Producer Controlled Research Organizations

In Making Science Useful To Agriculture

Adelaide, 26-29, November 2018

Richard Gray
University of Saskatchewan

# Academic and Producer Perspective



# Introduction

- Producer controlled research organizations (PCROs) are prominent in Australia, Canada, and United States.
- They are typically regulation via marketing orders to levy the sale of agricultural commodities
- research funds are typically administered by an organization reporting to a board of directors representing producers
- Given the apparent success of many of these PCROs in facilitating agricultural innovation, they very much belong in a discussion of *Making Science Useful to Agriculture*.

# PCROs?

- Producer controlled research organisations
- Levy funded
- Producer reps (producer nominated or elected board of directors)
- What role do they play in ag innovation?
- How do they make decisions?
- What role do they play in the social capital for innovation?

# Objectives

- to develop a better understanding of how PRCOs contribute to effective innovation systems
   I'm looking forward to a two way
- I'm looking forward to a two way exchange

# Outline

- a theoretical exploration of the role that PCROs can play in addressing market failures and externalities in R,D&E
- An overview of PCROs, their activities and their performance.
- the internal decision-making processes of grain based PCROs located in Canada and United States.
- The role of producer organisations in the development and launch of zero tillage
- conclusions

### Market failures

- Very broadly speaking, science based agricultural innovation involves investment to undertake research to create knowledge that is eventually used to develop new products that are adopted by producers (farmers).
- For at least 150 years, governments have recognized that markets often fail to provide adequate incentives for purely privately funded systems in agricultural innovation.

## What does economic theory have to say?

 The products of Ag research are non-rival meaning the same discovery can be used by others without depletion (Marginal cost is equal to zero)

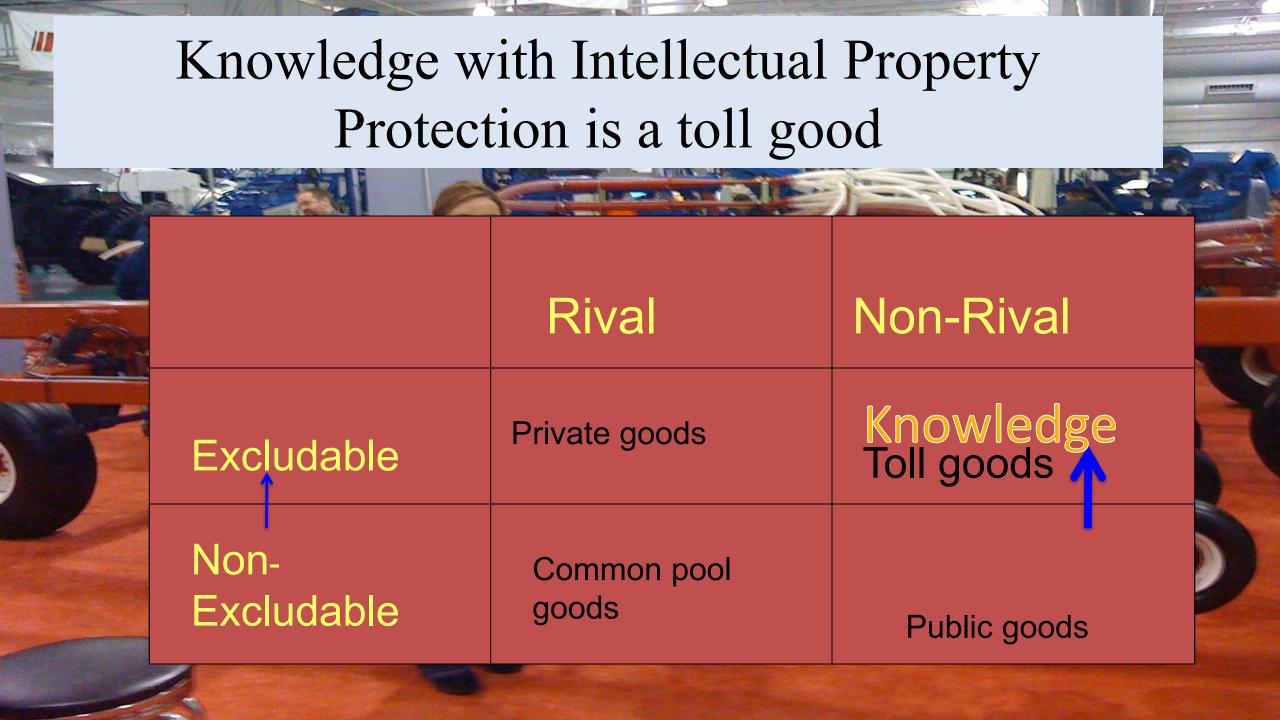
 When the products are not protected by IPRs, there no willingness to pay for something that is free so this unprotected knowledge is either a public good or an industry good

## Industry Goods Definition

- Industry goods are public goods where the spillovers are concentrated within the industry
- Example: In the wheat industry the release of a parasitic wasp to combat wheat midge would increase supply and would benefit the whole supply chain.
  - In the case of a large country this includes consumers at home and abroad.
  - In the case of a small country price does not change and consumers do not benefit from research

## What does economic theory have to say?

- When well-protected by IPRs these public goods become toll goods
- The private sector can provide toll goods but it cannot be a competitive industry and prices greater than marginal costs will deter adoption
- Governments are withdrawing from toll goods and industry goods
- PCROs fund toll goods and industry goods



## Information Asymmetry

- Given the sellers have more information than buyers of a new technology, governments have played a role in testing and verification.
- In many cases this knowledge is an industry good where trust is higher if validation comes from government or a PCRO
- Local PCROs can also help adapt new technologies to local conditions

## Incentive Alignment

- Farmers are price takers and have the incentive to increase quality and/or reduce the costs of production
- Farms are complex with an element of scope that goes beyond the disciplinary silos of genetics, agronomy, machinery, regulatory structures, market development
- They often have a long-term, multi-generational view of sustainability for their farms
- They have an incentive to maximize the return on their investment they are investing their own money



#### **Rationale for Producer Involvement**

- Producers perceive that they are paying for variety development efforts regardless of whether it is through the seed price, technology use agreements, EPRs, or producer levies dedicated to research.
- Producers have an interest in shaping the direction of research efforts in their favour, particularly to favour choice and market competition.
- Question is:
  - "If producer funding is different than private funding and public sector funding, how are producer commissions unique in their approach to research and the outcomes they desire?"



### Incentive Alignment in Agricultural Research

Governments

Producer Organisations



Private Firms

Public Goods (non-excludable)	Industry Goods (non-excludable)	Private Goods (excludable)
Basic Science Research	Crop genomics, germplasm, unprotected varieties	IP Protected crop varieties/traits/processes
Science literacy/ ecology /chemistry/ biology	Agronomy/ best management practices	Protected production process
Business management	knowledge dissemination product, input testing	Patentable mechanical innovations
Human and model crop Genomics	Crop disease research, biological control systems	Chemical Pesticides Inoculants
Pathogen Research	Quality standards/systems  Market access	product and market development





## The PCROs We Sampled

Table 1: The Producer Controlled Research Organizations Surveyed							
Organization	Commodity	Year	2015/16 Incon				
		Est.	Million (USD)				
Alberta Wheat Development Commission	Wheat	2011	5.1				
Grain Farmers of Ontario	Multi-Grain	2010	8.8				
(Australian) Grain Research and Development Corporation	Multi-Grain	1990	171.4				
Iowa Corn Promotion Board	Corn	1976	17.2				
Iowa Soybean Check-off Program	Soybean	1964	11.0				
Kansas Wheat Commission	Wheat	1957	6.0				
Manitoba Canola Growers	Canola	1996	2.1				
Montana Wheat and Barley Committee	Wheat	1967	4.5				
Saskatchewan Canola Development Commission	Canola	1991	5.2				
Saskatchewan Flax Development Commission	Flax	1996	1.0				
Saskatchewan Pulse Growers	Pulse	1984	17.4				
Saskatchewan Wheat Development Commission	Wheat	2013	4.9				
United Soybean Board	Soybean	1991	99.2				
Western Grain Research Foundation	Multi-Grain	1981	6.6				
Source: Organization websites and public annual reports							

## PCRO decision making

- Hossieni (2017) interviewed managers and directors of 14 grain based PCROs across Australia, the United States and Canada.
- During these interviews, it became clear that with the exception of the GRDC, the BODs are involved in both oversight and management decisions.
- In the case of the GRDC producers are involved in many steps of the decision making

## The Theory of Decision making

- In the standard model of governance for most FP and NP there is a separation of management and BOD oversight
- Hire talent and incentivize them
- Prendergast (2002) argues for employees:
  - With simple tasks reward input
  - Complex task reward output
  - If output is difficult to measure then reward inputs

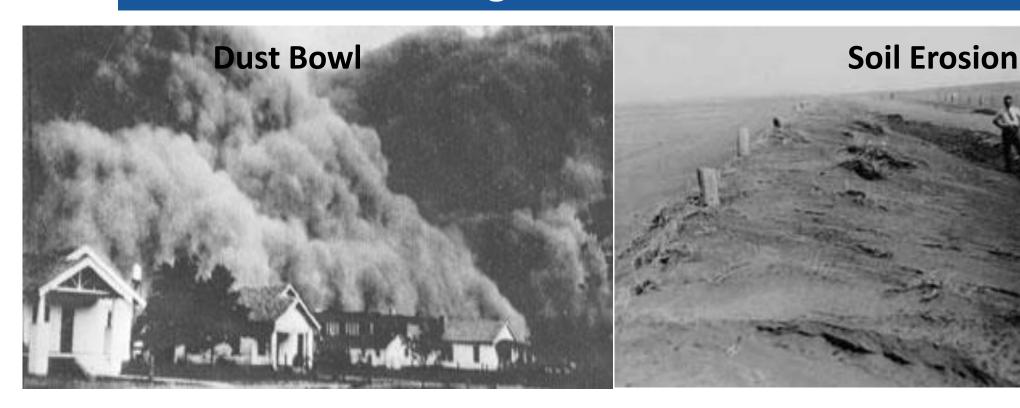
## The Non-Separation in most PCROs

- The only way to estimate a manager's quality of decision making is to be part of the process
- BOD pay is generally low and are rewarded through industry benefits, learning, and altruism for other farmers

## Implications of producer engagement

- Producers involved in PCRO governance learn a lot about research and about innovation
- This also brings BOD knowledge and investment skills to the table
- This knowledge is transferable across PCROs and other organisations
- This might be a very important source of organisational social capital
- Eg. soybeans and zero tillage

#### **Land Degradation on the Prairies**



- ➤ In the 1930s, the Prairies experienced a period of severe drought and a number of dust storms: Dirty Thirties or Dust Bowl
- High winds moved millions of tonnes of topsoil from fields, resulting in soil degradation

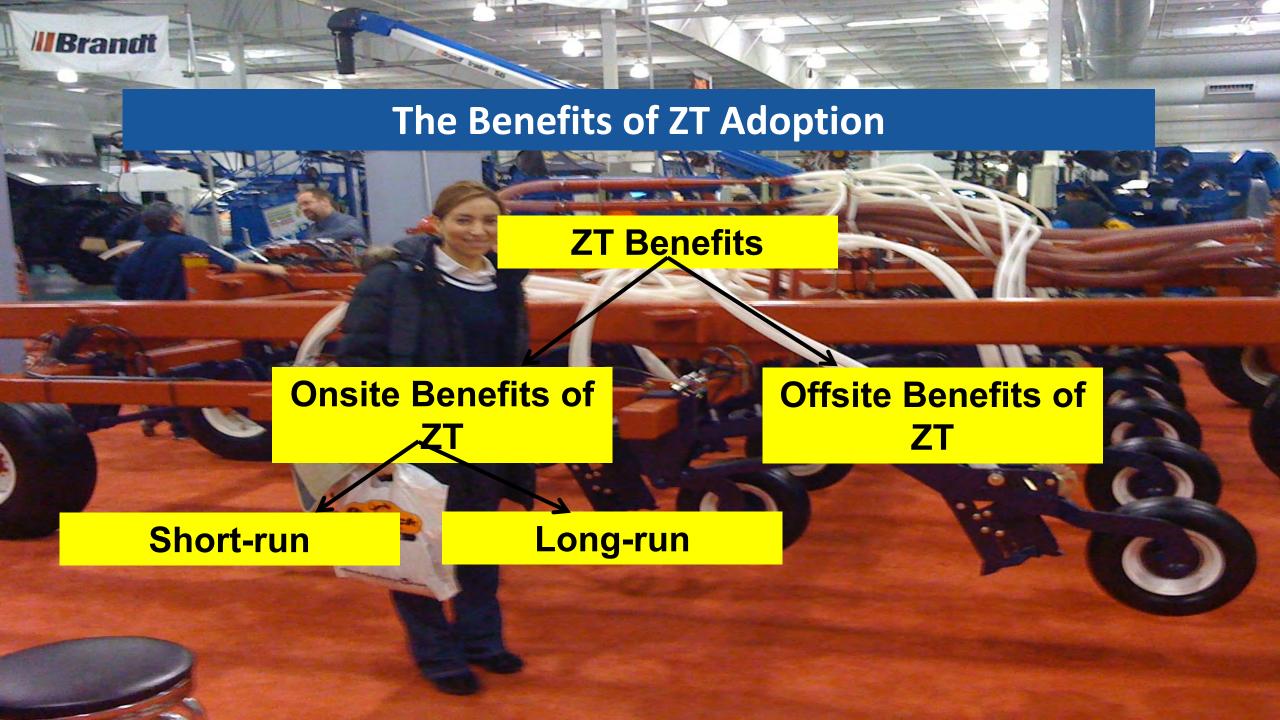
#### Air Seeder



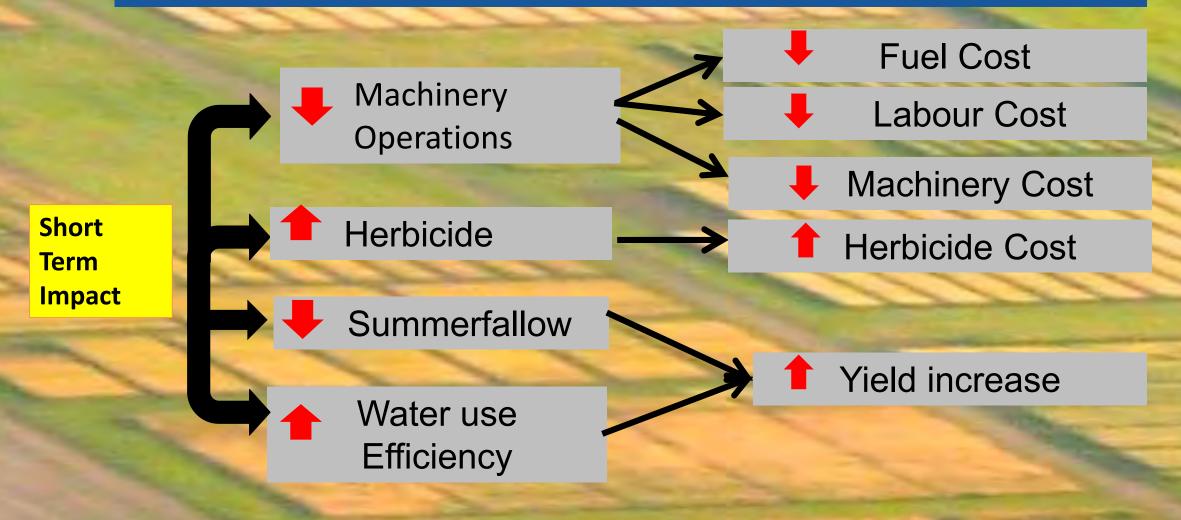








#### The Onsite Benefits of ZT Adoption



#### The Onsite Benefits of ZT Adoption



## 2014 Present Value of Benefits from Accelerated Adoption Zero Tillage RD&E on the Canaidian Prairies 1985-2012

Variables	5 year delay counterfactual Base Case	2 year delay counterfactual Scenario 1	10 year delay counterfactual Scenario 2
		Million \$2014	
<b>Short Run On-site Benefits</b>		·	
Reduced machinery cost	620.0	260.1	999.8
Reduced labour cost	223.9	93.9	361.2
Reduced fuel cost	563.3	235.8	908.1
Reduced other inputs cost	52.6	28.1	129.1
Total input cost reduction	<i>1459.8</i>	<i>627.9</i>	<i>2398.2</i>
Increased production-reduced fallow	4,287.5	$1,\overline{255.2}$	9,744.2
Increased water use efficiency	1,532.9	588.3	2,559.3
<b>Total Short Run Onsite benefits</b>	5,747.4	1,873.1	12,142.2
Long Run On-site Benefits			
Reduced wind erosion	256.0	102.7	432.2
Increased soil organic matter	2,186.4	900.0	3,436.0
Reduced soil salinity	51.6	21.0	85.2
<b>Total Long Run Onsite benefits</b>	4,027.0	1,612.1	6,512.8
<b>Total Onsite Benefits</b>	9,774.2	3,485.1	18,655.1
Offsite Benefits			
Reduced Carbon Dioxide			
Soil carbon sequestration	390.1	154.3	616.8
Fuel emission reduction	18.4	7.4	31.1
Reduced NO <sub>X</sub>	8.8	3.4	13.7
<b>Total Offsite Benefits</b>	417.2	165.0	661.8
<b>Total Zero Tillage benefits</b>	10,191.6	3,650.1	19,316.7

Source: Authors estimate see text.

#### Table 4. Benefit Cost Ratios for Zero Tillage RD&E

	B/C	B/C	B/C	
	5-years	2-years	10-years	
	<b>Base Case</b>	Scenario 1	Scenario 2	
Short run onsite benefits/public costs	<b>61.6</b>	20.1	130.2	
Long run onsite benefits/public costs	43.2	17.3	69.8	
Total onsite benefits/public costs	<b>104.8</b>	37.4	200	
Offsite benefits/public costs	<b>4.5</b>	1.8	7.1	
Total Benefits/Public RD&E Costs	109.3	39.1	207.1	
Short run onsite benefits/total costs	<b>34.3</b>	11.2	72.5	
Long run onsite benefits/total costs	<b>24.1</b>	9.6	38.9	
Total onsite benefits/total costs	<b>58.4</b>	20.8	111.4	
Offsite benefits/total costs	<b>2.4</b>	1.0	4.0	
<b>Total Benefits/Total RD&amp;E Costs</b>	<b>60.8</b>	21.8	115.4	

The return to ZT research is the highest payback for any agricultural R&D on the Prairies



- Jim Halford (farmer, ag economist, part time farm business extension worker, Nuffield scholar) became very interested in zero tillage
- Jim teamed up with Dr. Guy Lafond a co-located gregarious Agriculture Canada agronomist, to transform air seeders into precision planters
- They did several years of research trying to figure out the optimal seed and fertilizer placement. It started to work very well.



- In 1986 Jim Halford toured Saskatchewan and recruited producers to form the SSCA in 1987
- In 1989 Jim patented his technology, and ConservaPac started to build seeders on his farm
- In 1993 Halford and others created the Indian Head Agricultural Research Foundation, which kept the AAFC site open and became the hub for ZT extension activities.
- IHARF has >1000 members today

## Conclusions and Policy Implications

- Producers have a role to play in providing industry goods related to R,D &E
- PCROs have incentives to get it right
- With a foot in both the public and private realms PCROs provide many important linkages
- Producer board members understand many aspects of innovation and have experience in making complex risky investments ie. they have to think like economists
- New innovations may require new institutions, which can be created more quickly if there is social capital
- PCROs and their BOD create and maintain social capital



## Can we spend our research dollar more effectively?

Bill Long

Adelaide –November 2018

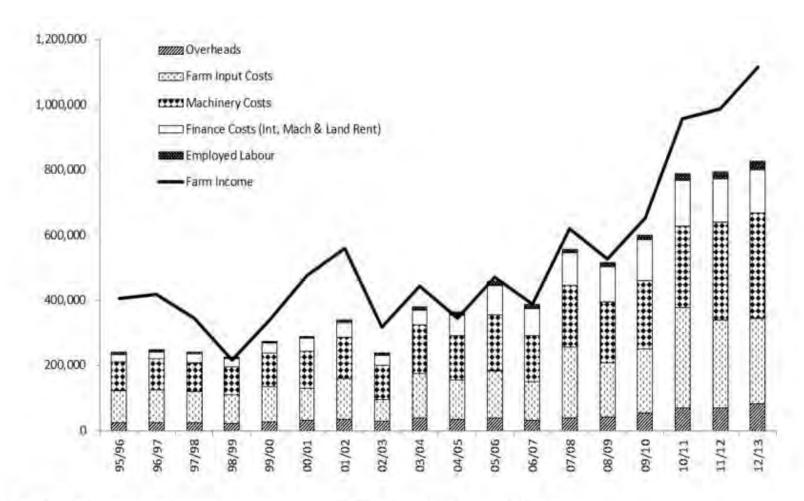


Figure 1. Wimmera farm income and costs from 1995/96 to 2012/13. Source; ORM data.

#### S14.4 WHEAT: UNIT VALUE AT 2004 PRICES



Source: Value of Agricultural Commodities Produced, Australia (7503.0); ABS data available on request.

#### Climate influence

Temp increase 1 degree
Reduced rainfall 76mm over 26 years



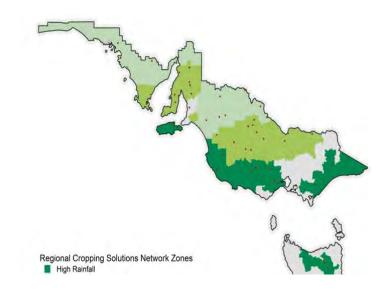
#### **GRDC Vision**

# Investing in R D & E to create enduring profitability for Australian Grain Growers

#### Issue Identification

- Panels 30 members
- Regional Cropping Solutions Network 45 in the south
- GRDC Staff





#### **Process**

- Issues identified by RCSN –MRZ + panel
- Modeling changes to net farm profit using our own farm – an "average" farm in the medium rainfall zone (Mike Krause P2P Agri)
- 2500ha (now 3150 ha)
- Lentils, chickpeas, canola, beans, durum, wheat, barley
- Meat and wool





#### Identified Priorities – MRZ RCSN

- Measuring profit itself benchmarking and planning can realise 8% ROAM
- 2. Intensification of high value pulse crops (Lentil/ chickpea)
- 3. Continuous cropping farms no livestock infrastructure and skills
- 4. Skill of an adviser
- 5. Glyphosate resistance
- 6. Variability of seed supply in Canola (hybrids vs OP)
- 7. Robotic weeder
- 8. Pesticide Legislation
- 9. Improvements in the confidence of weather forecasting
- 10. Growers not being able to predict pest and disease



Agribusiness consultant Simon Vogt of Rural Directions delivers an 'Opportunity for Profit' workshop at Booleroo Centre, South Australia.

PHOTO: Rebecca Jennings

Grain growers are learning what gives the top performers among their peers the 'edge' at a series of GRDC workshops delving into profit drivers

#### Benchmark data



#### What makes to top 20%

- 1. Better gross margins generating 7% more and investing 4% less
- 2. Low cost business model –top performers investing 27% of business TO into TPML – Ave 36%
- 3. People and management implementation rather than knowledge gap
- 4. Risk Management

#### Benchmarks to consider

- ROAM
- Total power machinery and labour
- Debt to income (0.66 top20% -0.94 ave.)
- Finance costs
- Variable costs < 40%?</li>
- Fertiliser cost <\$30/tonne of wheat yield/ha</li>
- Chemical costs < \$25/tonne of wheat yield/ha</li>

#### Improved financial performance

- ROAM of 3% = EBIT of \$419,120 or a Farm Net Profit Before tax of \$251,650
- ROAM of 8% = EBIT of \$1,117,655 or a Farm Net Profit Before tax of \$950,185

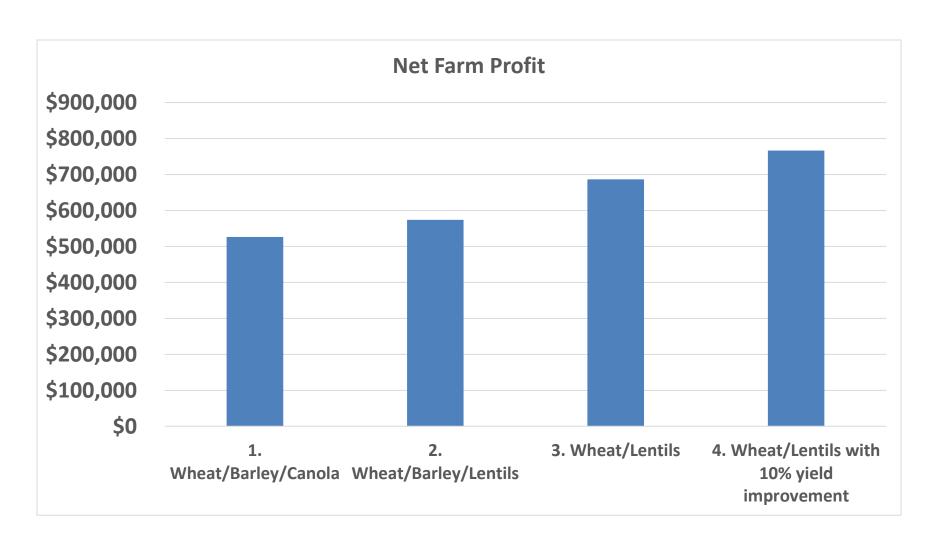
#### 2.Intensification of lentil/chickpea?



#### More adaptable high value pulse crops



#### 2. Rotation with Lentils (average season)



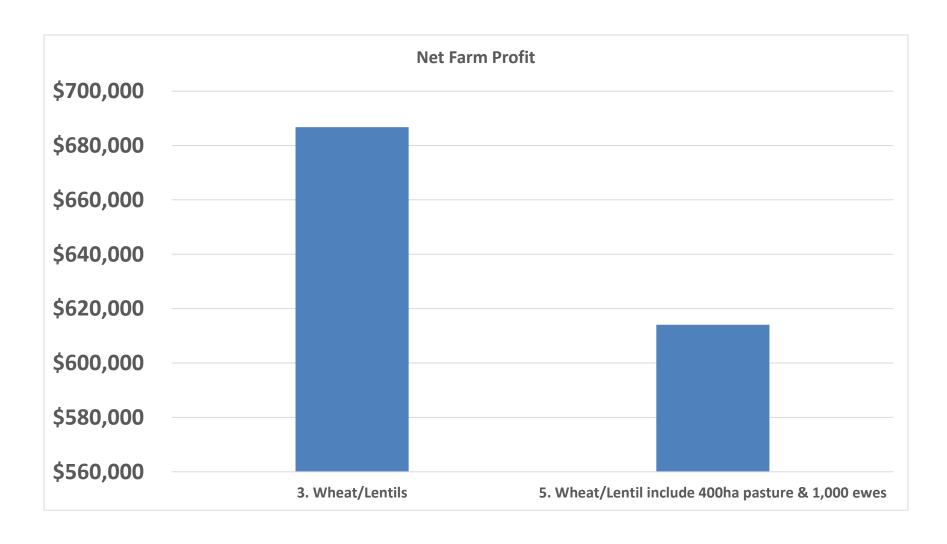
#### 2. Rotation with Lentils (average season)



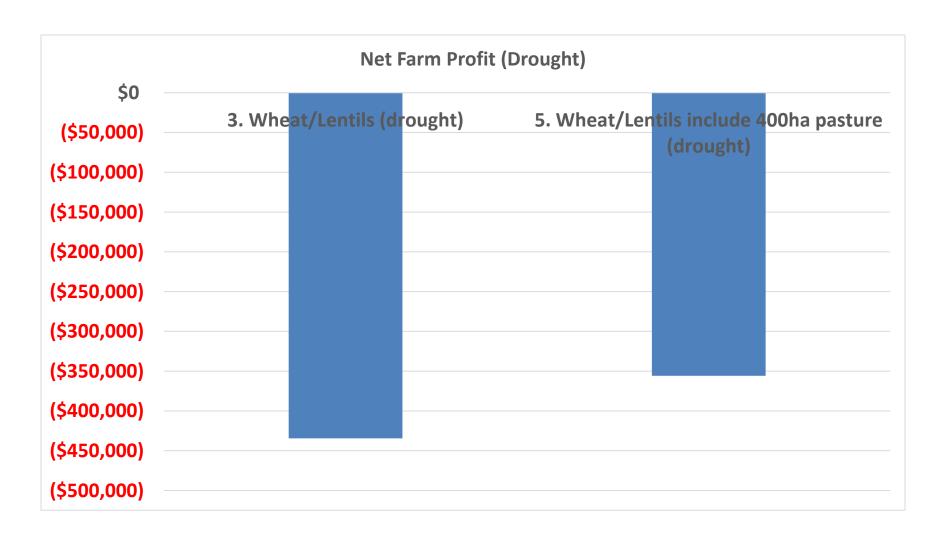
#### Continuous crop vs. Livestock in the system



#### 3. Continuous crop vs livestock average season



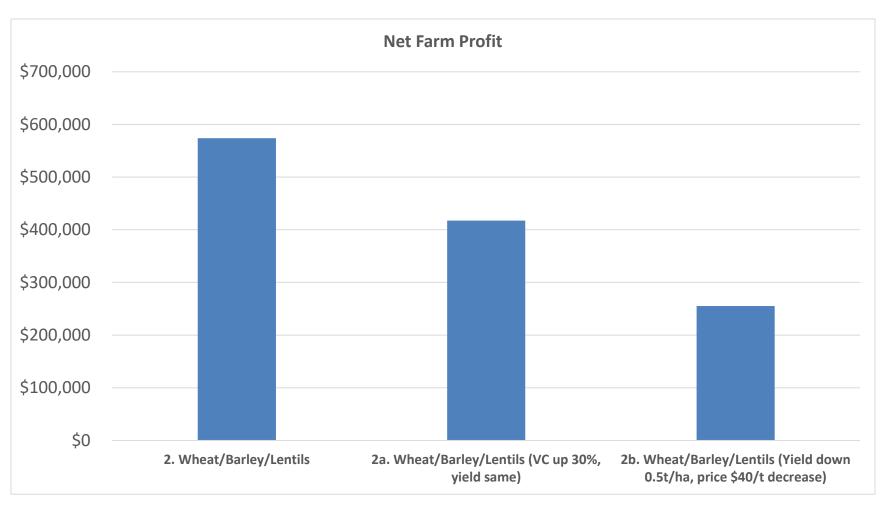
#### 3. Continuous crop vs livestock - drought



#### Role of the advisor?



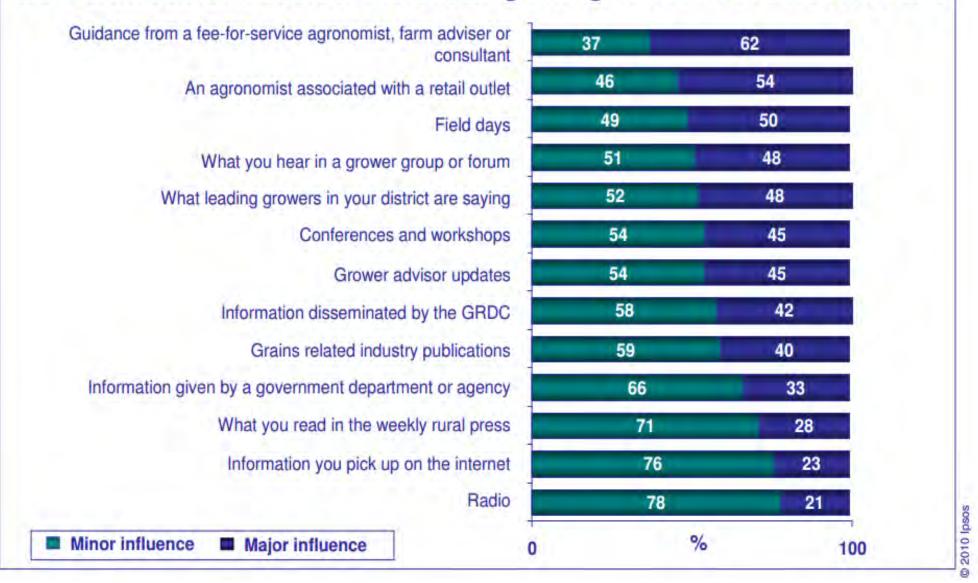
## 4. Level of knowledge and skill of advisors (average season)



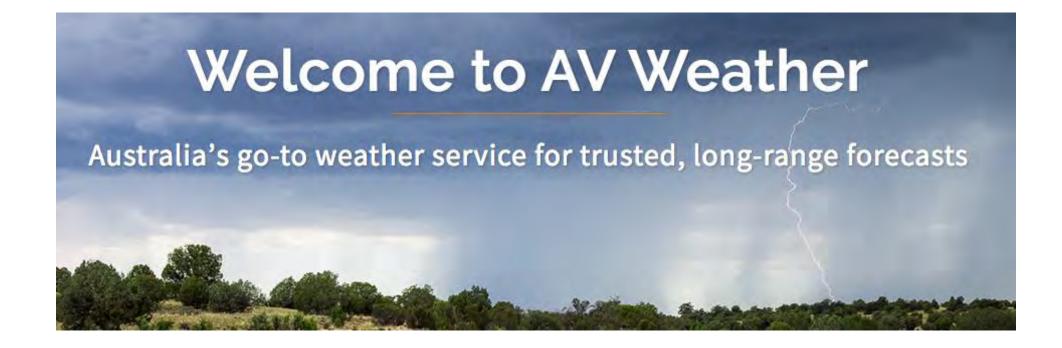


#### Agronomists have a major influence over grower change decisions

#### Level of Influence of Sources in Motivating Change On-Farm in Last Two Years



#### Weather forecasting



#### New priorities after modelling

- 1. Number 1: If measurement of profit increases the probability of achieving 8% ROAM
- 2. Number 2: Rotation selection aiming for high value pulse intensification
- 3. Number 4: Skill of an adviser
- 4. Number 8: Timeliness of Pesticide Legislation
- 5. Number 10: Growers not being able to predict pest and disease
- 6. Number 9: Improvements in the confidence of weather forecasting
- 7. Number 7: Robotic weeder
- 8. Number 5: Efficacy of glyphosate
- 9. Number 3: No-till cropping farms no livestock infrastructure
- 10. Number 6: Variability of seed supply in Canola

#### What makes successful research?

- Focus on profit
- Modelling
- Adoption advisors extension throughout the project farmers don't read academic papers
- Capacity building
- Stands the test of time regurgitate and train
- Investments matched to a strategic plan
- Manager ability to translate intent on investments researcher interpretation
- Clear relative advantage to consumer (farmer)

#### What leads to waste or failure?

- Loss of corporate knowledge
- Silo's what are others doing?
- Issue identification and rigour id the research question
- Timeframes 3 year investments
- Organisational culture (egos and empires!)
- Scientists in management roles?
- Too big too much process/ too much/ too little accountability
- Too little process/ accountabtility
- Group think attitudes ( eg organics)

#### IP issues in public/ private research

- Invariably delays technology adoption
- Income stream
- What business are you in?

#### Peer review of research proposals

- Researchers often shut out of next phase development because of probity/ COI
- Research managers could benefits from a wider team beyond the research proposal - (agros, farmers, researchers)

#### Collaboration or competition?

- Competition healthy
- Collaboration possible with transparent process –Who gets the management money? reputations, kudos, egos, attribution

#### Comparison of models/ scales

- SAGIT \$1.5mill
- GRDC \$200mill

#### SO.....

- How does your research impact my bottom line?
- Profit financial literacy
- People -great researchers and advisors
- Extension

Lets start some robust discussion!

#### State-of-the-art in genetic resources

## Making science useful to agriculture November 2018

Peter Langridge

Wheat Initiative, Julius-Kuhn Institute, German Ministry for Food and Agriculture, Berlin School of Agriculture, Food and Wine, University of Adelaide

#### Reductionism and Black boxes

- Statistics
- Physiological breeding
- QTL mapping
- Genomics
- Phenomics
- Genomic selection
- Machine learning and Al



#### Breeders' equation

Rate of genetic gain =

Extent of diversity x Population size x Heritability

Breeding cycle

#### Population size

- Mechanization
- Advanced phenotyping techniques
- Predicting performance early versus late selection

### Trait heritability - Intensity of selection

- Biometrics and field design
- Scale of line evaluation
- Accuracy of phenotyping



#### Phenotyping

## Increasing heritability Population size

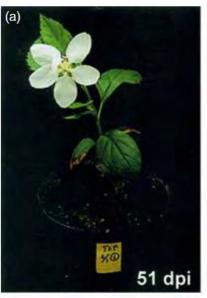
- Fixed environment
- Detailed environment monitoring
- Precision Phenotyping
- Statistical analysis
  - Prediction of performance
  - Spatial analysis
  - Fixed genetic effects





#### Duration of the breeding cycle

- Double haploidy
- Rapid cycling techniques
- Genomic selection
- Predictive phenotyping early generation screening

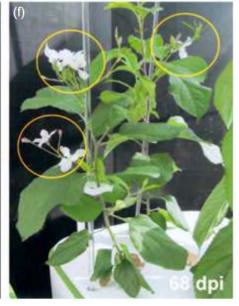












# Early flowering apples

- 5-12 years juvenile phase
- Use of latent virus to overexpress AtFT and silence MdTFL1-1
- Flowering starts in 1.5 to 3 months

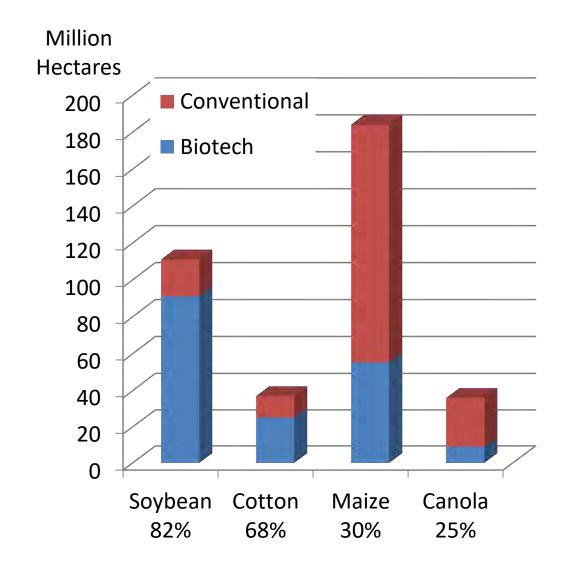
N Yamagishi, R Kishigami and N Yoshikawa. Plant Biotechnology Journal (2014) 12, pp. 60–68

#### Diversity in the breeding program

- Efficient use of genetic resources
- Generating novel variation
  - Mutagenesis
  - Gene editing
  - Genetic engineering
- Accessing genomic regions
- Exploiting heterosis hybrids and apomixis

#### The major GM crops





## What's out there?

Traits	Events	Crops
<b>Drought tolerance</b>	7	Maize, Sugarcane
Yield	2	Soybean
Disease resistance	24	Phaseolus, Papaya, Plum, Potato, Squash, Sweet pepper, Tomato
Herbicide resistance	218	Alfalfa, Canola, Carnation, Chicory, Cotton, Bentgrass, Flax, Maize, Potato, Rice, Soybean, Sugar beet, Tobacco, Wheat
Insect resistance	184	Cotton, Eggplant, Maize, Poplar, Potato, Rice, Soybean, Tomato
Quality	62	Alfalfa, Canola, Carnation, Maize, Melon, Petunia, Potato, Rice, Rose, Soybean, Tomato
Fertility control	23	Canola, Chicory, Maize

# Regulation

- Costs and complexity of evaluation
- Widespread confusion and unease
- Complex & time consuming regulatory process
- International regulations
  - High Regulatory costs
- Keeping up with technology



## New Plant Breeding Techniques

A range of techniques which rely on gene technology but where the end products **may not** be transgenic.

- Facilitated breeding final food producing line is nontransgenic
- Grafting of transgenic with non-transgenic plants foods derived from the non-transgenic part
- Cisgenesis/intragenesis gene technology used to introduce genetic material from the same or cross compatible species
- Gene technology used as a tool for mutagenesis –
   Genome editing





# Complex adaptive traits

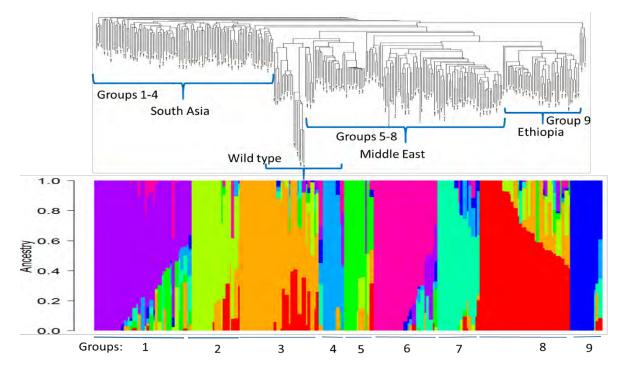
- Breeders select for adaptation to target environmental conditions
  - Broad versus narrow environment
  - Ability to cope with abnormal conditions
- Components of the stress response
  - Individual stresses
  - Physiological breeding
- Integrated response
  - Yield under different environmental conditions
  - Yield stability



# Germplasm collections

7 million accessions in 1750 genebanks

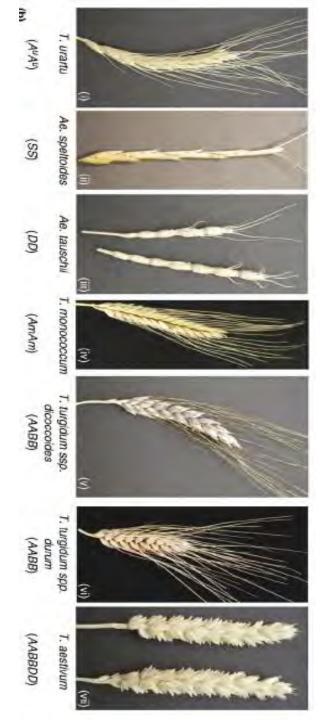
- Capturing value
  - Single major genes
  - Additive QTL



#### Wheat wild relatives in world collections

	Genome	CIMMYT	World	Utilized
Triticum dicoccum	AABB	779	??	24
Triticum dicoccoides	AABB	880	1390	3
Triticum timopheevii	AAGG	280	640	2
Triticum monococcum	AA	880	1520	120
Triticum urartu	AA	392	516	21
Aegilops speltoides	(~BB) SS	140	540	34
Aegilops bicornis	(~BB) SbSb	14	28	0
Aegilops longissima	(~BB) S <sup>I</sup> S <sup>I</sup>	10	59	2
Aegilops tauschii	DD	400~600	1144	400
Totals		>3,775	>6,616	606

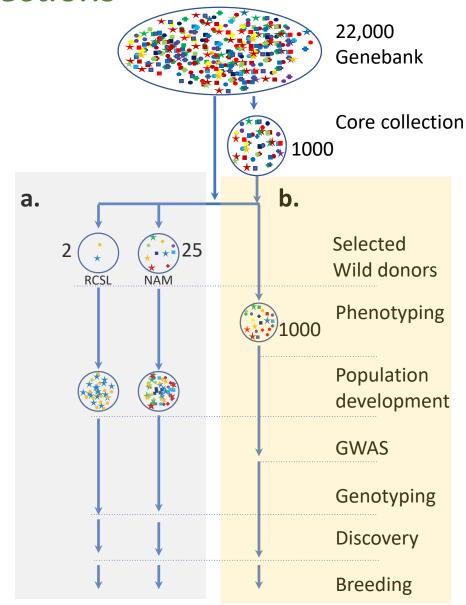
The world collection was estimated by Konopka & Valkoun, ICARDA



Revealing the potential of germplasm collections

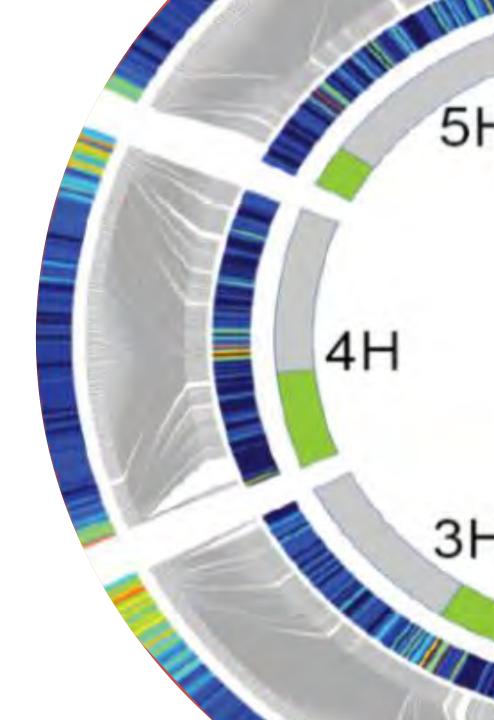
Milner, S et al. Nature Genetics (2018)

- Simplified global genetic analyses
- Identified duplicates
- Geographical structure
- Likely mix-ups

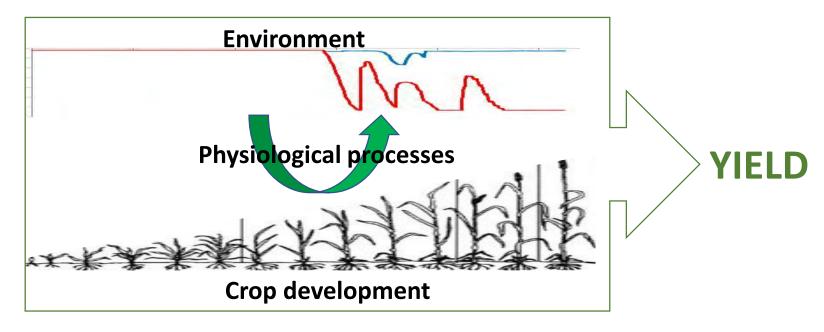


### Problems

- Which accessions?
- Screening un-adapted germplasm
  - Simple traits
  - Clear phenotype
  - Focussed Identification of Germplasm Strategy (FIGS)
- The 'cost of domestication' weakly deleterious alleles
- Low recombination rate
  - 60-80% of each chromosome rarely (if ever) recombines



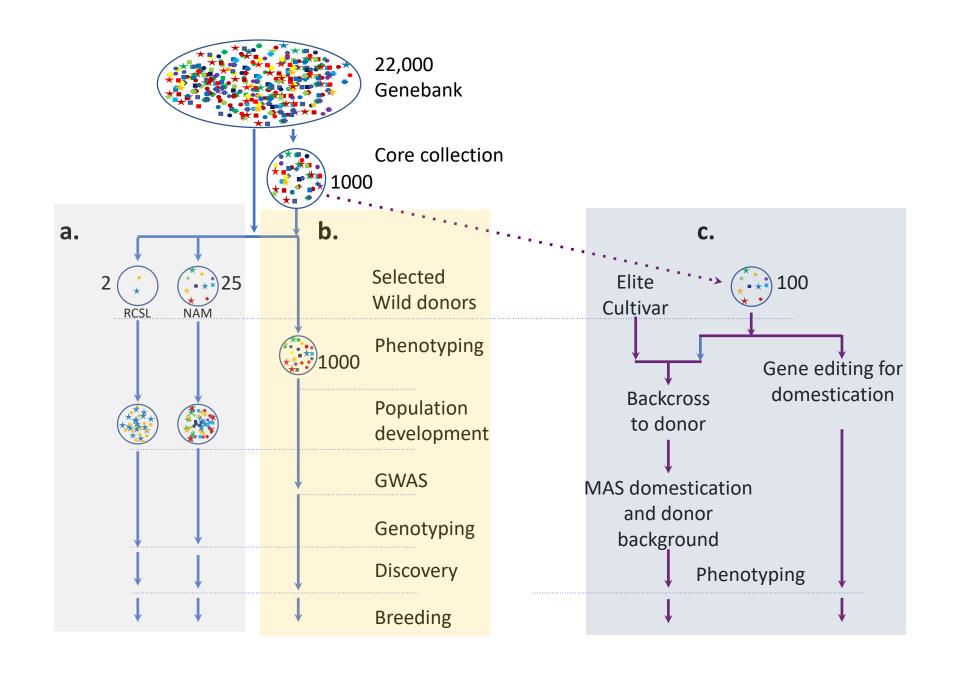
#### Assessing yield under stress



Yield is the **integration** of all physiological processes over time under a fluctuating environment

Multiple stresses and interactions

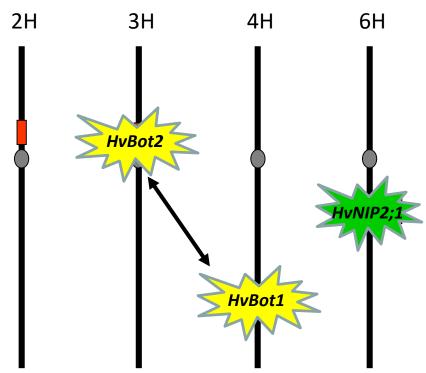
genotype / environment (GE) interactions



# B-tolerance QTL cloning

#### **Barley**

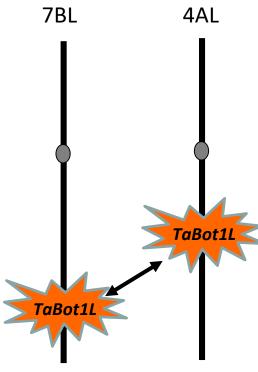
Tolerance source: Sahara 3771, CM72



Jefferies et al., 1999 TAG Sutton *et al*. 2007 Science Schnurbusch *et al*. 2010 Plant Physiol.

#### Wheat

Tolerance source: Halberd, G61450 and others



Jefferies et al., 2000, TAG Schnurbusch et al. 2007. *TAG Pallotta et al 2014, Nature* 

## Agronomy – redefining breeding priorities

- Breeding strategies that consider cropping history
- Linking agronomic and genetic approaches to managing pests and diseases

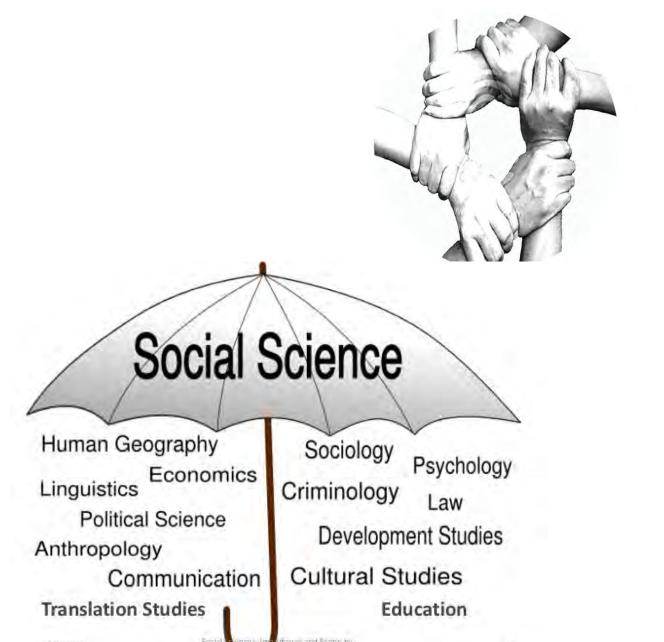
AGRONOMY FEEDS THE WORLD!

- Managing abiotic stresses
- Crop modelling



#### Social sciences

- Technology adoption
- Communication
- Research support
- Diversity and equity
- Access and sharing



# Technology adoption

- Integration
  - into the cropping system agronomy, crop rotations
  - into the broad environment
- Technology transfer between species and crops minor crops
- Adoption by poorly resourced breeding programs
  - Capabilities and capacity
- Adoption by farmers
  - Must be the "full package"
- Regulation and acceptance by consumers/governments
- PVR and patents

#### Reductionism and Black boxes

A lot has ben spent on work that has not resulted in outcomes for farmers

This does not mean we haven't haven't profited from the work or learnt important lessons





# The importance of context in plant biology

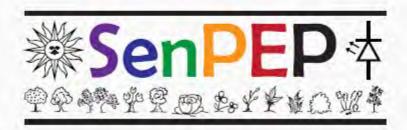
A possible framework for its analysis

Pedro J. Aphalo

Adelaide, 27 November 2018

Organismal and Evolutionary Biology Research Programme and

Viikki Plant Science Center, University of Helsinki



#### ©2016–2018 by Pedro J. Aphalo

Organismal and Evolutionary Biology Research Programme, University of Helsinki, Finland.

http://blogs.helsinki.fi/senpep-blog/

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# Background

## An evolutionary viewpoint

- · Focus of my presentation: sensory capabilities of plants and fitness.
- · Fitness represents an ultimate cause (a why question).
- Physiological and/or molecular mechanisms are proximate causes (how questions).
- In animal ecology sensory ecology is an important discipline.
- In the case of plants this approach has been rarely used...
- ...based on the assumption that information processing is very limited in plants.
- Recent evidence shows this assumption is wrong.

## Forecasting: its relation to fitness

- · Our everyday life depends on forecasting.
- Sometimes we do this consciously, but most of the time we are not aware of what our brain is doing.
- This becomes evident if when lifting a cup of tea we misjudge how full it is...
- I will use information as abstraction, and ask you to ignore how it is processed...
- ...and accept that every organism's fitness can benefit from "forecasting" important future events.
- The mechanism does not matter, as long as information is acquired, transmitted, stored and combined successfully.
- The role of "future perception" for fitness of plants is considered important by ecologists (e.g. Novoplansky 2016).

#### Vocabulary: information as an abstraction

- · A technological example is radio broadcasting vs. internet-"radio"...
- ...same information and a different carrier.
- First a signal (or cue) needs to be sensed or perceived.
- To extract information a signal or cue must be decoded.
- A signal or cue may carry useful information or not...
- · ...if it does not carry information that we can decode we call it "noise".
- Memory is the storage of information.
- Processing is the combination of different bits of information.
- Communication is the exchange of information (there is an emitter and a receiver).

### Can plants forecast? Preemptive acclimation

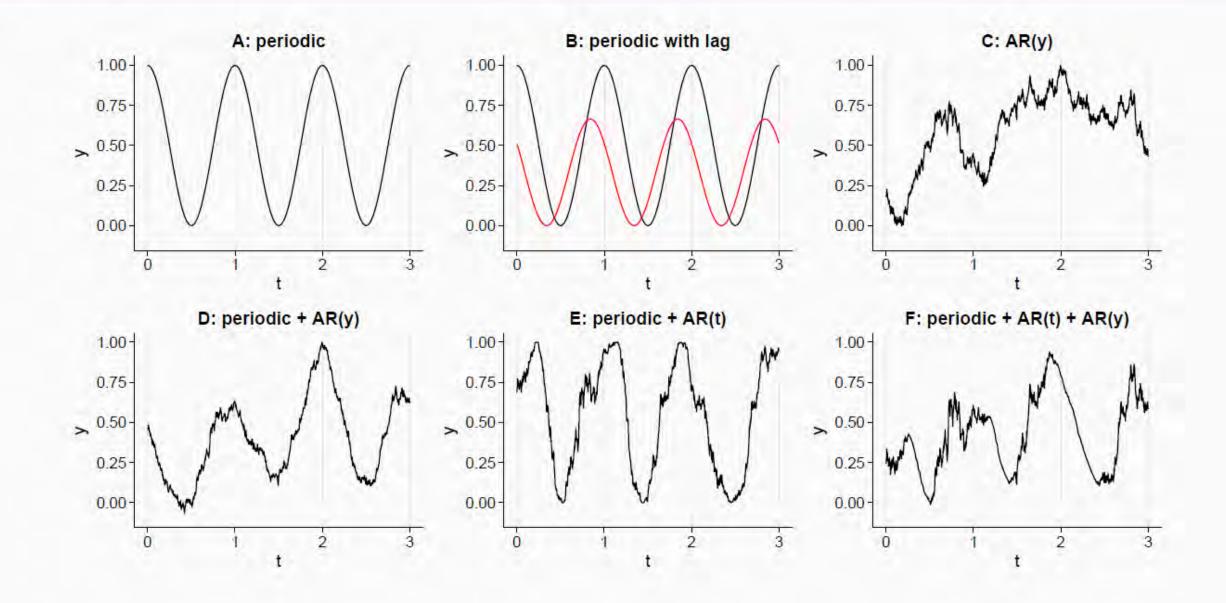
- Several plant responses from evolutive/fitness perspective consist in 'preparation' for future events, either favourable or stressful.
  - Example 1: Timing of phenology.
  - Example 2: Preemptive shade avoidance in response to reflected far-red light from neighbouring plants.
  - Example 3: Eavesdropping-on/communicating-with neighbours to preemptively acclimate/prepare for...
    - ...drought, herbivore attacks, even to synchronize flowering.
  - Example 4: Possibly (a hypothesis) preemptive acclimation to future soil drying triggered by ultraviolet-B exposure.

# Why sensory ecology?

#### My view on the role of information

- 1. Information sources are crucial to the fitness of organims...
- ...⇒ correlations among variables in their environment are key sources of information
- 3. ...⇒ we need to pay more attention to 'joint statistical properties of environmental variables'...
- 4. and on how sensory and signalling mechanisms have been "tuned" by evolution to decode information.

#### Correlations in the environment



### Forecasting

- 1. Lagged cross-correlations and autocorrelations make it possible short-term forecasting of non-deterministic variation.
- 2. Organisms can generate "correlated variables" through the emission of signals that propagate faster than the event they have perceived.
- 3. e.g. emission of volatile organic compounds in response to insect herbivory.
- 4. e.g. release of ABA to the shared soil volume with drought or salinity.
- 5. e.g. unknown signal in the soil inducing synchronization of flowering.
- 6. **Constraint:** to persist during evolution signals must benefit the emitter!!

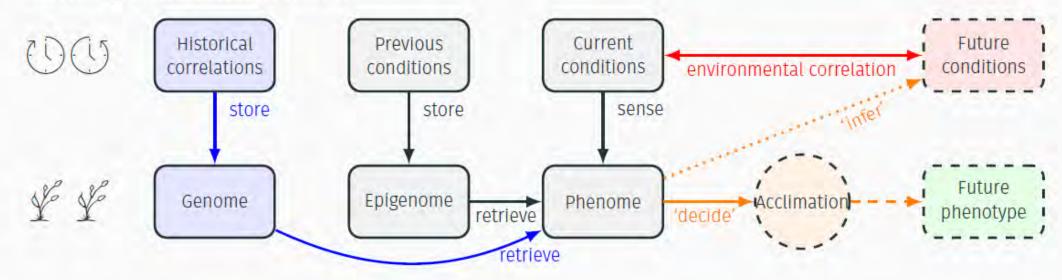
# A possible framework

## Models (added after Monday's discussions)

- I see models as tools that can guide research more than as end products.
- They help with the integration of knowledge and logical validation of hypotheses.
- They are useful for communication of ideas.
- The objective for which a model is designed determines what complexity is left out.
- Generality is obtained by ignoring details specific to individual systems.
- Abstract conceptual models can be useful for the formulation of testable hypothesis.

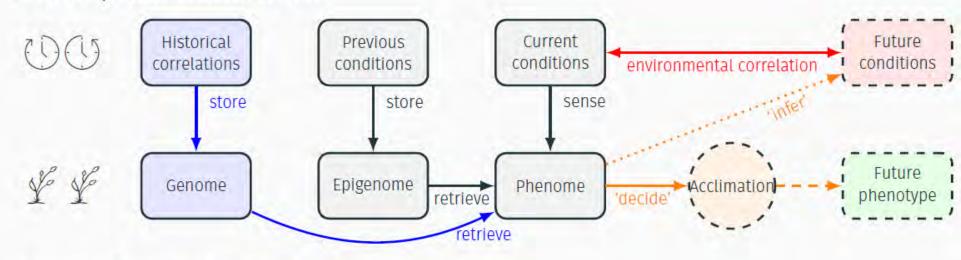
#### Proposed theoretical framework (I)

#### Conceptual framework

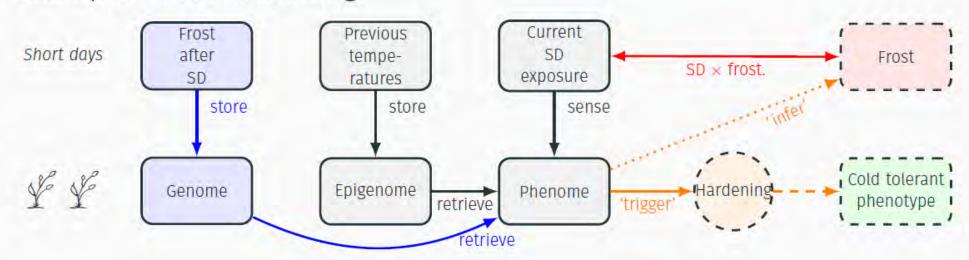


#### Proposed theoretical framework (I)

#### Conceptual framework

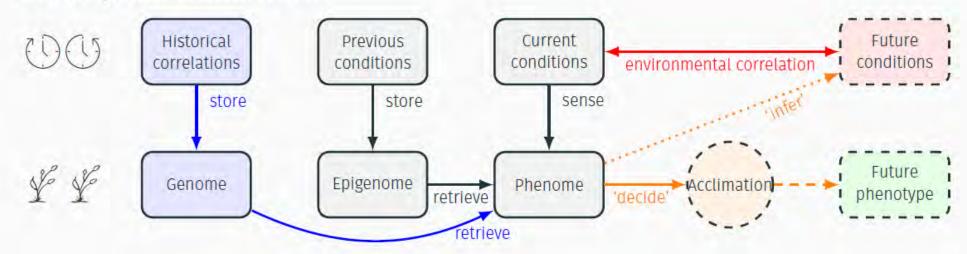


#### Example: Frost hardening

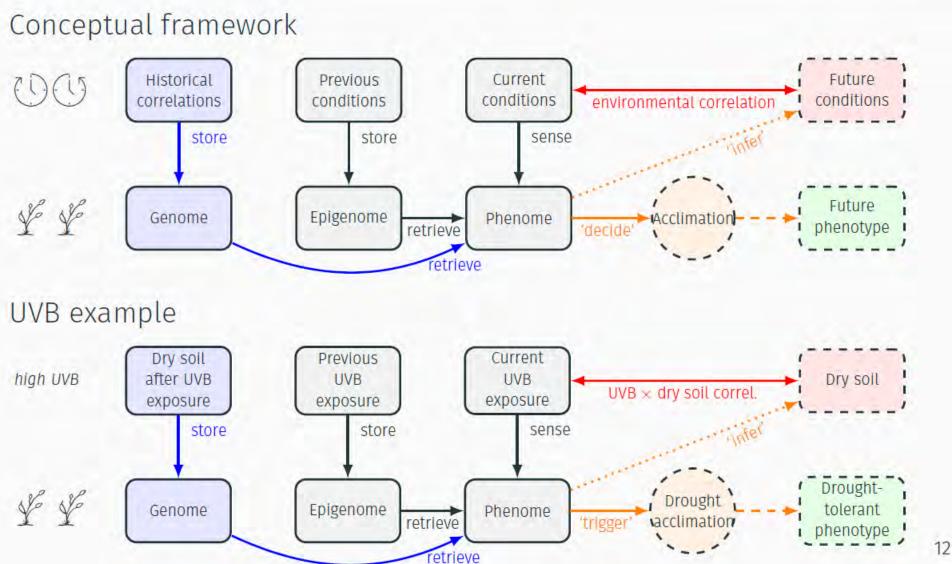


#### Proposed theoretical framework (II)

#### Conceptual framework



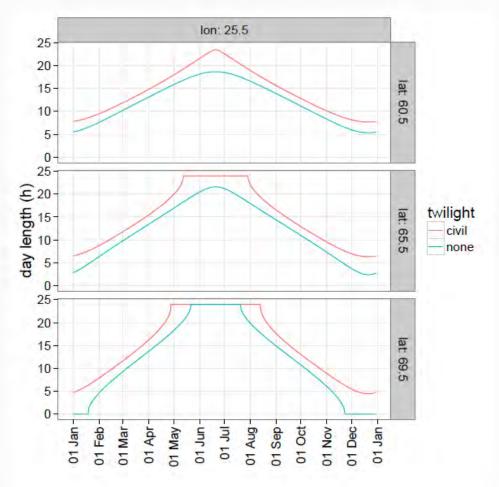
#### Proposed theoretical framework (II)



# Some familiar variables

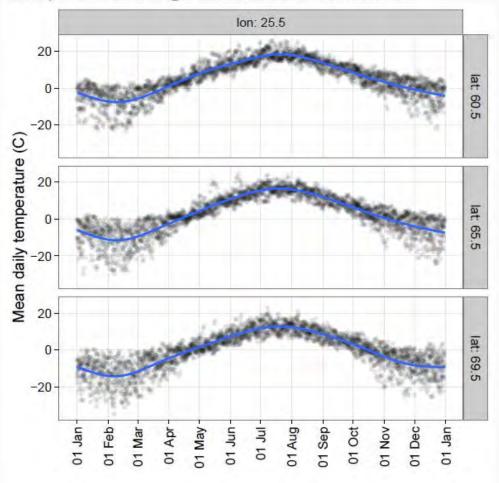
#### Day length and twilight

Almost deterministic at each of three latitudes in Finland = reliable source of information.

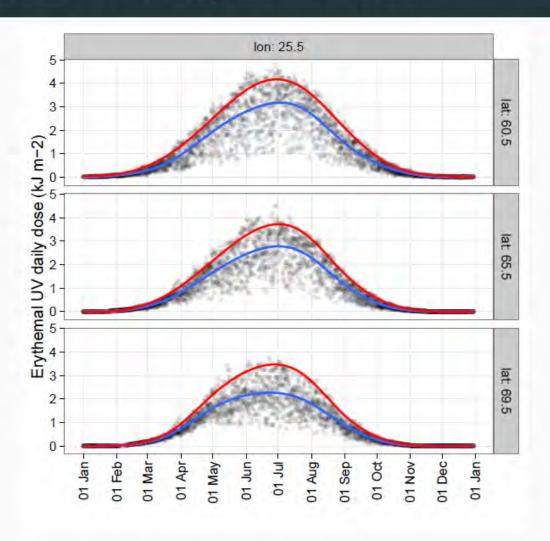


#### Temperature and its variability: 2004–2014

Large day to day variation at different latitudes (three grid points in Finland) = reliable only if averaged/accumulated.



#### UV radiation and its variability: 2004-2014



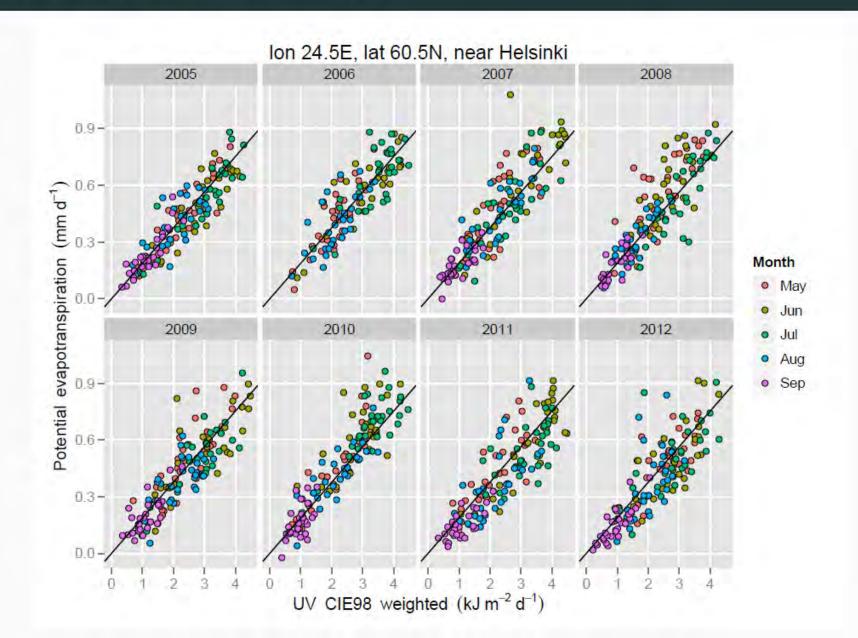
(P. J. Aphalo, A. Lindfors, unpublished)

# Preemptive acclimation to drought: available cues

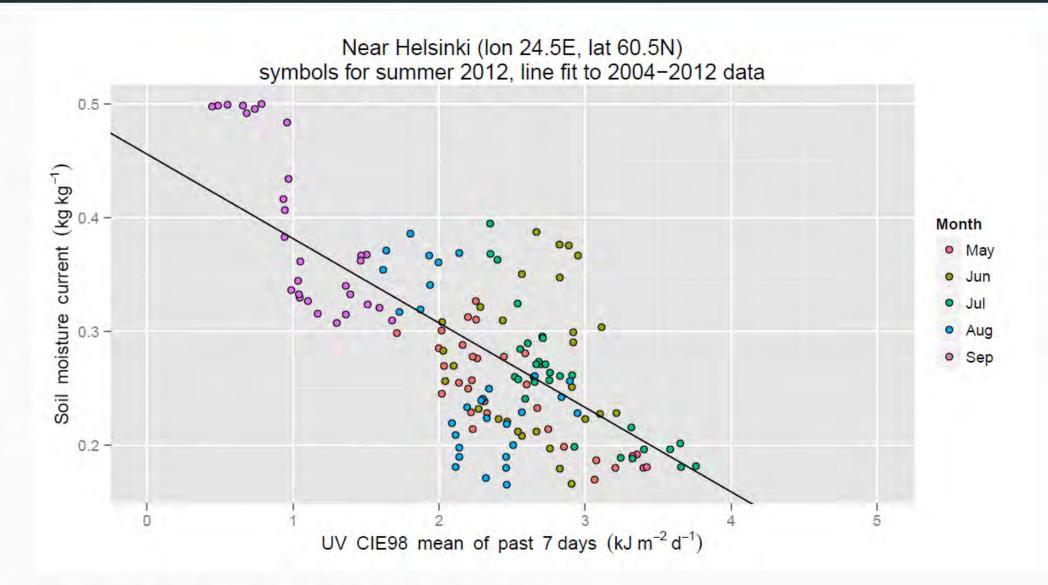
#### Soil water content as a cue

- · Plant roots can perceive dry soil (e.g. split root-system experiments) ...
- but, does this provide early-enough information for preemptive acclimation?
- Exposure to UV radiation can enhance drought tolerance...
- Could exposure to UV radiation be an additional source of information?

#### PET-UV correlation? Yes



#### Soil water-UV correlation? Yes



# Preemptive acclimation to drought: possible mechanism

#### Responses to growth under UV radiation

- Smaller and thicker leaves
- Increased reflectance of leaves
- Slower opening of stomata when illuminated
- Compact growth habit
- · Inhibition of shade avoidance responses driven by R:FR ratio
- Expression of genes related to "water deprivation"...
- ...aquaporins, proline synthesis, ABA signalling, stomatal responses to ABA

#### Signalling networks

- Gene expression responses are interconnected and multiple interactions involved
- · leading to very complex regulation.
- · We can mostly get snapshots into a dynamic system
- · The examples in the previous slide are convincing...
- · ...but cherry-picked from a long list of genes
- · Drought on the other hand triggers the expression of genes...
- · ...involved in light signalling (e.g. HY5)

# Drought acclimation under UVB: possible implications

#### Take home message from our research on UV

If our hypothesis holds, there would be much to rethink:

- reduced growth under UV-B exposure could improve fitness instead of being deleterious,
- phenotyping for drought tolerance of dryland crops in the absence of UV-B could lead to suboptimal progress,
- what should we do with field crops under irrigation: do we need to breed out some of the UVB responses?,
- what about rain shelter experiments: should we supplement with UVB when it is cloudy or raining?
- what about climate change: should we acknowledge that changes in rainfall will correlate with changes in UVB due to cloud cover?

#### A caveat

- The model is mainly dealing with "normal business", events that take place frequently.
- · But wild plants species have been exposed infrequent extreme events.
- These events have also shaped current genotypes, so we may need to also consider risk analysis when analysing the use of information by wild plants.
- Survival through very infrequent extreme events is less important for crops.

#### How does this affect usefulness of research

- Direct short-term usefulness of research depends on use of a realistic context and tends to be problem based.
- Indirect long-term usefulness is less predictable, can be curiosity driven or based on a theoretical question.
- Both approaches are needed and how much funding is assigned to each type of research depends on policy.
- Proposals of each "kind" need different approaches to evaluation, to ensure that policy is realized.
- The first approach to research is a "productive" activity.
- The second approach to research is a "cultural" activity.
- (Loosely based on ideas in Mario Bunge's (1984) Ciencia y desarrollo.)

### Acknowledgements



Members of my research group: Sari Siipola, Fang Wang, Neha Rai, Yan Yan, Cyntia Ayala.

Current collaborators: Luis O. Morales, T. Matthew Robson, Anders Lindfors, Víctor Sadras, Jorge J. Casal, Saara Hartikainen, David Israel, Mikael Brosché, Tarja Lehto, Åke Strid, Gareth Jenkins, Andreas Albert, Fred Stoddard



An umbrella organization at our campus.



My employer.



For funding, decisions 252548, 16775.

OECD for funding allowing me to participate in this meeting.

#### References



Novoplansky, A. (2016). "Future Perception in Plants". In: *Anticipation Across Disciplines*. Springer, pp. 57–70.

#### Vocabulary: other terms

- · "Plant neurobiology".
- · "Plant intelligence".
- In my view they are not useful.
- They are not abstract enough.
- · They have an everyday meaning that is at odds with the proposed use.
- · They distract us from the actual phenomena under study.

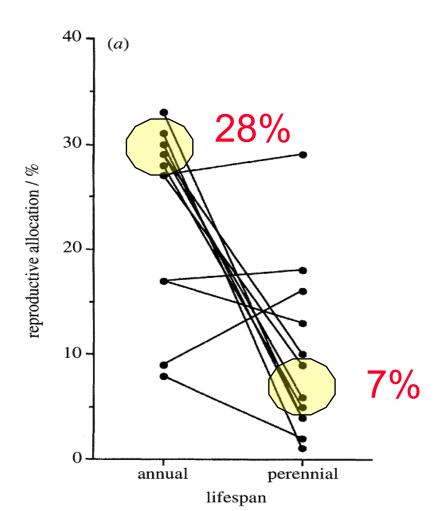
# **Evolutionary Tradeoffs as**Constraints and Opportunities

R. Ford Denison University of Minnesota



# Harvest index versus perenniality

Silvertown & Dodd, 1996



### Tradeoffs as opportunities

- Past versus present conditions
- Individual versus community
- Symbiont versus host fitness
- Current versus future crops

#### Darwin was inspired by plant breeders...



Wild Brassica (Lorenzo Maggioni)



Kale (Rasbak)



Brussels sprouts (Jamain)



Kohlrabi (Rasbak)

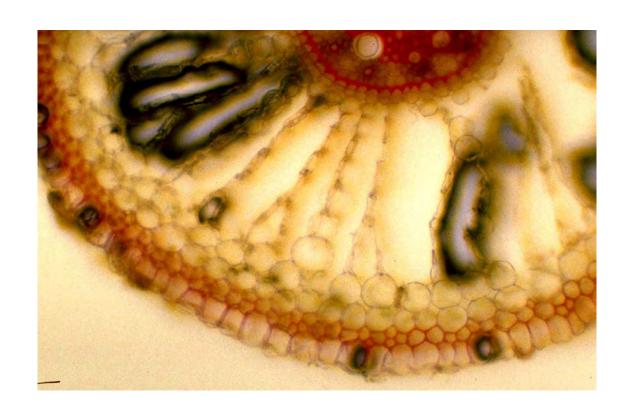


Sicilian Broccoli (Thomas Bjorkman)

# "Natural selection is as superior to man's feeble efforts as nature is to art."

- Charles Darwin

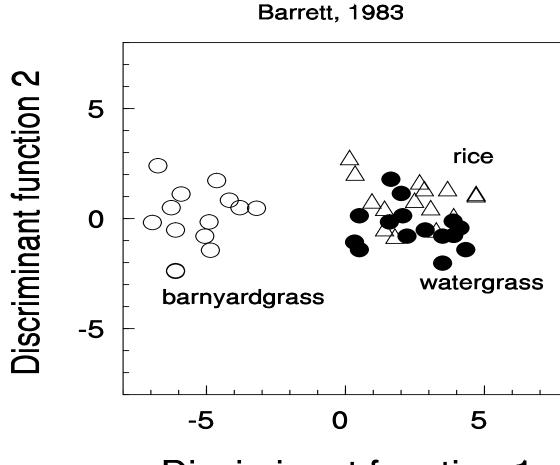
## Flood-tolerant Echinochloa "watergrass" evolved from barnyardgrass in only a few thousand years.





barnyardgrass "watergrass" rice

**Barrett** (1983)

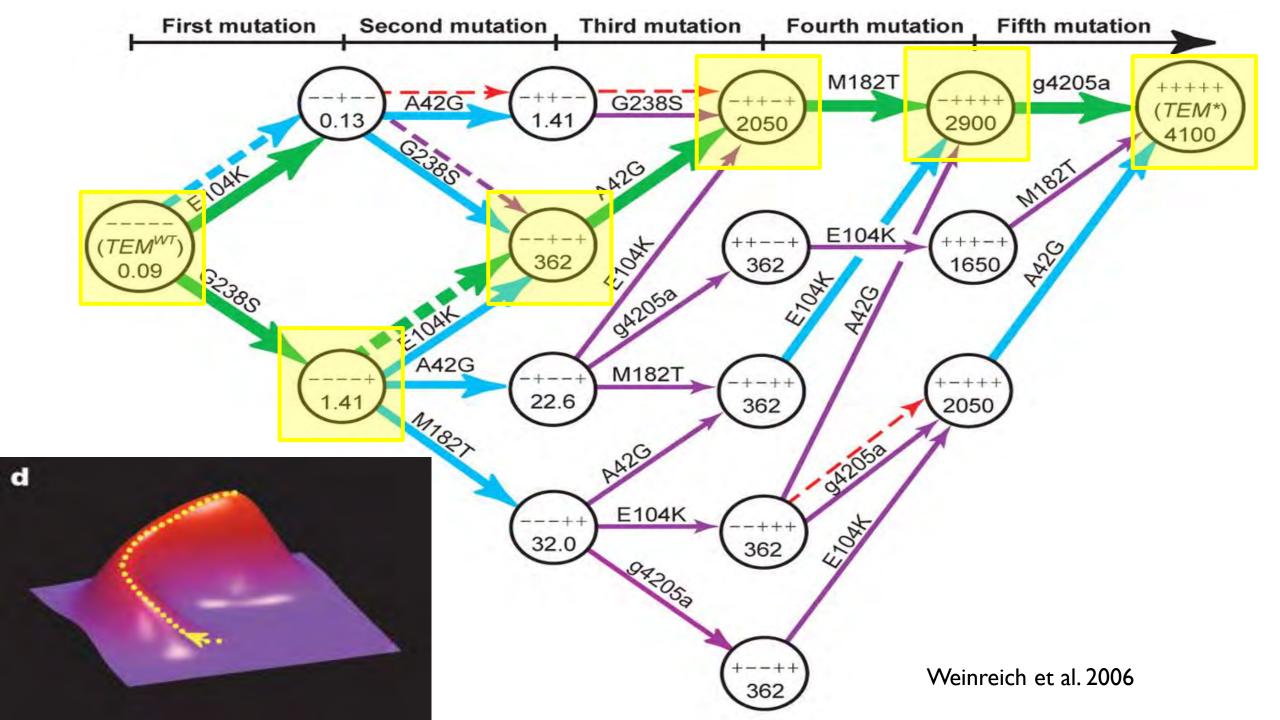


Disciminant function 1

# Given millions of years, what improvements did natural selection miss?

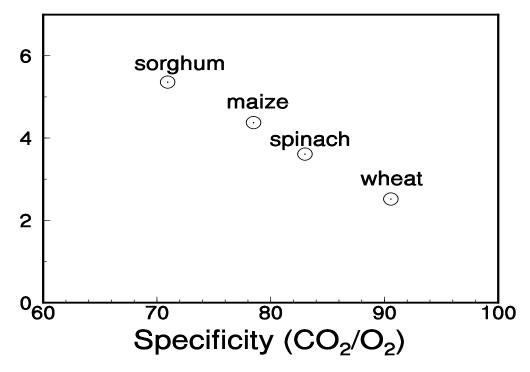
### Hypothesis

- ☐ Past natural selection has **not** missed simple, tradeoff-free improvements to the fitness of crop ancestors.
  - Simple: phenotype arose repeatedly
  - Tradeoff-free: never reduced fitness

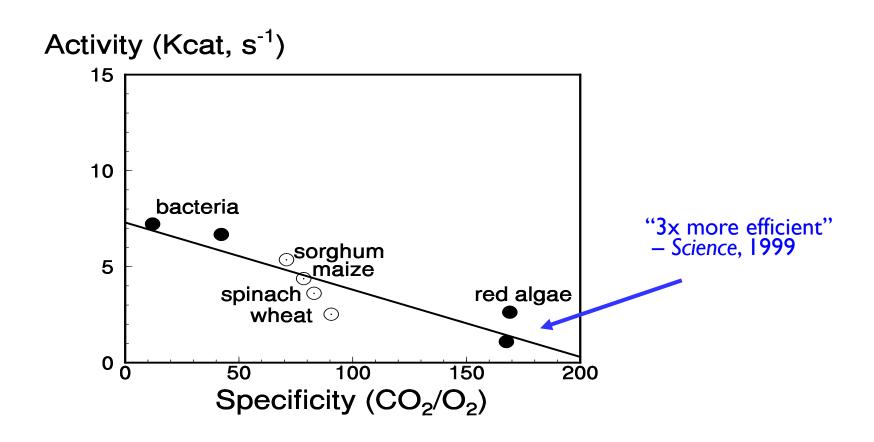


### Rubisco activity vs. CO<sub>2</sub>-specificity



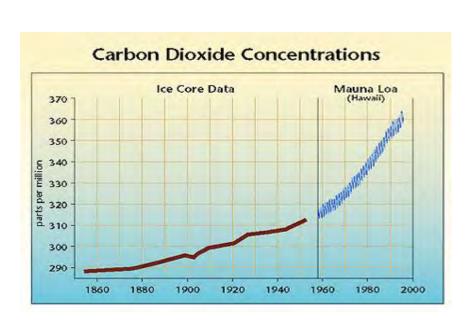


### Transfer red-algal rubisco to crops?



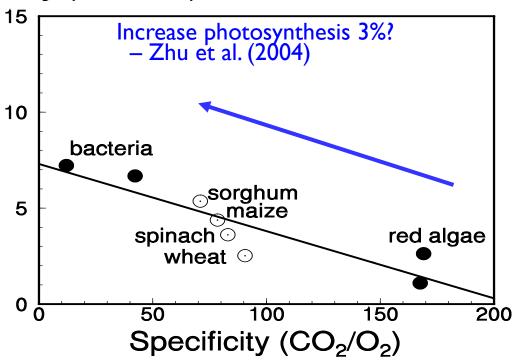
### Tradeoffs as opportunities

- Past versus present conditions
- Individual versus community
- Symbiont versus host fitness
- Current versus future crops

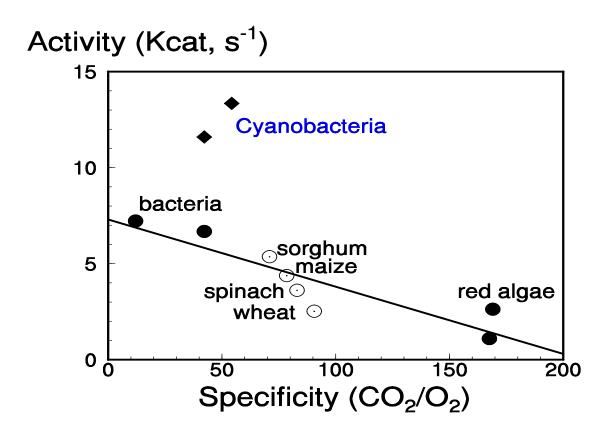


# Given rising CO<sub>2</sub>, specificity is less important

Activity (Kcat, s<sup>-1</sup>)



### Non-simple innovations?



### Tradeoffs as opportunities

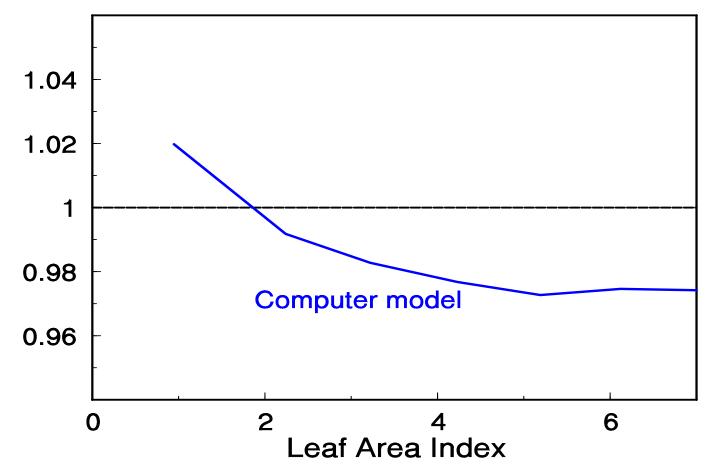
- Past versus present conditions
- Individual versus community
- Symbiont versus host fitness
- Current versus future crops





### Less photosynthesis w/ tracking?

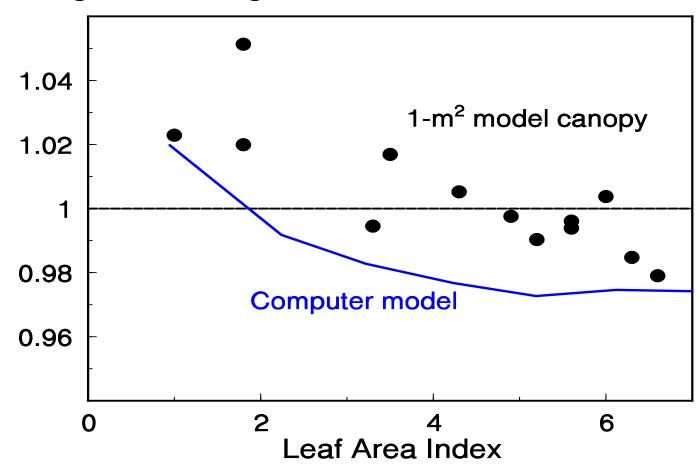




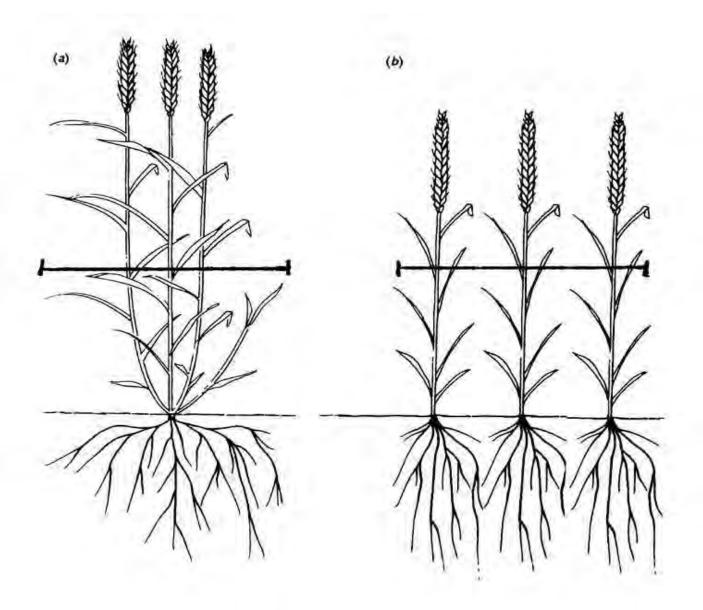


# Solar tracking may decrease photosynthesis at high LAI

Tracking:Nontracking



### Donald's "cooperative ideotype"

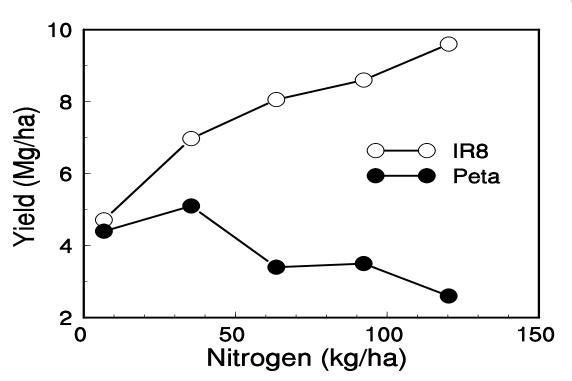


- Sample traits:
  - » Short
  - » Erect leaf

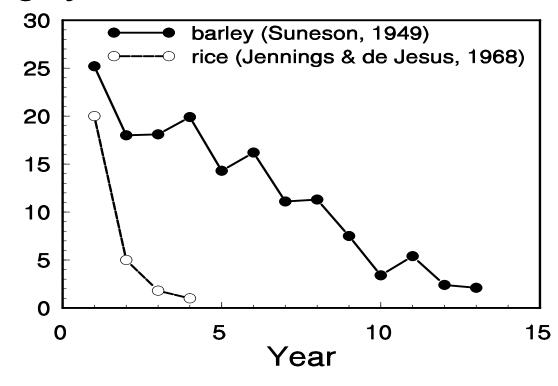
Donald, 1968 Jennings, 1964



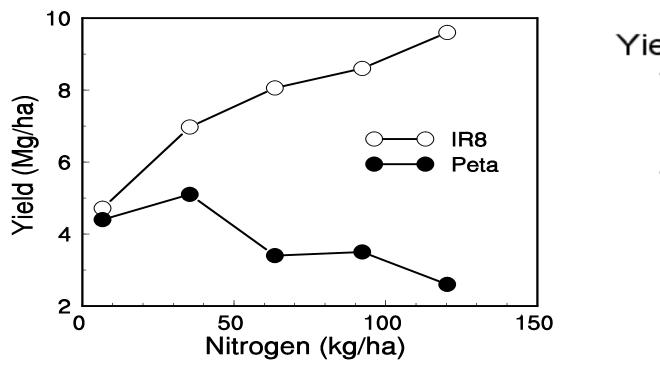
# Higher-yield genotypes were less competitive.

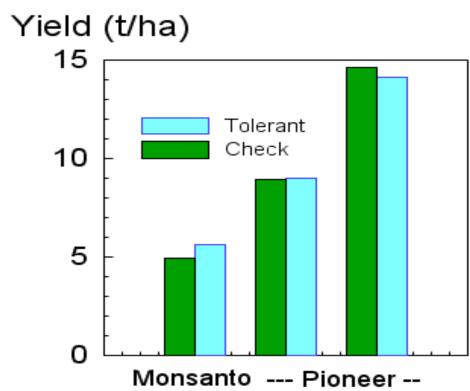


% High-yield cultivar



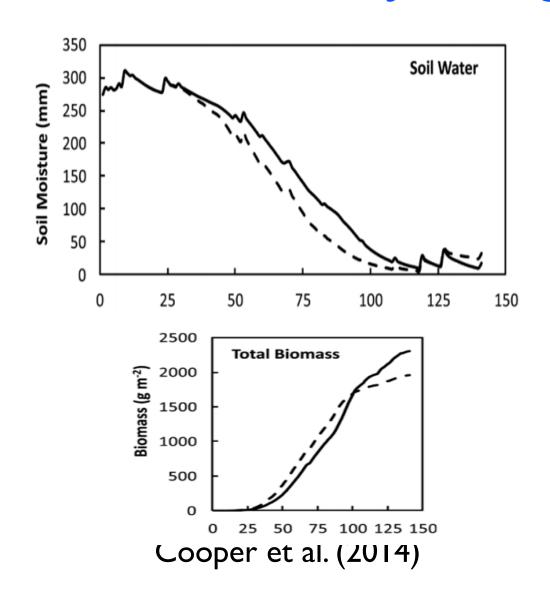
## Green-Revolution yield increases dwarf recent gains from "drought tolerance"

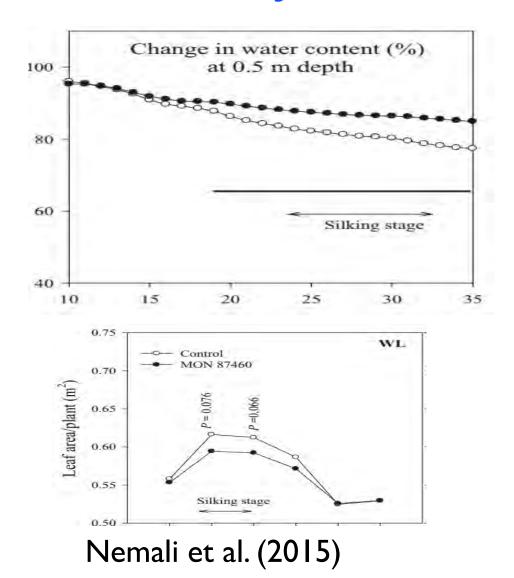




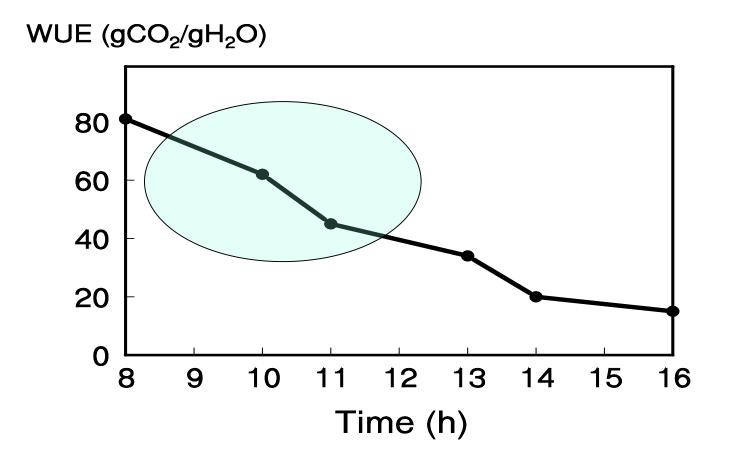
De Datta, 1988; Castiglioni et al., 2008; Roth et al., 2013

# "Drought-tolerant maize saves soil water by using less of it early...



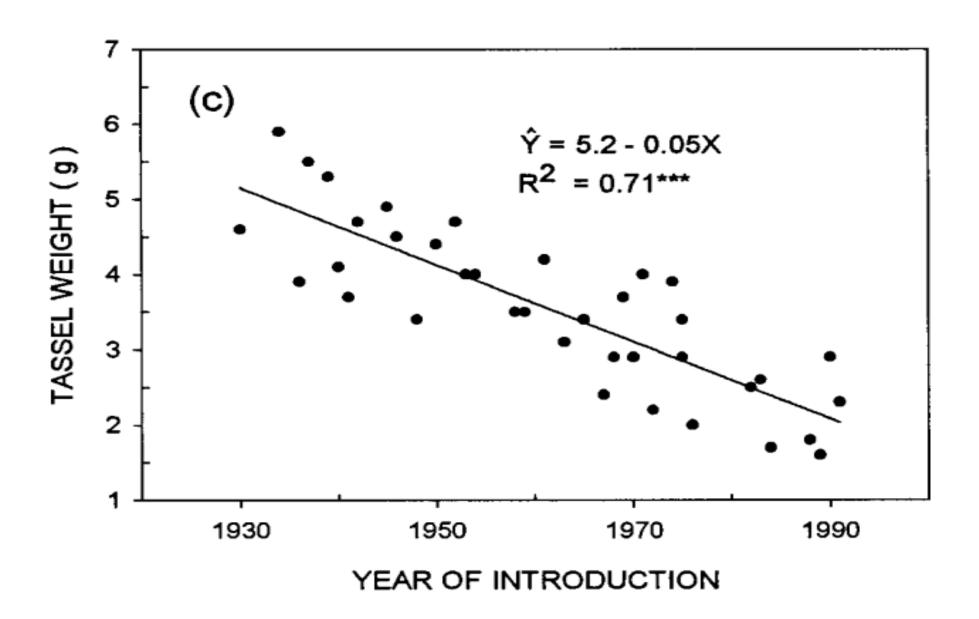


## Open stomata only when WUE high?

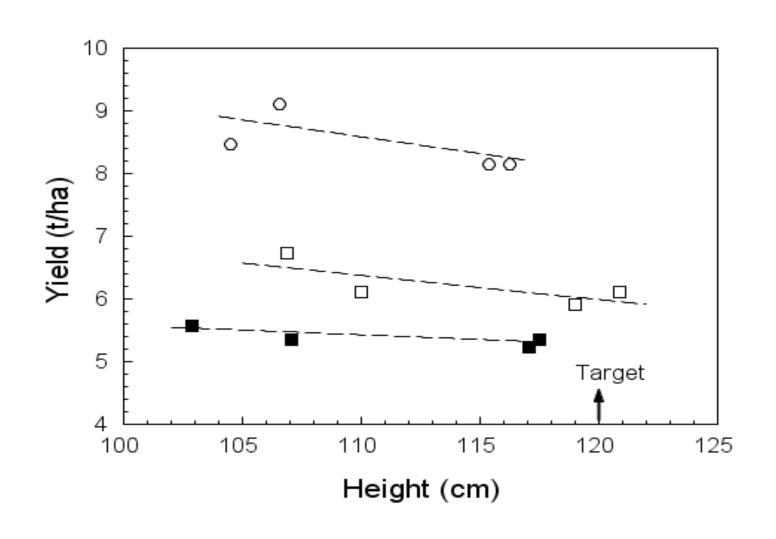








## "Ideotype" versus yield

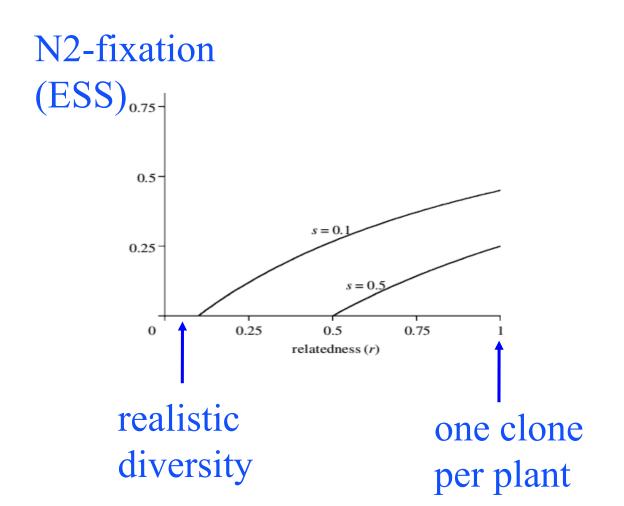


### Tradeoffs as opportunities

- Past versus present conditions
- Individual versus community
- Symbiont versus host fitness
- Current versus future crops



# Multiple symbionts per plant can create a tragedy of the commons...



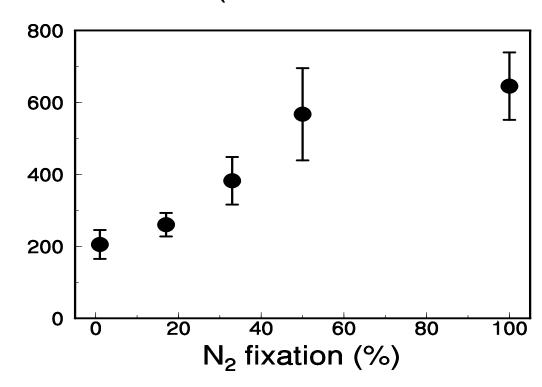
West et al. 2002





## Although legumes "punish" the worst nodules...

#### Rhizobia/nodule (10<sup>6)</sup>

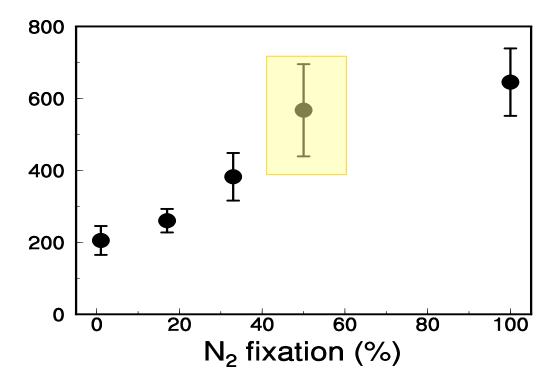




Kiers et al., 2003, 2006, Oono et al., 2011

## ...stricter sanctions might reduce abundance of "mediocre" rhizobia.

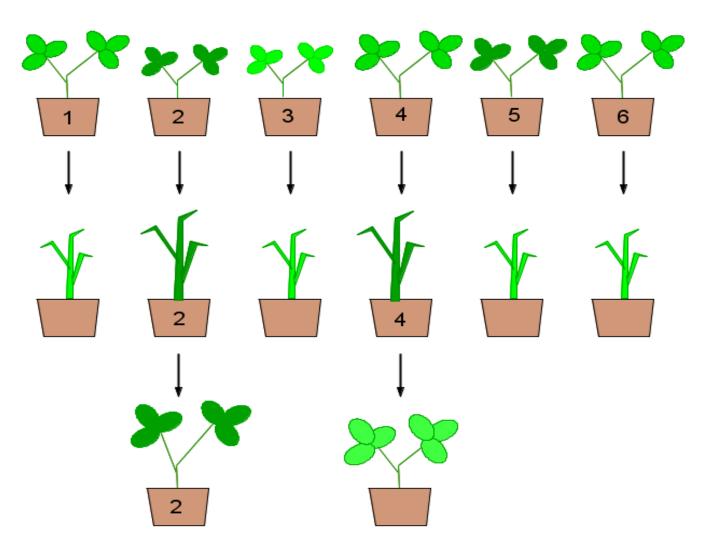
Rhizobia/nodule (10<sup>6)</sup>



### Tradeoffs as opportunities

- Past versus present conditions
- Individual versus community
- Symbiont versus host fitness
- Current versus future crops

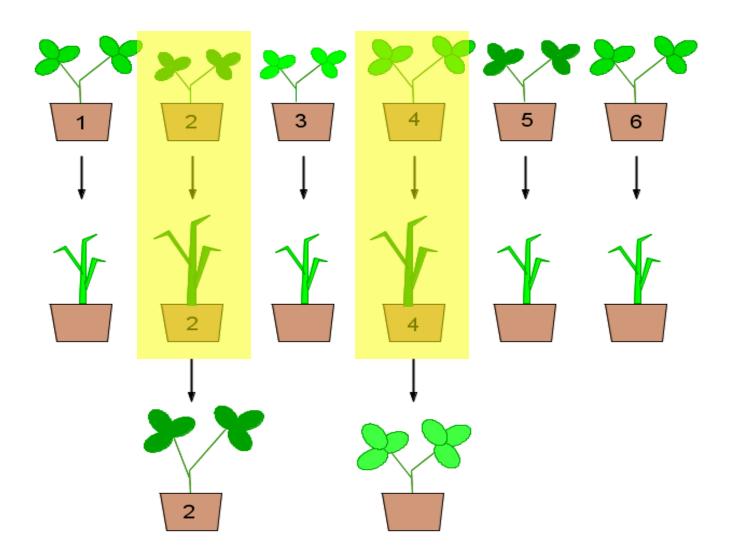
### Select for benefits to future crops



Diverse soybean pop'n selected for future benefits to...

... "test" maize (one genotype)

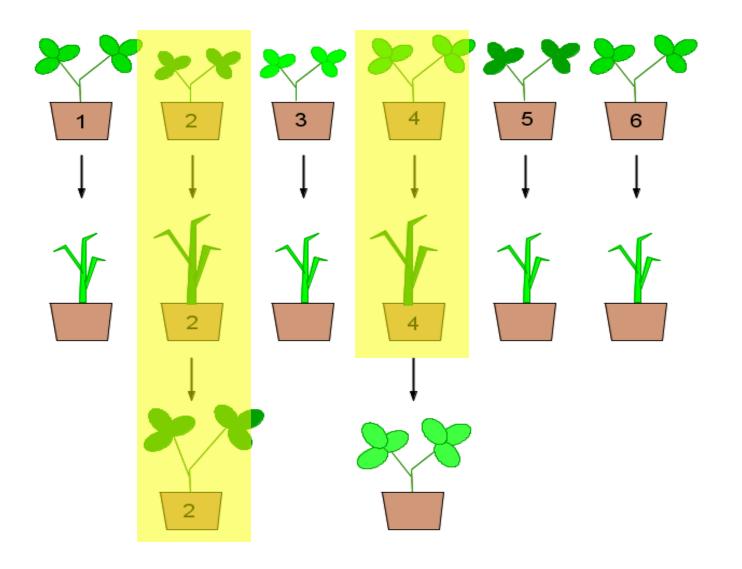
... "test" soybean (one genotype)



Diverse soybean pop'n selected for future benefits to...

... "test" maize (one genotype)

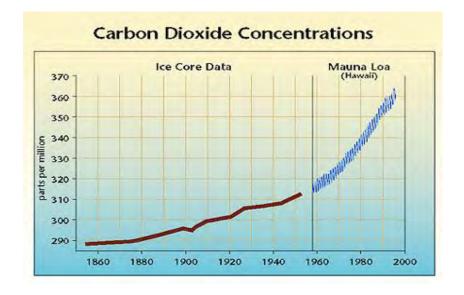
... "test" soybean (one genotype)

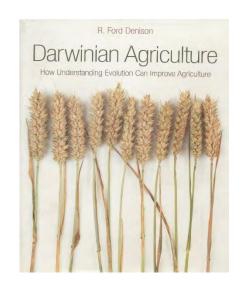


Diverse soybean pop'n selected for future benefits to...

... "test" maize (one genotype)

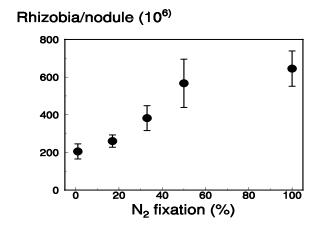
... "test" soybean (one genotype)



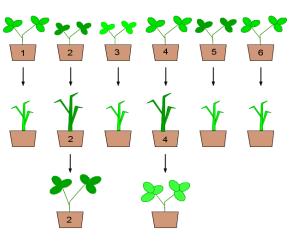




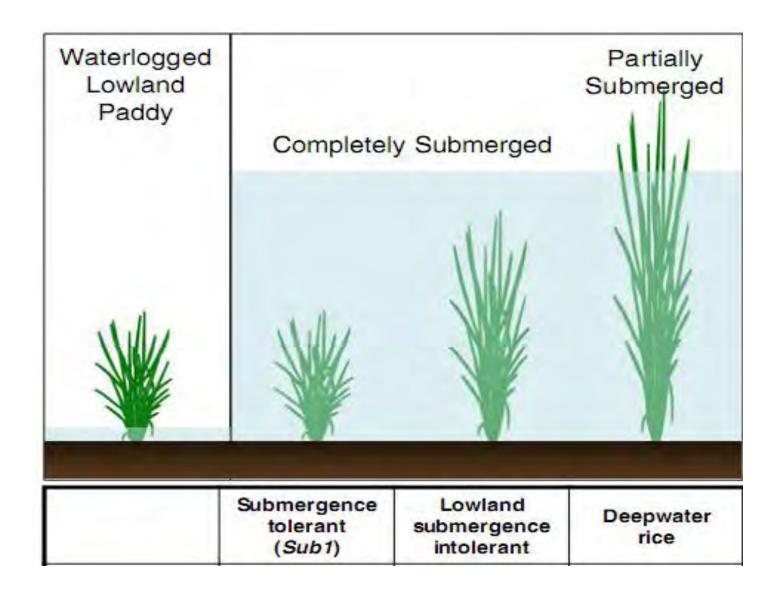
 Accepting some tradeoffs that were rejected by past natural selection may still be the easiest route to crop improvement.







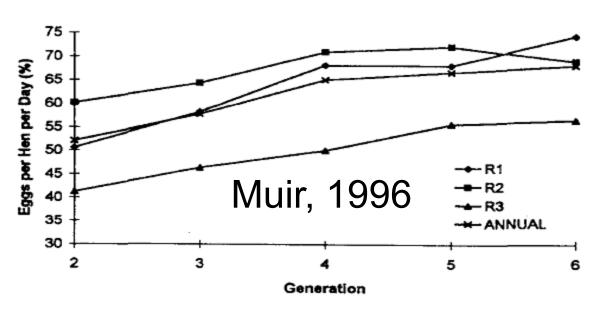
## Short- versus long-term flooding

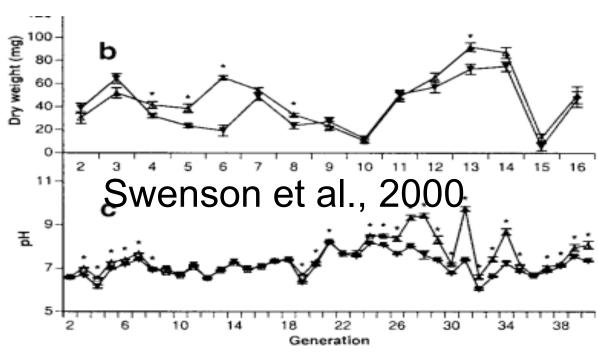


Bailey-Serres, 2010

# Group selection works best with:

- High among-group diversity
- Low within-group diversity
  - Group size < 25
  - < 5% migrants
  - Levin & Kilmer 1974

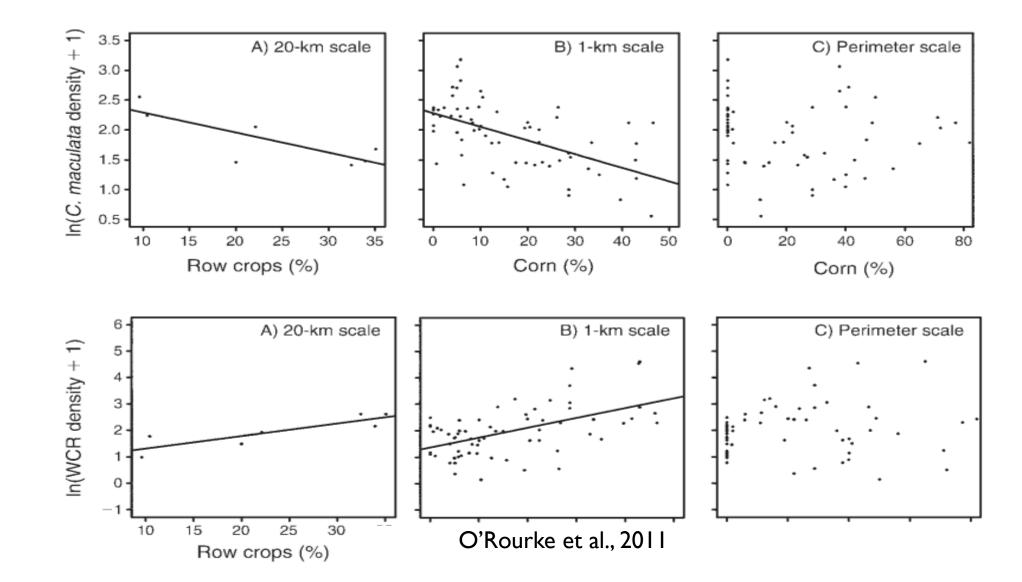


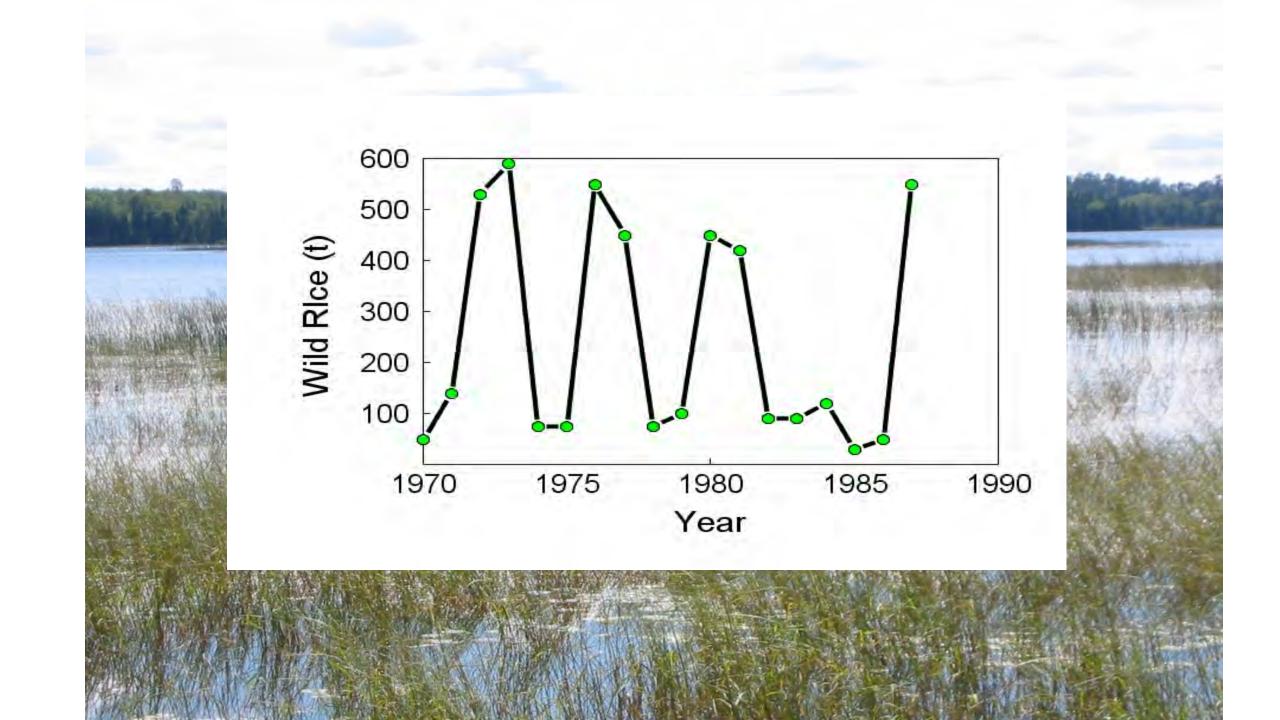


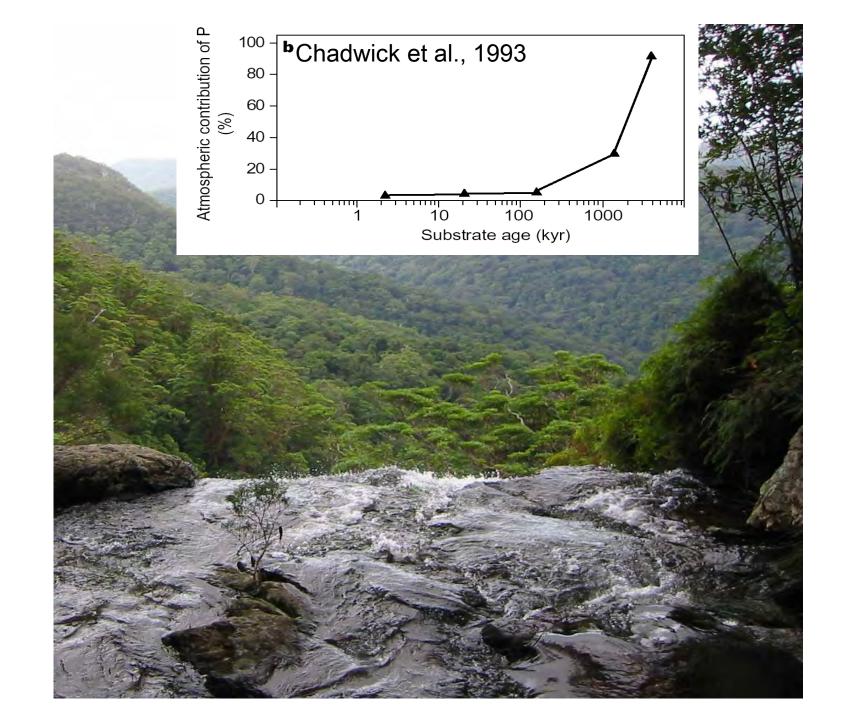
### Diversity benefits at 20-km scale



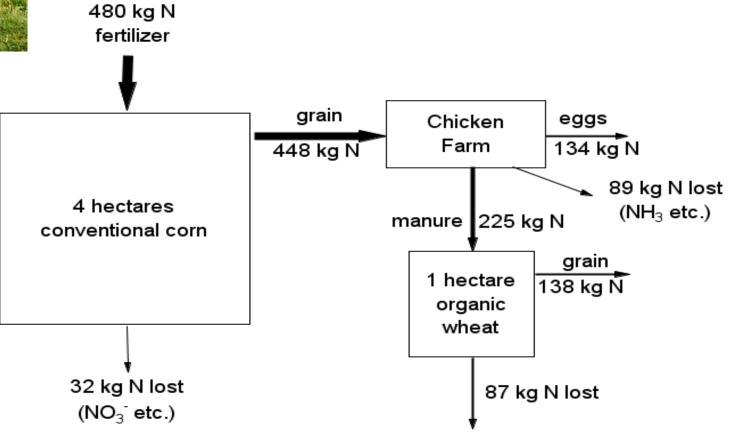
Rootworms



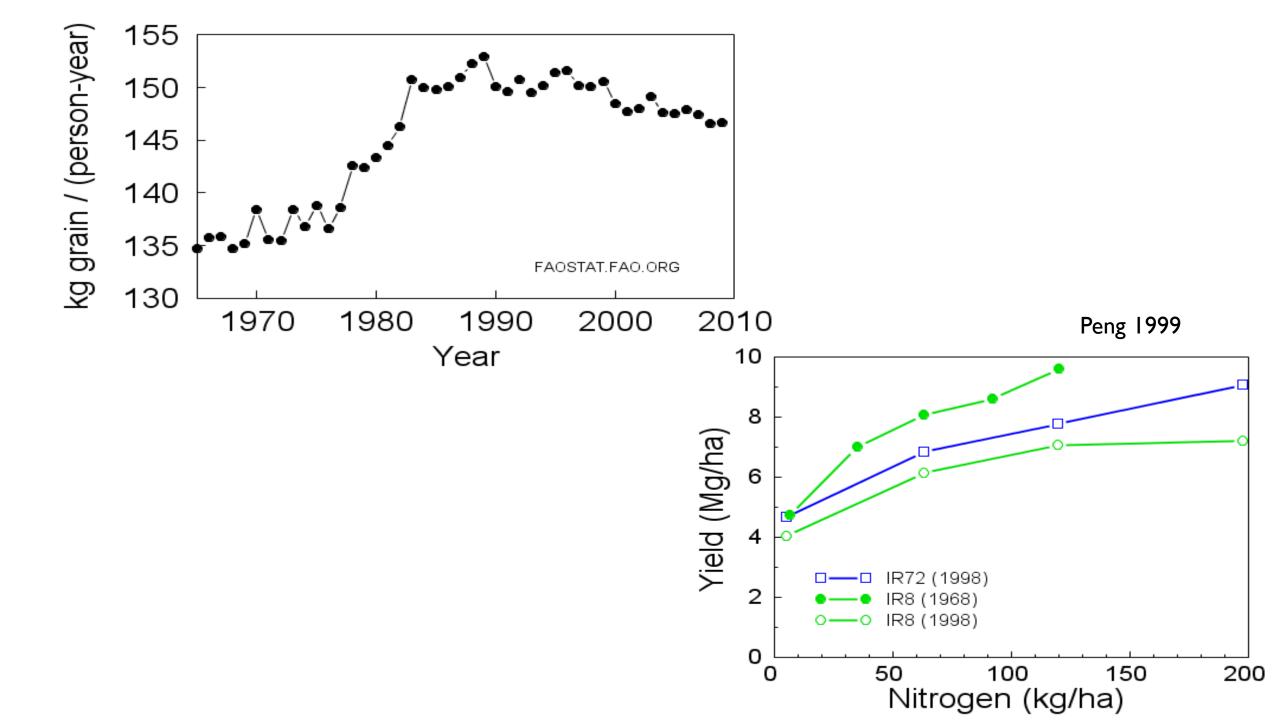


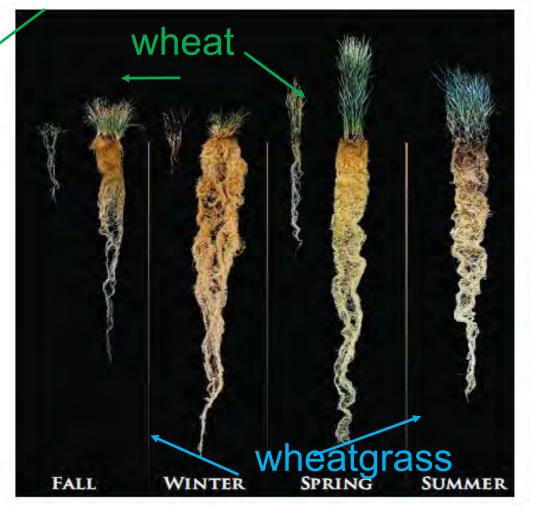


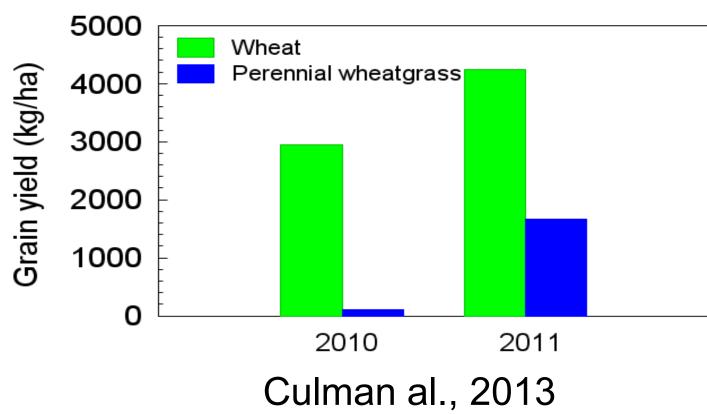




Wheat N balance from Rothamsted, lowa corn and chicken efficiency from Loomis & Connor





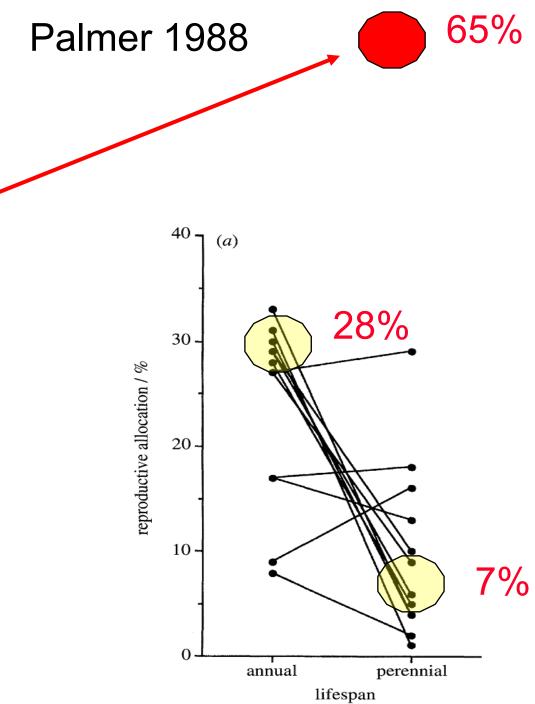


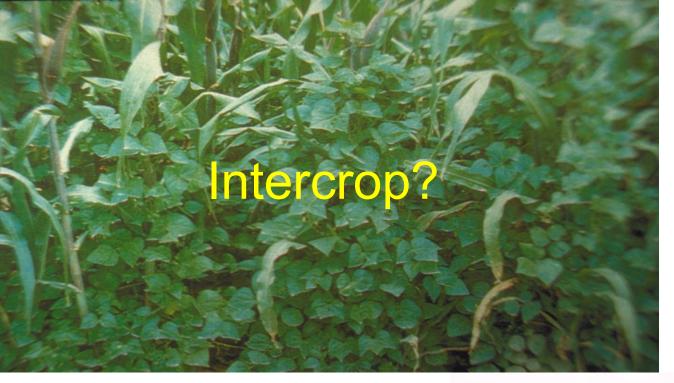
Glover et al., 2010

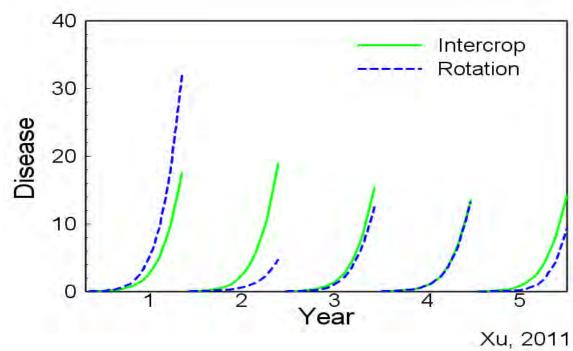
"modeling to assess the potential for novel perennial grain crops... in Africa"

snapp@msu.edu













### Adaptation to 2-year rotations

- Two-year life-cycle teosinte to escape grazing (Wilkes, 1977)
- ...and in corn rootworm to synchronize with host availability (Krysan, 1986)

### Making Science Useful to Agriculture

University of Adelaide, 26-29 November, 2018

# Scientifically sound conservation of genetic resources for crop breeding

J. M. Lenné and D. Wood, Aberdeenshire, Scotland

### Coverage

- Recent developments in the ex situ conservation of genetic resources for crop breeding and the in situ conservation of crop landraces on-farm from a CGIAR perspective
- Impact of political developments on the R&D agenda for ex situ conservation
- Lack of application of scientific approach and methodology for in situ conservation
- Science marginalized and scarce R&D resources wasted

### Ex situ conservation: CGIAR 1960's – 2000's

- <u>Activities</u>: Collection, conservation, evaluation, documentation, exchange and use
- <u>Sound science:</u> Protocols for collection; sound storage methodologies (seed physiology); cryopreservation methods for recalcitrant species (banana and cassava – UL, Belgium); in vitro conservation methodologies - CIP; efficient genotyping; high through-put phenotyping; sequencing; development of cores and mini-cores etc.
- Achievements: More than 600,000 accessions of major food crops, sourced worldwide, are safely stored, partly evaluated and documented for features of value to crop breeders, available worldwide and duplicated in other safe genebanks for security

### Ex situ conservation: CGIAR 1960's – 2000's

- Ex situ conservation of genetic resources for the use by crop breeders is a proven cornerstone of crop improvement for global food security.
- Until 1990's free and willing acquisition and exchange of genetic resources was based on trust and a clear understanding of the benefits to food crop production in developing countries.



#### Ex situ conservation: CGIAR 2018

- All CGIAR genetic resources under the Genebank Platform managed by the non-CGIAR Crop Trust
- Remit substantially reduced to conservation; use; policy
- Conservation: facility upgrades; quality management systems; seed health
- <u>Use:</u> repackaging existing knowledge for efficient use by breeders
- Policy: CGIAR operations under the ITPGRFA
- <u>Collection:</u> sporadic and dependent on short-term funding e.g. IRRI; donor priorities shifted to wild species (\$50 million in recent years) Crop Trust conflict of interest
- <u>Evaluation</u>: remit of Agri-Food Systems CRPs under CGIAR management e.g. ICRISAT and IRRI
- Research on genetic resources has suffered from a severe lack of funding and expensive distractions.
- Multiple millions have been spent on meetings for the CBD and ITPGRFA over the past 25 years
- WHY?

### First development - Biopiracy Campaign

- In the 1990's, a high-profile misinformation biopiracy campaign, led mainly by NGOs, highlighted apparent exploitation of valuable genetic resources from developing countries by developed countries and multinational companies Australia and chickpea.
- Developing countries were led to believe they were sitting on a genetic goldmine.
- The biopiracy campaign sowed the seeds of mistrust: it was inevitable that the former free movement of crop genetic resources was compromised and began to slow.
- The substantial contribution of genetic resources to food production and security in developing countries was largely forgotten.
- In retrospect, this campaign was a major long-term danger to global food security.

# Second development - Convention on Biological Diversity (CBD)

- In 1993, the CBD recognized sovereignty of countries over their existing biological diversity, including crop genetic resources.
- Not retroactive it did not cover the 3.5 million genetic resources already conserved in genebanks globally.
- Negative impact on the international genetic resources system: new samples could be accessed and conserved but could not be used or distributed due to unresolved issues surrounding access and benefit sharing e.g. IRRI
- Twenty-five years on, the CBD is still in the process of resolving the issues surrounding access and benefit sharing originally raised by the biopiracy campaign.
- Distracted attention away from mainstream genetic resources research and used scarce resources

# Third development - International Treaty on Plant Genetic Resources for Food & Agriculture (ITGRFA)

- In 2004, the ITGRFA came into force for the conservation and sustainable use of genetic resources for food and agriculture and the fair and equitable sharing of benefits arising from their use for sustainable agriculture and food security.
- One of the main justifications was that the CBD had stopped the CGIAR collecting genetic resources although not true, CBD did affect the efficiency of exchange and use e.g. IRRI.
- It was developed in harmony with the CBD resolution of access and benefit sharing will impact on ITGRFA.
- Unlike the CBD, the ITGRFA was retroactive. All countries and CGIAR centres were invited to place all collections under the "Multilateral System".
- In the case of the CGIAR collections in perpetuity.

# International Treaty on Plant Genetic Resources for Food & Agriculture (ITGRFA)

- Immediate problems arose complicating the collection, exchange and use of genetic resources: number of members was restricted (144 vs 195 for CBD) and the list of crops (Annex 1 <a href="www.fao.org/fileadmin/templates/agphome/documents/PGR/PubPGR/annex1">www.fao.org/fileadmin/templates/agphome/documents/PGR/PubPGR/annex1</a>) was incomplete e.g. groundnut, soybean etc. not included.
- The complexity and conditionality fostered further mistrust among developing countries.
- The CGIAR developed a Standard Material Transfer Agreement (SMTA) to provide a mechanism for exchange and use of their genetic resources (not possible under CBD) with contractual responsibilities for the provider and the recipient including fair and equitable benefit sharing from commercialization.
- Over 93% of genetic resources distributed annually under the ITPGRA are from CGIAR genebanks.

## Fourth development -Svalbard Global Seed Vault

- The Global Seed Vault, established in 2008, is a long-term, underground, permafrost seed store for vulnerable genetic resources stored in the world's 1,700 genebanks. It cost \$8.8 million.
- No distinction was made among genebanks even CGIAR genebanks were considered "vulnerable" due to their locations in developing countries.
- Of almost 1 million samples currently stored in Svalbard, the majority are from CGIAR and developed country genebanks e.g.
   USDA which are already under secure, safe storage and often duplicated in other safe stores (see: <a href="https://www.nordgen.org/sgsv/">https://www.nordgen.org/sgsv/</a>
- All genetic resources deposited in Svalbard are automatically placed under the ITPGRFA e.g. Mexico

# Svalbard Global Seed Vault - 2008 & 2018





2008 2018

## **Svalbard Global Seed Vault**

- The Global Seed Vault has a major design fault.
- Melting snow seeps into the downward sloping access tunnel forming ice sheets when meeting the permafrost.
- Significantly compromises the safety and security of the vault for longterm storage of global genetic resources.
- Original design was criticised by local coal mining engineers before construction.
- Upgrading the vault (repaired access tunnel, heat exchangers, emergency power etc.) will cost \$12.7 million (total for vault = \$21.5 million).
- Funds better spent in upgrading national genebanks, urgent evaluation of key genetic resources for use in crop breeding etc.
- The Global Seed Vault an expensive distraction even a vanity project.

# Ex situ conservation of genetic resources in the CGIAR: a tragedy of errors?

- A well-functioning, productive and trusted system which had measurable impact has been replaced by a shadow of its former self.
- Complexity and conditionality have replaced free and willing acquisition and exchange of genetic resources and a clear understanding of the benefits to food crop production in developing countries.
- Science has been marginalised and fragmented and scarce R&D funds have been distracted by numerous meetings etc.
- A well-functioning international system has been compromised by vested interests.

# Ex situ conservation of genetic resources in the CGIAR: a tragedy of errors?

"The interaction between the various elements discussed has had largely negative effects for global ex situ management of genetic resources for food security. The result is an emerging complex situation where multiple actors can exclude each other from the use of genetic resources for food and agriculture" (Andersen, 2008).

## *In situ* conservation – on-farm conservation



### *In situ* conservation – on-farm

- Maintenance of variable populations in their natural or farming environment, within the community of which they form a part, allowing natural processes of evolution to take place.
- On-going crop evolution is the main justification for in situ conservation on-farm – much speculation and very little hard evidence.
- It is argued that continuing evolution on-farm will render obsolete those genetic resources "frozen" in genebanks.
- This has created an unnecessary polarity between in situ and ex situ conservation.

### *In situ* conservation – on-farm

- Brown (1999) noted the novel and contentious nature of in situ conservation on farm – highlighted that the scientific basis and optimal procedures were lacking.
- Evidence of the nature, pace and causation of genetic change on farm is virtually non-existent – crucial to its understanding and how it is monitored.
- Harper (1990) occurrence of resistance genes long past selective forces.
- Stressed dynamic process which requires monitoring overall genetic diversity (marker diversity) and functional diversity for abiotic and biotic factors (variation in adaptation).
- New alleles or combinations will arise but others will disappear.
- Formulating a rationale for management will be difficult and potentially conflicting – maximizing allelic richness or improving population performance?
- In situ strategies may not only fail to conserve diversity but also resultant genetic changes may be unrelated to the needs of posterity.

## *In situ* conservation – on-farm: 1990's – 2000s

- There has been a lack of application of scientific approach and methodology for in situ conservation in spite of Brown (1999) recommendations.
- Most effort has been devoted to guidelines; manuals and conceptual frameworks.
- Token effort has been given to assessment of overall genetic diversity and more to documentation of indigenous knowledge.
- No attempts to monitor changes in diversity.
- No attempts to evaluate functional/adaptive diversity
- On-going requests for more "research" and more funding

### *In situ* conservation – on-farm current activities

- In situ conservation on farm has now morphed into the Community Biodiversity Management Program lead by Bioversity.
- Short-term projects on: diversifying agriculture; conserving traditional crops; diversifying diet and nutrition; gender empowerment; community seed banks; farmers rights; social inclusion; participatory research etc.
- In situ activities in the CGIAR have lost sight of the original concepts and the science required to support it has been forgotten.
- Since 2010, \$29 million has been spent on these so-called in situ on farm conservation projects.
- Two exceptions: Heirloom rice project (IRRI) and Potato park (CIP).

## *In situ* conservation – pearl millet in Niger

- Recent study in Niger now used by proponents of in situ conservation on-farm to justify more projects and funding.
- Samples of pearl millet landraces collected in Niger in 1976 and 2003 showed significant shift to shorter life cycle and reduction in spike size.
- Early flowering allele at the PHYC locus increased in frequency.
- No monitoring of populations between 1976 and 2003; weather data was not presented – was there consistent selection pressure?
- Potential for adaptation in the diverse landrace populations?
- Potential for introgression with ICRISAT improved varieties with Okashana parent?
- Uncertainties surround this study that need to be resolved to justify more funding.

### *In situ* conservation – on-farm – need for science

- Unnecessary polarity has been created between ex situ and in situ conservation of genetic resources.
- In situ conservation on-farm is being promoted as an alternative and better method of conservation than ex situ.
- Risks associated with *in situ* conservation on-farm e.g. loss of genetic resources (biotic and abiotic factors) and farmer needs (incentives?) are rarely considered.
- Much of the diversity currently conserved on-farm is not useful for crop breeding.
- In the absence of appropriate science, in situ conservation on-farm is an expensive distraction.

# Making science useful to agriculture for genetic resources

- Need for a rethink of the most scientifically sound and resourceand cost-effective way to conserve valuable genetic resources in the CGIAR.
- Twenty years ago the need for an integrated system for conserving genetic resources for crop breeding was recommended (Wood & Lenne, 1997).
- Brown (1999) recommended that this was the optimal way to conserve genetic resources.
- Closely linking targeted, structured, objective-led and science-based in situ conservation with ex situ evaluation and conservation is likely to identify the most valuable resources for future use.

# Making science useful to agriculture for genetic resources

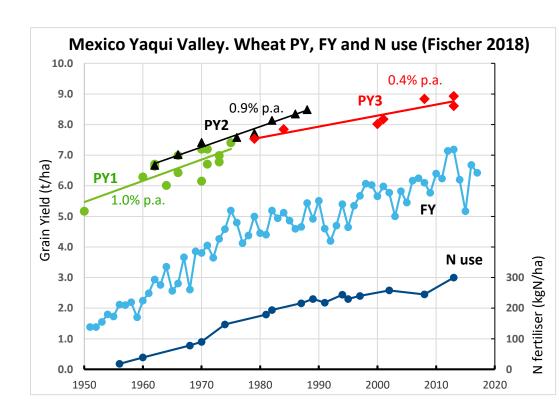
- Agricultural scientists have an important role to play to better inform investment decisions on appropriate genetic resources research as a basis for future food production.
- By hesitating to enter the debate, we can only accede the field to the biologically naïve and find ourselves able to serve as peripherally significant technicians in the pursuit of the objectives of the uninformed" (Namkoong, 1991).

## **Expensive distractions in pre-breeding research: can we do better?**

Tony Fischer, Honorary Fellow, CSIRO Agriculture and Food, Canberra, Australia

### Introduction

- Focus on yield research
- Progress in potential yield (PY) and water-limited potential yield (PYw) is now slow (0.4 to 0.7 % p.a. for staples)
- PY and PYw progress comes largely through improved cultivars, with a smaller impact from improved agronomy and its positive interaction with new cultivars (see example)
- Role in this of publically-funded research in pre-breeding and related technologies, noting that today it delivers impacts mostly via private commercial breeders (but also NARS)?
- Have we spent these public funds efficiently?
- Will focus separately on (1) physiology and (2) molecular biology in pre-breeding, their track records and lessons



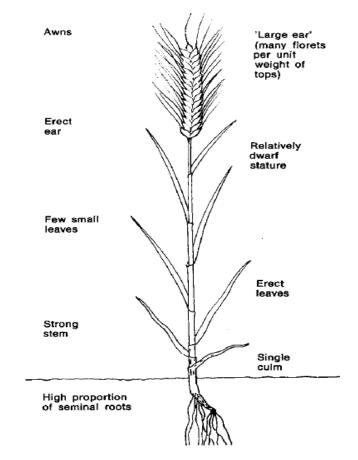


## Plant/crop physiology and pre-breeding

 Major boosts in the 1960s: Colin Donald's (at UA) ideotype notion, Peter Jennings et al success with IR8 rice. Catalysed physiology for breeding, a veritable "bandwagon"!

- Especially in CGIAR, PBI Cambridge, CSIRO Canberra, Midwest USA, prairie states of Canada, later reaching Uni. of Buenos Aires, then others.
- Retrospective studies (why did cultivar yields vary) which fostered....
- prospective studies to test desirable traits for yield.

#### Wheat ideotype (Donald 1968)





## Physiology in pre-breeding for yield

- Wheat (and other crops) quantifying control of phenology (flowering) by daylength and temperature through known major Ppd and Vrn alleles: first via patient genetics, now via molecular markers (e.g. Albert Pugsley, Howard Eagles, both UA, et al).
- Understanding/manipulation of phenology vital for soybean adaptation to lower latitudes.
- Shorter stature (e.g. rice, wheat, sorghum, etc) for lodging resistance, and later for greater HI but knowledge never used in breeding, too laborious.
- Temperate maize......despite the physiology, yield trials have always dominated (Don Duvick), giving steady PY and PYw progress (and unconsciously delivering a Donald ideotype!)
- Maize for subtopics and tropics. CIMMYT: height reduction and earliness for PY (Goldsworthy, Johnson), followed by 30+ year effort on PYw from Ken Fischer, Greg Edmeades, Marianne Bänziger, etc) with ultimate success in farmers' fields in Eastern Africa.





## More physiology in pre-breeding for yield

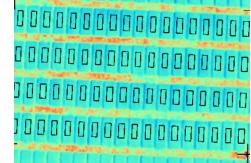
- Stomatal conductance (g<sub>s</sub>) in wheat, seen in 1970s at CIMMYT (Tony Fischer, Pat Wall), later better instruments (esp. IR thermometer for canopy temperature (CT)), facilitated quick field measurements; PY progress linked to lower CT, greater g<sub>s</sub>.
- Now positive PY vs g<sub>s</sub> seen in many C3 crops (Roche 2015). Basis of successful low cost proximal remote sensing of yield plots.
- CT or g<sub>s</sub> not yet mainstreamed in selection anywhere; still under test in CIMMYT Wheat (Matthew Reynolds et al), and in CSIRO.
- Transpiration limitation trait: the secret to Aquamax maize hybrids (?), more to come?
- Sustained wheat trait pre-breeding at CSIRO, Canberra staring mid 1970s (Richard Richards, Tony Condon, Greg Rebetzke). Some successes (low delta C13 cv,), more now reaching breeders (fast winter cvs, long coleoptile dwarfs, early vigour,...)
- How to attribute impact?



Airflow porometer (one leaf 10s)



Infra-red thermometer (many leaves, 5s)

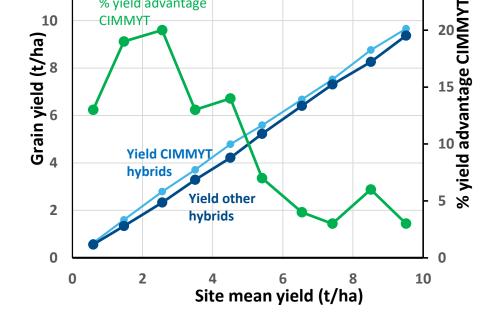


Helicopter and IRT (many plots in 10s)



## **Conclusion for physiology and pre-breeding**

- Many failed projects, especially those targeting PYw with wheat and rice in pots; so easy to water stress the plants, so difficult to mimic water stress seen by the field crop.
- Generally, studies which did not start in the field and end there were useless, because the plant in the field in a crop community is a "different animal", as is the soil profile it encounters.
- But there have been some successes, and some in the pipeline, example of former:
- Smarter phenotyping is now helping. Needs long term continuing effort. Also intimate links to mainstream (commercial) breeding is critical for success and often were lacking.



Banziger et al (2006)

50+ trials E Africa

12

% vield advantage

- For many crops, crop physiology has also driven:
  - faster breeding: doubled haploids, single seed descent, and now "Speed Breeding"
  - better awareness of yield distortions arising from plot edge effects
  - better understanding of G x E, often with crop modelling; concept of managed Es



## Molecular biology and pre-breeding

Starting 1980s, DNA-based markers and the possibility of genetic engineering (GE or GM):

#### DNA Markers:

- Spectacular ongoing advances in molecular techniques, including sequencing, greatly reducing costs and opening many options
- Markers for useful physiological traits and for yield: slow progress with quantitativelyinherited traits (QTLs), but now genomic selection (GS) seems promising (came from dairy breeding)

#### Genetic engineering (GE):

- GE was not originally for PY or PYw, although many totally over-hyped yield-targeting projects appeared from the 1990s onwards.
- To date only one GE cv released with direct yield benefit (PYw, DroughtGard maize, 2013); a couple in pipeline (drought resistant wheat, high sucrose sugar cane).
- Multitude of papers on GE traits for yield and hype on hype in media: concepts either never field tested or failed when this was tried.
- Many reasons for 20+ year lag; essentially crop yield much more complex that Roundup Ready or Bt (released 1995, 1996, single new genes), or omega-3 canola (2018, 7 new genes)



DNA sequencing gel



Hyping up GE for yield



## **Examples of attempted GE for yield**

- Rice and cytokinin oxidase (Ashikari et al 2004), unconvincing recent field results
- Rice and abscisic acid metabolism (Miao et al 2018), already done by breeders?
- Greater leaf photosynthetic activity, the holy grail, moving very slowly
- DREB and NAC for PYw, languished
- Trehalose-6-phosphate in maize, Syngenta delayed publication of data for a decade, why?
- DroughtGard in wheat (Yu et al 2017) ? At least good field testing in a modern cv.
- Overall, little or no progress: much hype, overlooking all the difficulties to be faced taking the result from plant in glasshouse to field crop, as repeatedly warned by crop physiologists.



High PS GE tobacco, 22d after transplant =harvest (Kromdijk et al (2016) in Illinois)



Drought tolerant wheat (front)...at least proper plots (Yu et al 2017)



### So could we have done better with R and D funds?

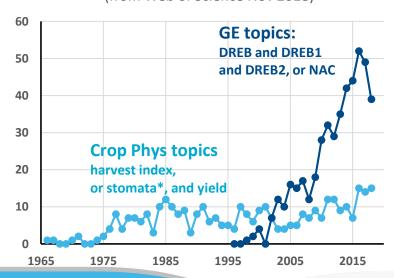
- There have been many bandwagons in plant improvement: Simmonds (1991), a successful plant breeder, ridiculed six, including crop physiology and biotechnology.
- He pointed to exaggeration of likely impact and underestimation of difficulty, and the diversion of resources from "proper agricultural research".
- From 1970s to 1990s:
  - Physiology got a brief run but scepticism remained despite some successes; there were a few bandwagon excesses but fortunately short lasting
  - Serious limitation for physiology was low rate of throughput in the field
  - Ag economics and social sciences, then sustainability (and environment) rose into fashion

#### Since 1990s:

- Complacency and sustainability ruled until 2008, then urgency of ensuring "world food security" in face of climate change took over
- Huge optimism and investment in molecular biology, limited investment in crop physiology.
- Research into DNA markers or GE has to date delivered only small direct yield benefits

#### Papers published each year with title words

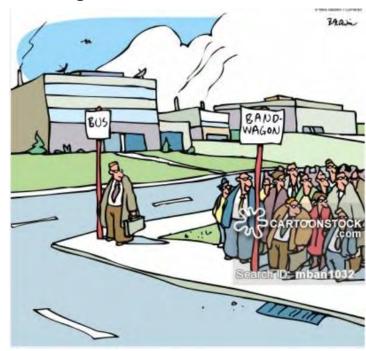
(from Web of Science Nov 2018)





## What are the lessons for pre-breeding?

- Simmonds was right to warn about fashion, and lazy and dishonest thinking, and to urge "decent scepticism", as did Bernardo (2016) recently, but serious investors cannot ignore new technologies, even if they look like bandwagons.
- Most lessons common for investment in both physiology and molecular biology
- First lesson: beware of "hype", get broad review of proposals, especially from downstream beneficiaries
- Yield is field performance; it is complex, with hidden trade-offs, and hard to measure:
  - Understanding the field environment essential, and existing yield vs trait relationships may help, possibly also simulation modelling with actual climates
  - Development and validation takes years, with good continuity of support and purpose, meaning longer projects with sensible milestones
  - Stay focussed and avoid the temptation of digging into bottomless functional genomics holes
  - Involvement of breeders is essential, agronomists helpful also
- Molecular biology needs crop physiology, especially for GE, while physiology cannot ignore molecular markers any longer (e.g., for traits, for genomic selection).
  - interesting question: can GS for key traits, fed into a physiological crop model, handle yield and G x E, delivering the best of both worlds (Technow et al 2015)?





## More lessons and questions for pre-breeding?

- Investors (public and private) need to be better informed, more consistent and constant in support, embracing "more of the same", and to consider substance of route to impact.
- Are CGIAR commodity programs uniquely set up to pursue task?
- Role of consortia like IWYP in wheat?
- Role of private sector, and of public-private partnerships? Latter needed but fraught with other hurdles
- Can ex-ante cost benefit analyses be used in better choosing targets for prebreeding research investments? Or ex-post studies?
- Journal editors and reviewers, and abstracters for popular media, need to be more circumspect with claims surrounding the word "yield", while failures as well as advances need to be published.









## **Conclusions again:**

- For yield breeding, not much clearly coming from yield physiology, but more indirect influences; very little from molecular biology (so far)
- Need long term yield-targeted investments carefully judged (not just by proponents in field)
- Need to get physiologists, molecular biologists and breeders together, really together in the field!
- Is IWYP a model: 2017-18 AR impressive range of investments with \$58 M USD so far, we should have answers soon but needs substantial outside review soon (at least 6 reviewer man months, it is huge and complex).

#### • Stop Press:

- Argentina's drought adapted GM wheat....solid evidence
- Reynolds's 4 WYCYT claims to have a line, selected on physiological traits (PTs), 7% above Borlaug100, the #1 yielding BW in Yaqui Valley.... evidence not 100% (stats complex and novel...BLUPs +Factor Analytics + Dunnetts)
- Time will tell, remember these two "breakthroughs", one in each of Simmonds's bandwagons.

#### Thanks for allowing me to run wild on my favourite topic!



# Making Science useful to Agriculture

Maize and Wheat science to improve livelihoods







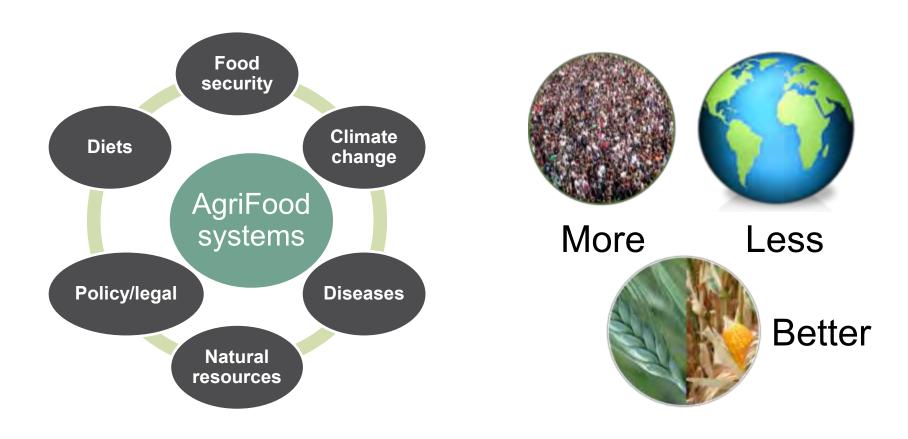
# In this presentation

- 1. Introduction
- 2. CIMMYT: research for impact
- 3. Breeding at CIMMYT
- 4. Impact from breeding
- 5. Agronomy / physiology
- 6. Collaboration with Australia





## **Challenges 2050**







# The 9 billion person question





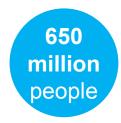


# **Challenge: Hunger and malnutrition**



800 million people

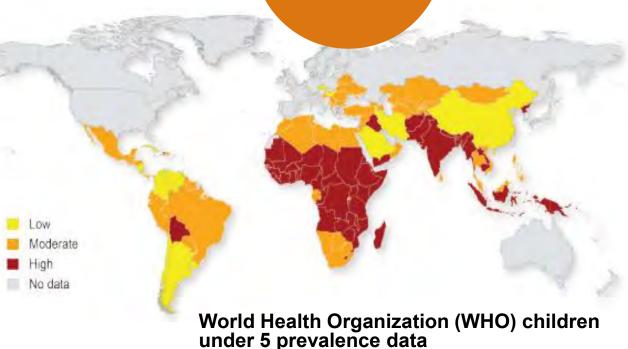
Obesity

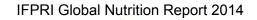


Micronutrient deficiency

2 billion people

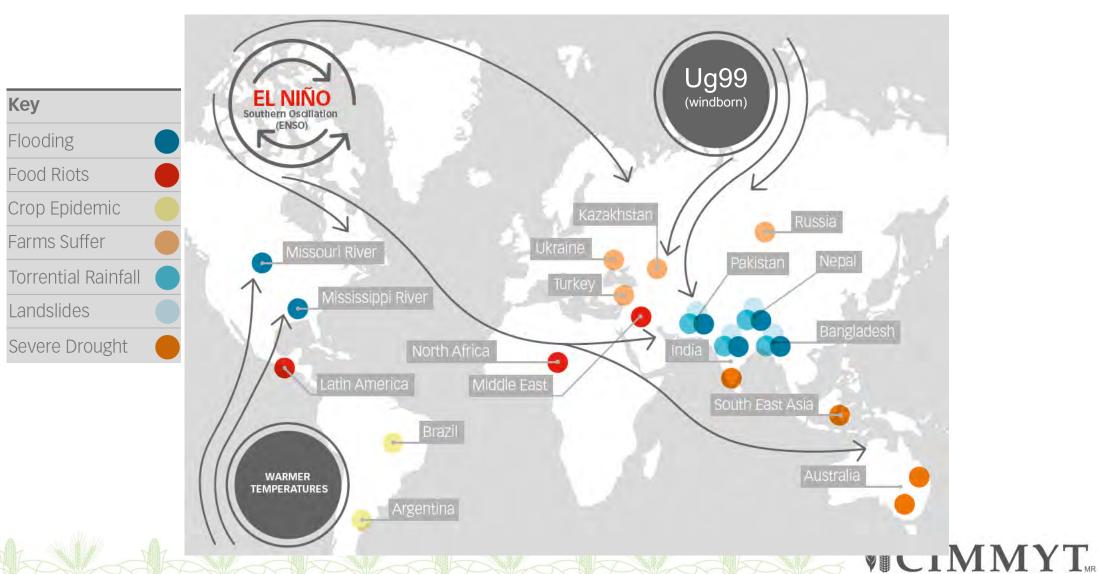
2050?





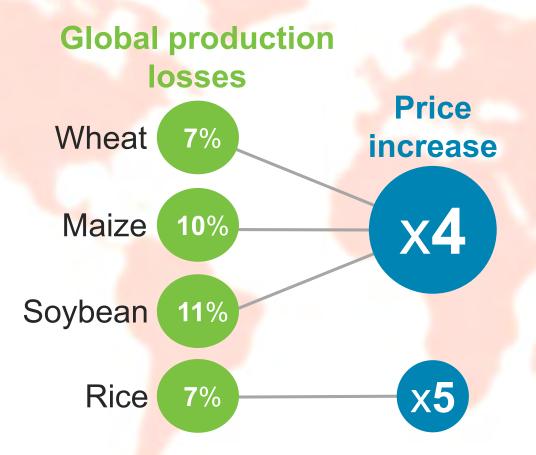


# Food system shock scenario





## **Impacts**



#### **Human cost**

- Humanitarian crisis
- **Food riots**
- Stock market losses
  10% in EU
  5% in US

# Feeding the world maize & wheat: Need by 2030 + 40%

MAIZE PROVIDES

15-56% OF

TOTAL CALORIE INTAKE

in Sub-Saharan Africa, Latin America and Asia

**PREFERRED** 

STAPLE FOOD TO million people

LIVING ON LESS THAN \$2 A DAY



Global production in 2016

1026 million metric tons WHEAT IS THE LARGEST PRIMARY COMMODITY

**735** million metric tons



WHEAT PROVIDES 18% OF OUR TOTAL AVAILABLE CALORIES

\*†\*†\*†\*†\*†\*†\*†\*†

2.5 billion people in 89 countries

\*†\*†\*†\*†\*†\*†\*†\*†

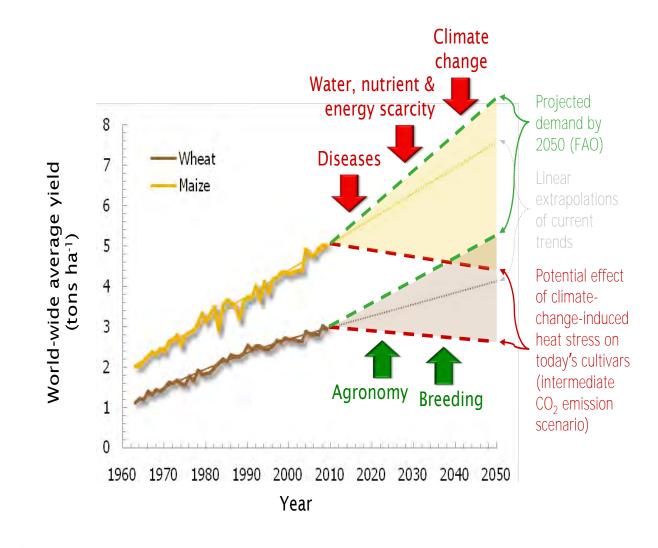




# **Challenge: Clima**

For food prices to remain constant, annual yield gains would have to increase:

- from 1.2% 1.7% for maize
- from 1.1% 1.7% for wheat

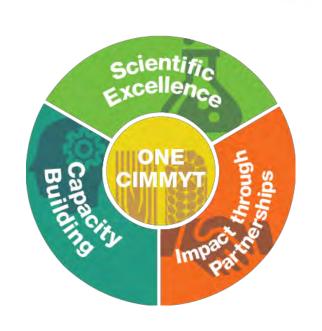






# In this presentation

- 1. Introduction
- 2. CIMMYT: research for impact
- 3. Breeding at CIMMYT
- 4. Impact from breeding
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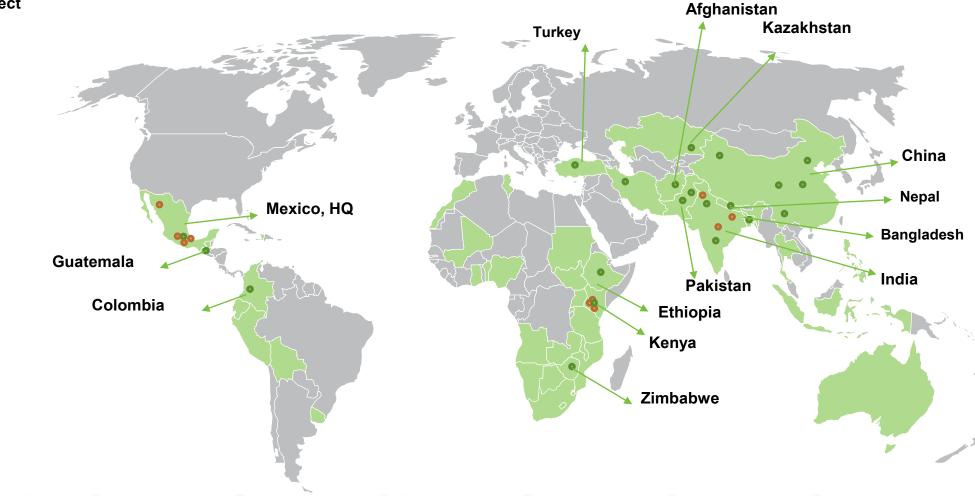


## **CIMMYT** around the world

1,400 staff from over 50 countries, 13 offices

Key Office

Field StationProject







# CIMMYT's major achievements



**Generates \$3.5 – 4 billion in** annual benefits to farmers in developing countries.



50% of maize and wheat grown in the developing world based on CIMMYT varieties.



10,000 researchers and professionals worldwide alumni of CIMMYT training.



1 Nobel Peace Prize winner, 3 World Food Prize winners



# Integrated research agenda



#### **Genetic diversity**

- Conserve and use diverse maize and wheat collections
- Seed health
- · Unlocking genetic potential



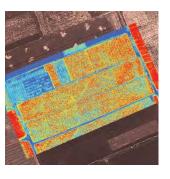
## Develop and improve access to varieties

- Stress, disease and pest resilience breeding
- Molecular tools
- Developing seed sectors
- Nutritional and end-use quality



#### **Farming systems**

- Crop management practices
- Mechanization
- Participatory research



#### **Increasing impact**

- Social sciences
- Big data
- Gender and youth
- Foresight and impact assessments

**CROSSCUTTING** 

**Capacity development – Partnerships** 





# A change in thinking: From commodities to agri-food systems

Agri-food systems are...

The activities and relationships that determine how food is produced, processed, distributed and consumed,

together

with the **human and biological systems** that shape these activities at every stage







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# CIMMYT's maize and wheat breeding programs









# Maize and wheat improvement at CIMMYT

Philosophy behind breeding programs

Breeding new maize and wheat varieties that are adapted to

- climate change-related stresses
- with farmer-preferred traits
- resistance to major diseases and insect-pests
- enhanced nutritional and end-use quality.













# Maize and wheat improvement at CIMMYT

Philosophy behind breeding programs

#### Accelerating genetic gains:

- Exploiting greater diversity
- Capturing key environmental constraints/representing the environment
- Greater selection intensity at lower costs
- Increasing precision
- Accelerating breeding cycles













# Utilizing diversity from CIMMYT's germplasm bank



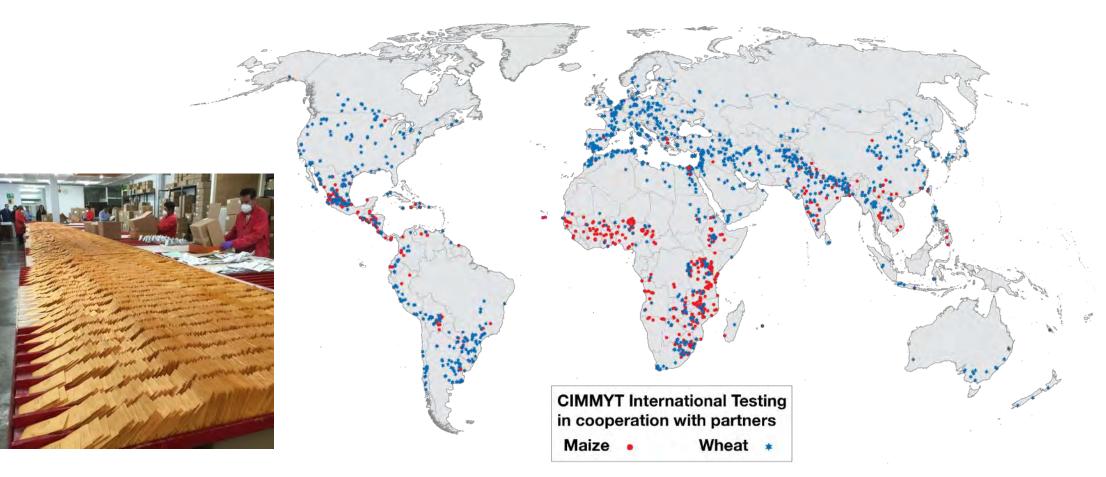
- Largest global maize and wheat germplasm bank
- 28,000 maize accessions
- 138,000 wheat accessions
- ISO certified







#### Global seed distribution network



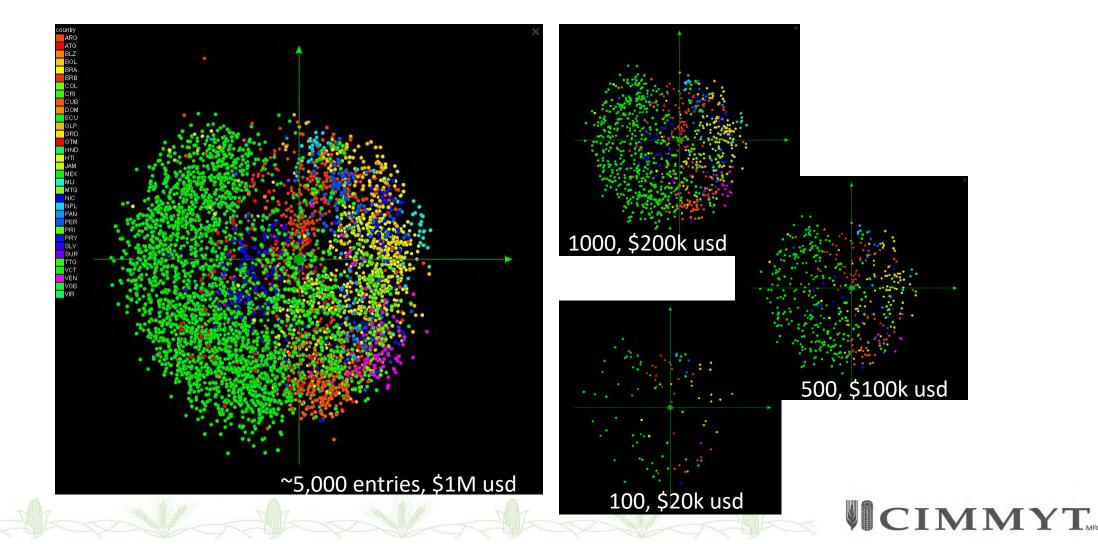
#### The CGIAR provides 80% of germplasm to the world.



Crucial traits: yield, stress tolerance, disease resistance, nutritional value. CIMMYT distribution increased 30% in 10 years



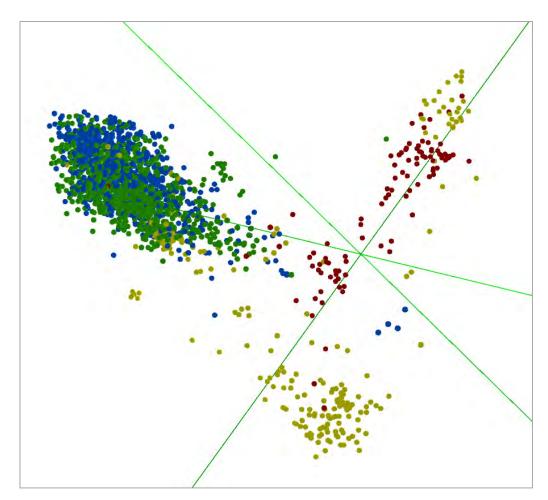
# Genomic characterization using DArTseq (SNP and PAV) >> Diversity panels for breeders





# **Exploiting greater diversity: Heat-adaptive** traits in wheat landraces

Elite lines: ESWYT- Blue SAWYT - Green



Heat Tolerant Landraces:

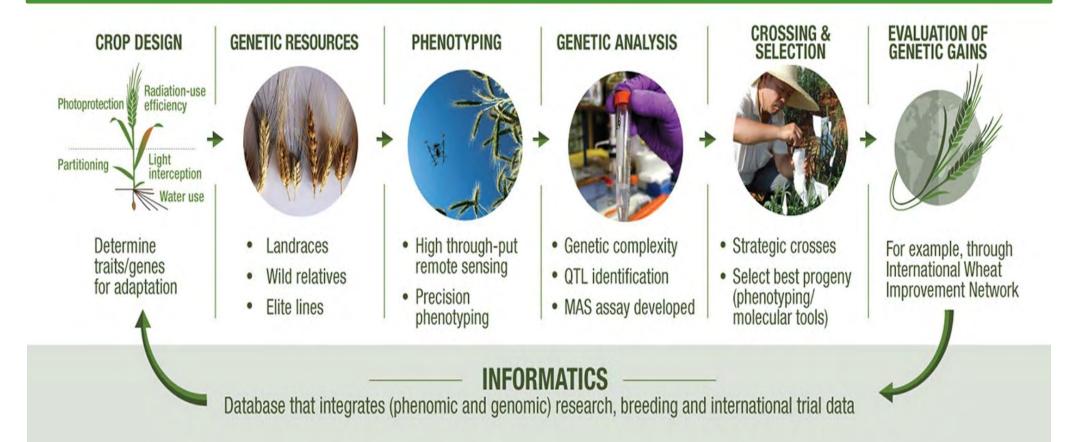
Iranian : Red Mexican : Yellow





## **Exploiting greater diversity**

#### PHYSIOLOGICAL PRE-BREEDING PIPELINE







# Increasing precision and greater selection intensity: phenotyping sites capturing key abiotic or biotic stresses

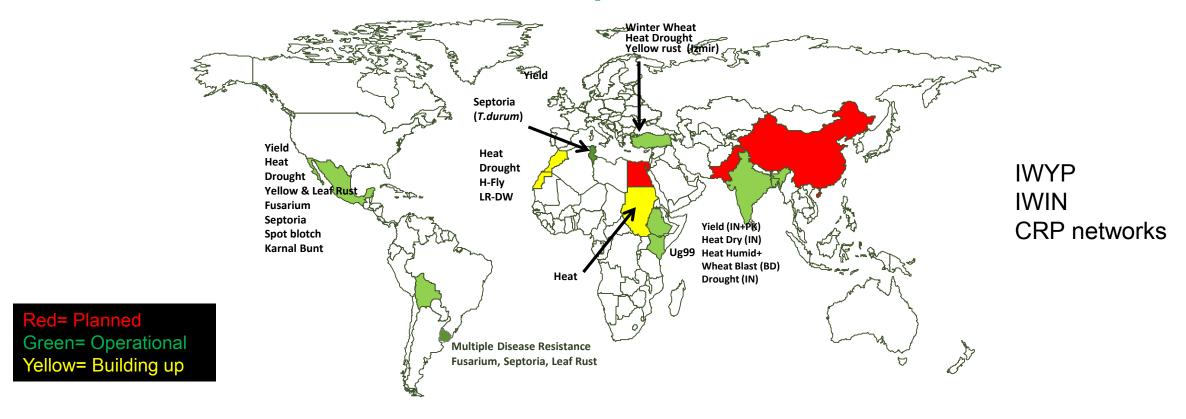








# Capturing key environmental constraints/representing the environment: A global phenotyping network for wheat improvement







# Intensive and accelerated breeding for MLN resistance





- > 122,000 diverse germplasm entries (268,700 rows) screened against MLN under artificial inoculation at the Naivasha facility since Sept 2013.
- Of these, 61% from CIMMYT, 18% from NARS, and 21% from the private sector.
- New: gene editing





#### Maize Doubled Haploid (DH) Facility at KALRO-Kiboko, Kenya



Offering DH development service as centralized platform to NARS and SME seed company partners → economy of scale!



The facility is producing annually >70,000 DH lines from diverse source populations







#### High-throughput & Low-cost Field-based phenotyping

Zaman-Allah et al. Plant Methods (2015) 11:35 DOI 10.1186/s13007-015-0078-2



#### METHODOLOGY

**Open Access** 

CrossMark Unmanned aerial platform-based multi-spectral imaging for field phenotyping of maize

M Zaman-Allah 1\*0, O Vergara<sup>2</sup>, J L Araus<sup>2</sup>, A Tarekegne<sup>1</sup>, C Magorokosho<sup>1</sup>, P J Zarco-Tejada<sup>3</sup>, A Hornero<sup>3</sup>, A Hernández Albà<sup>4</sup>, B Das<sup>5</sup>, P Craufurd<sup>5</sup>, M Olsen<sup>5</sup>, B M Prasanna<sup>5</sup> and J Cairns<sup>1</sup>



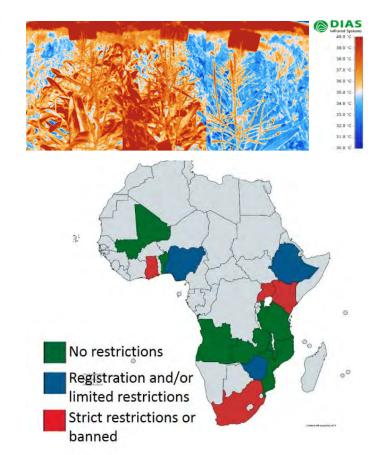
published: 18 May 2018 dat 10.3389/fpts.2016.00666



A Novel Remote Sensing Approach for Prediction of Maize Yield Under **Different Conditions of Nitrogen** Fertilization

Omar Vergara-Diaz<sup>1</sup>, Mainassara A. Zaman-Allah<sup>2</sup>, Benhildah Masuka<sup>2</sup>, Alberto Hornero<sup>3</sup>, Pablo Zarco-Tejada<sup>3</sup>, Boddupalli M. Prasanna<sup>2</sup>, Jill E. Caims<sup>2</sup> and José L. Araus<sup>1\*</sup>

Integrative Crop Ecophysiology Group, Plant Physiology Section, Faculty of Biology, University of Barcelona, Barcelona, Spain, 1 International Maize and Wheet Improvement Center, CIMMYT Southern Africa Regional Office, Harare, Zimbabwe, <sup>3</sup> Laboratory for Research Methods in Quantitative Remote Sensing, QuantaLab, institute for Sustainable Agriculture, National Research Council, Cordoba, Spain

























## Effectively using molecular markers in breeding

A few examples from CIMMYT-Global Maize Program

- Forward breeding using breeder-ready markers → Provitamin A, MSV
- Marker-assisted backcrossing → MLN
- Novel genetic stocks (tropical haploid inducers) using MAS →
   HIR
- Genomic prediction → MLN, TSC





# New CGIAR-wide initiative The Excellence in Breeding Platform

- Provide access to: Cutting-edge tools, services and best practices, application-oriented training and practical advice to accelerate genetic gains in applied breeding programs.
- From where? CGIAR, ARIs, private sector
- Benefit to: Public and private sector breeding programs targeting low- and middle-income countries
- CIMMYT-led, cross-commodity









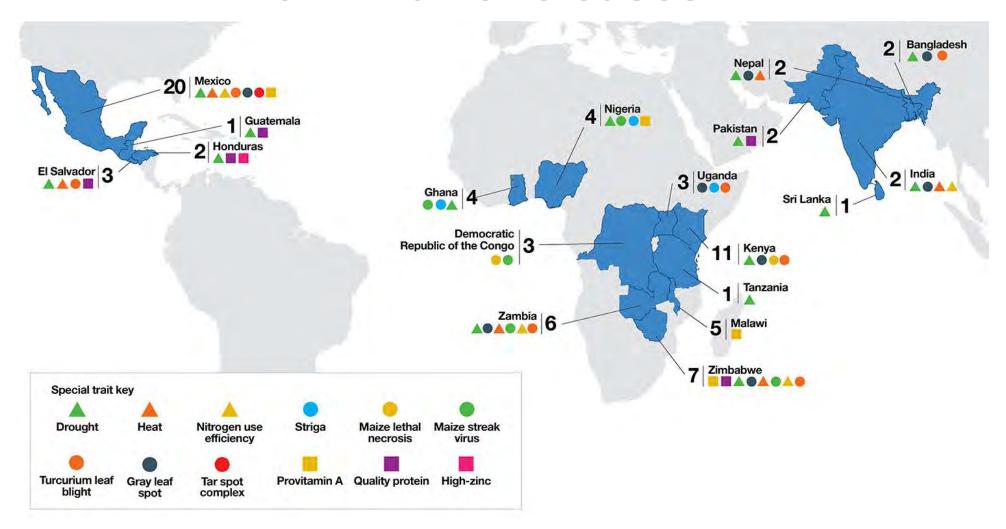
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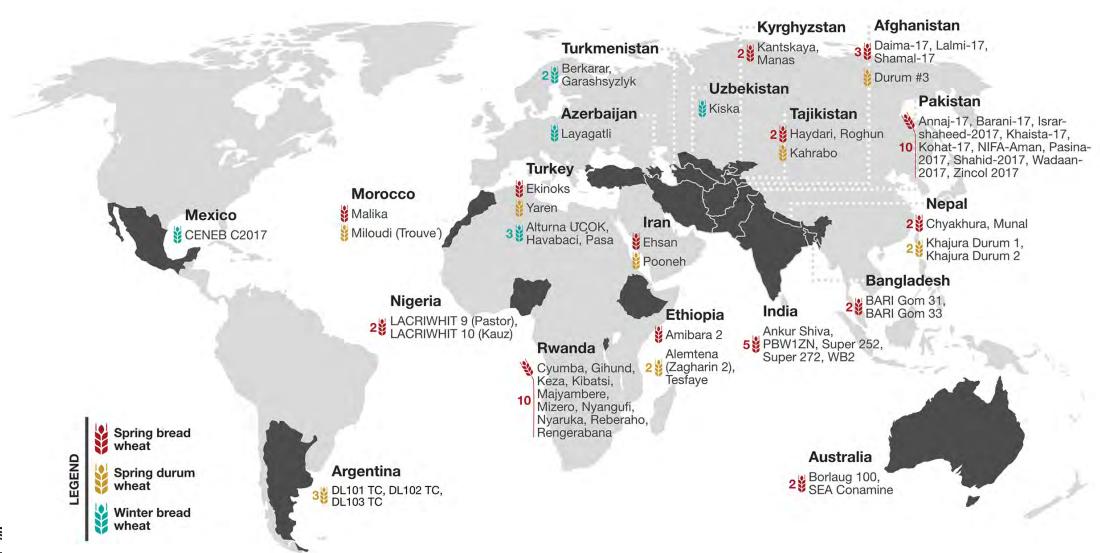
#### 2017 maize releases



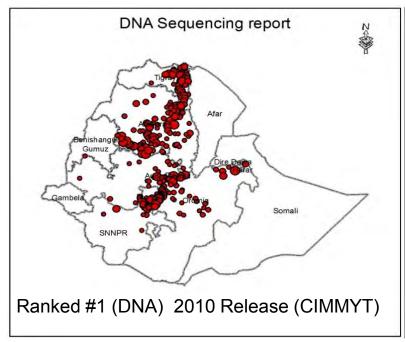


Varieties commercialized by CIMMYT partners with traits preferred by smallholder farmers – based on available information only

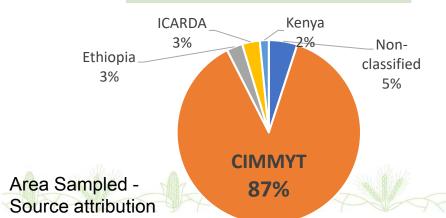
#### 2017/2018 wheat releases



### **DNA** fingerprinting in Ethiopia



#### Germplasm attribution



#### Wheat - 2016/17 Survey

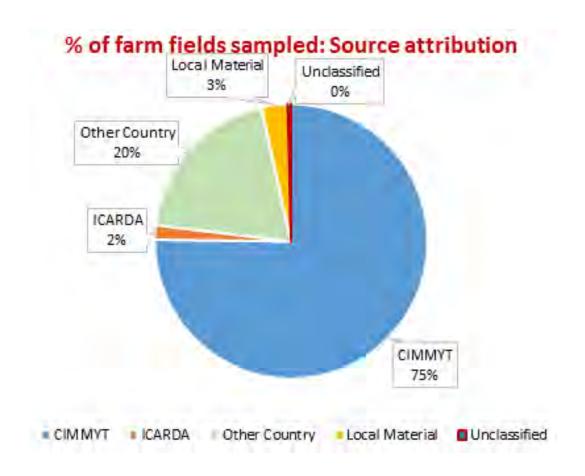
- First national scale DNA fingerprinting on staple crops
- ≈ 4000 wheat samples (maize to follow)
- 29% of farmers could identify variety name correctly
- 91% of varieties detected and 87% of area sampled from CIMMYT germplasm



## **DNA** fingerprinting in Afghanistan



ACIAR project 2012-2018



- 600 farm fields sampled in four provinces in East, North, West and Centre in 2015-16 season.
- Chonte #1, a CIMMYT variety released in 2010 was found in 43% samples (77% from last 10 years)
- 58% farmers predicted their cultivar name correctly.
- 75% of samples were found to be CIMMYT varieties





#### 20 Years of IWIN

Economic Benefits from 1994 to 2014

Additional annual production
 24 to 65 million tons of grain per year

Total benefits attributable to CGIAR wheat improvement research

USD 2.1 billion to USD 5.7 billion









## **Drought Tolerant maize**



- Over 300 elite DT maize varieties released across sub-Saharan Africa, and grown in nearly 3.5 M ha.
- Partnerships with over 100 SME seed companies in producing and commercializing DT maize in Africa.



#### DT maize adoption and impacts in Africa

Climate Change (2015) 133:283-299.

Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa

Monica Fisher<sup>1</sup> • Tsedeke Abate<sup>2</sup> •
Rodney W. Lunduka<sup>3</sup> • Woinishet Asnake<sup>4</sup> •
Yoseph Alemayehu<sup>4</sup> • Ruth B. Madulu<sup>5</sup>

Agriculture and Food Security (2017) 6:30.

RESEARCH

Open Access

Characteristics of maize cultivars in Africa: How modern are they and how many do smallholder farmers grow?

Tsedeke Abate<sup>1</sup>, Monica Fisher<sup>2,3</sup>, Tahirou Abdoulaye<sup>4</sup>, Girma T. Kassie<sup>5</sup>, Rodney Lunduka<sup>6</sup>, Paswel Marenya<sup>2</sup> and Woinishet Asnake<sup>2</sup>

Food Security (2014) 6:217-230.

Evaluating the impact of improved maize varieties on food security in Rural Tanzania: Evidence from a continuous treatment approach

Menale Kassie · Moti Jaleta · Alessandra Mattei

Agricultural Economics (2015) 46:1-12.

Ex post impacts of improved maize varieties on poverty in rural Ethiopia

Di Zenga,\*, Jeffrey Alwanga, George W. Nortona, Bekele Shiferawb, Moti Jaletac, Chilot Yirgad

<sup>a</sup>Department of Agricultural and Applied Economics, Virginia Tech, Blacksburg, VA 24061, USA
<sup>b</sup>Partnership for Economic Policy, P.O. Box 30772-00100, Nairobi 00621, Kenya
<sup>c</sup>International Maize and Wheat Improvement Center, P.O. Box 5689, Addis Ababa, Ethiopia
<sup>d</sup>Ethiopian Institute of Agricultural Research, P.O. Box 2003, Addis Ababa, Ethiopia

Climate and Development (2017) https://doi.org/10.1080/17565529.2017.1372269.

Impact of adoption of drought-tolerant maize varieties on total maize production in south Eastern Zimbabwe

Rodney Witman Lunduka, Kumbirai Ivyne Mateva, Cosmos Magorokosho & Pepukai Manjeru



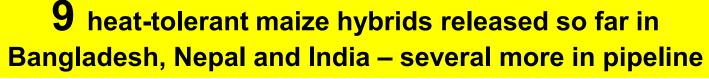




### **Heat tolerant maize for Asia**

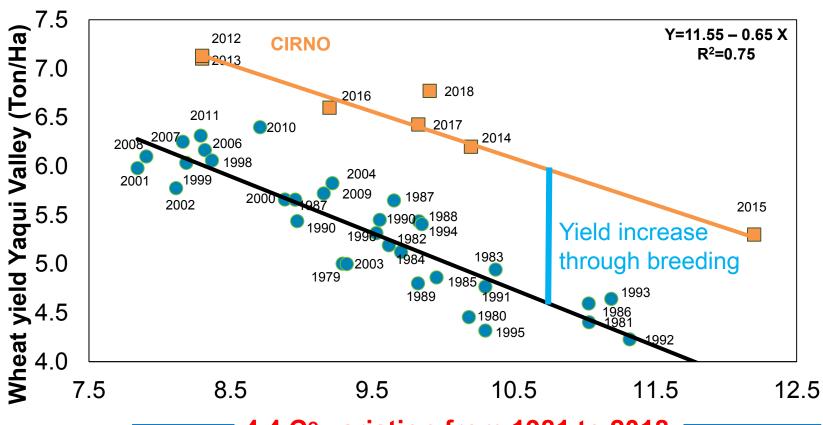








# Response of wheat to increasing night temperature in Farmers' Fields in Mexico



4.4 C° variation from 1981 to 2018

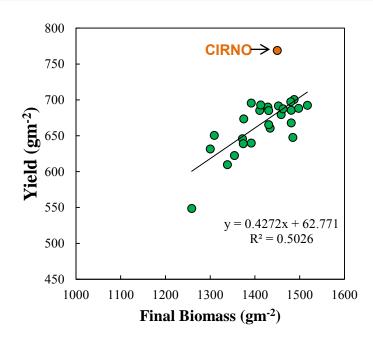
January-April Average min. Temperature °C

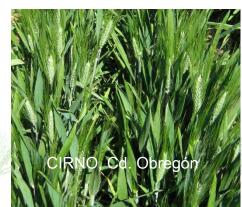


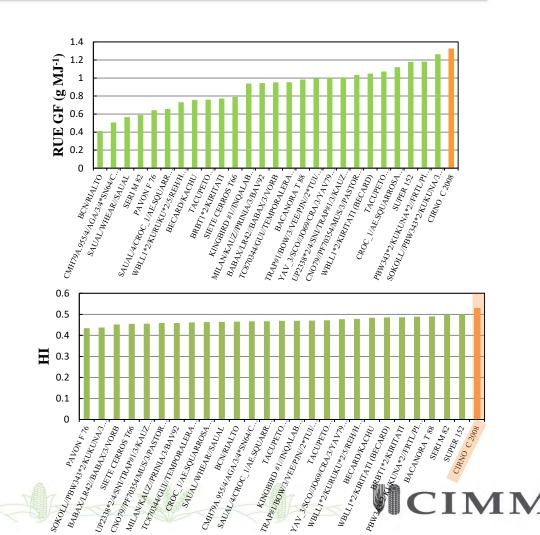


# CIRNO: an outstanding wheat line in NW-Mexico

**CIMCOG**, Elite Line Panel, n=27, 3 years, Cd. Obregon, Sonora, Mexico











# Disease epidemics



Maize Lethal Necrosis

2 viruses affect Kenya, Uganda, Tanzania, Rwanda, D.R. Congo, South Sudan, and Ethiopia



Tar Spot Complex

Mexico, Colombia, El Salvador, Guatemala, Nicaragua



Wheat blast

Argentina, Brazil, Bolivia, Paraguay, South Asia



**Stem Rust** 

Most feared! Global



Fusarium Head Blight

China,
Caspian and
Black Sea,
Cona Sur,
North America,
Western
Central and
Eastern Europe



#### **Septoria**

North Africa, Ethiopia, Latin America, Southern and Central Europe, Iran, Kazakhstan and Siberia





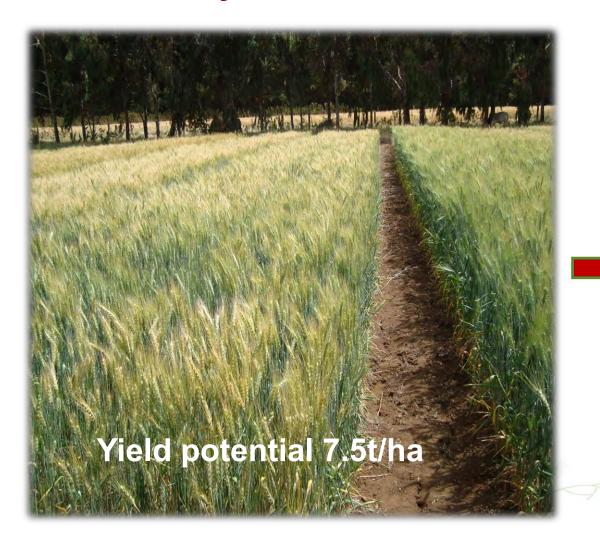
## **Breeding for stem rust resistance**

2Blades

Boom Variety Robin 2009

Bust Variety Robin 2014







## Wheat blast – the example of Bangladesh

**2015-16:** 1st report of WB occurrence in

Bangladesh in 7 districts. Losses: 25-30%

2016-17: Disease spread to three more

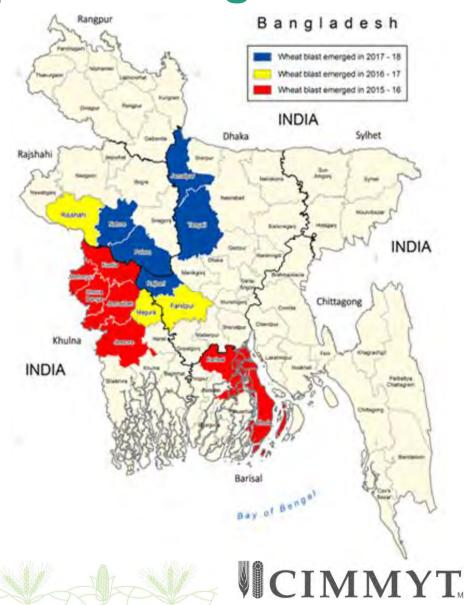
districts. Losses: 5-10%

2017-18: Conditions unfavorable for disease.

Spread to additional 5 districts. Losses: 1-5%

Wheat Blast is an established disease in Bangladesh

OFFICIALLY India does not have wheat blast but several newspapers report wheat blast occurrence

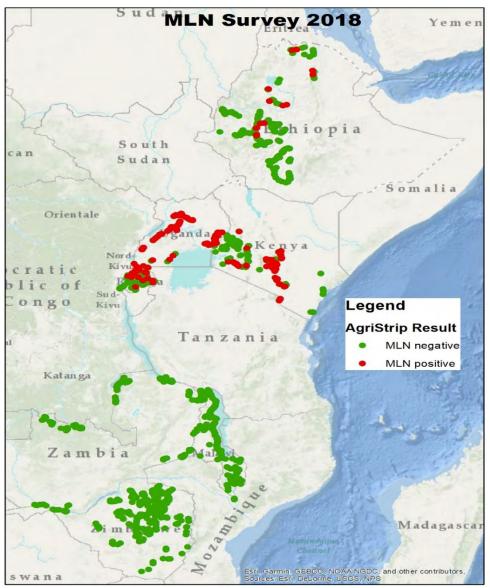


# Maize Lethal Necrosis (MLN)





One of the most devastating diseases in East Africa, including Ethiopia.



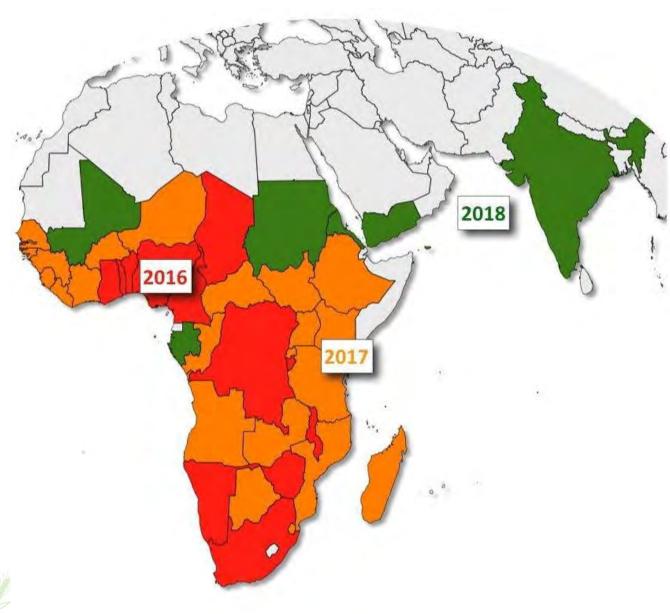






## Fall Armyworm spread



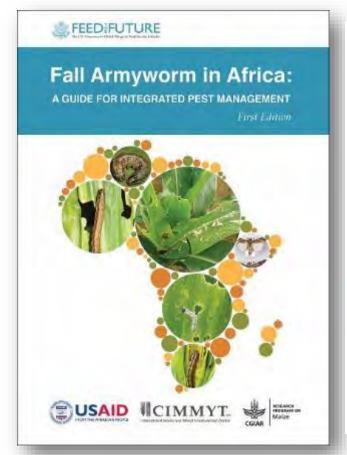




Map: FAO, August 2018

## There is no ONE solution that fits all

Need for Integrated Pest Management







Protecting crops from economic injury, and minimizing negative impacts on people, animals, and the environment



## Breeding for improved health and nutrition

Mainstreaming biofortification







## Making Zinc a core trait within 10 years

- Proof of Concept: <u>Competitive!!!</u> Zn enriched varieties released in Pakistan, India, Bangladesh
- Subsistence farmers unlikely to benefit from other interventions
- Hot spot for Zn in wheat genome identified
- 75% of elite lines will have high Zn grain by 2030
- NARS buy-in mandatory very positive responses





## In this presentation

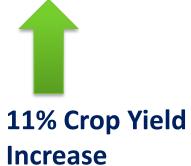
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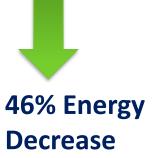


## A sustainable future: Conservation & precision agriculture & variety













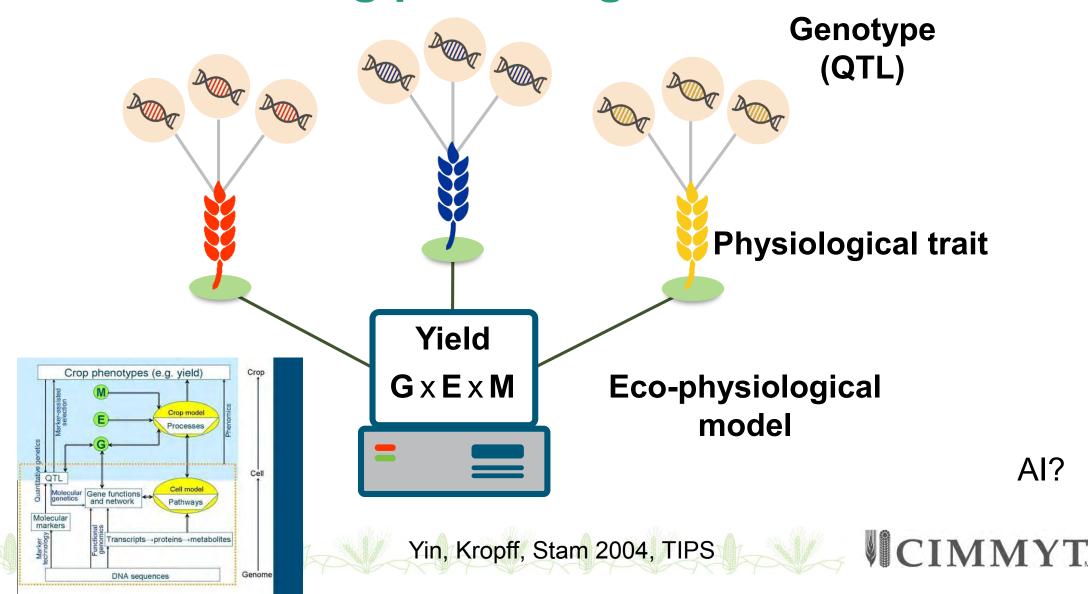








# Systems research: Breeding predicting G x E x M

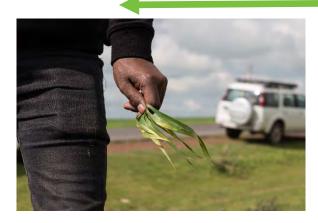


## Wheat Rust: Real-time, Mobile Pathogen Diagnostics

3 Days





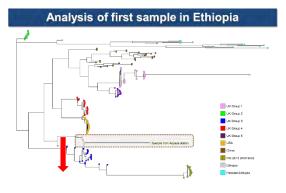


Field Sampling



MinION nanopore sequencing (Mobile)

- First field testing of Nanopore sequencing (MinION) in Ethiopia –Sept 2018
- First ever application on a rust fungal pathogen
- It works! Field samples to diagnostic in 3 days!!



fellow rust in Assasa station groups with samples taken in previous seasor

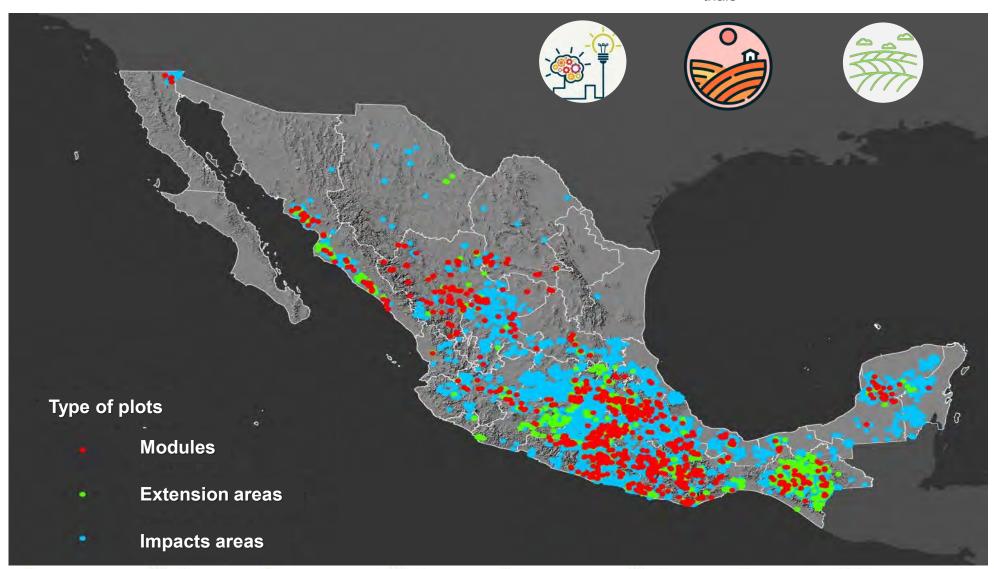
Diagnostics: Field Pathogenomics





>50 Platforms >600
On farm
comparative
trials

>35,000 Crowdsourced farms







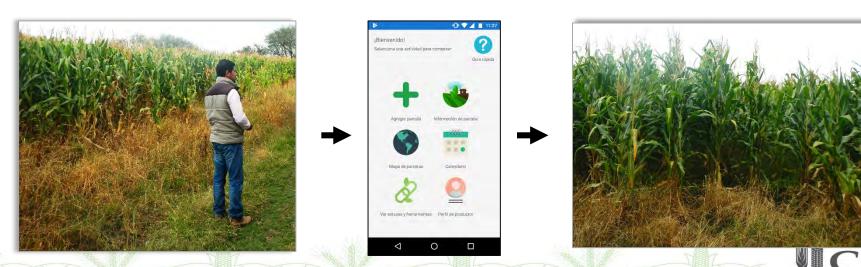
# Agrotutor: Sustainable intensification in Mexico through crowdsourcing

IIASA - CIMMYT collaboration project

Agrotutor: mobile farm management application

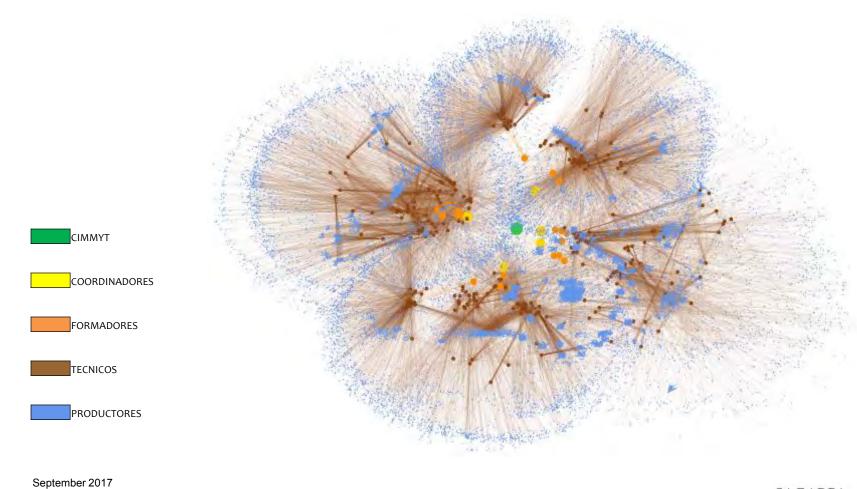


- Allows farmers to register and geo-locate parcels and crops among other functions
- For every geo-located parcel/crop, Agrotutor provides weather information and local benchmarking info on costs, income, etc.





## **Evolution of a network**

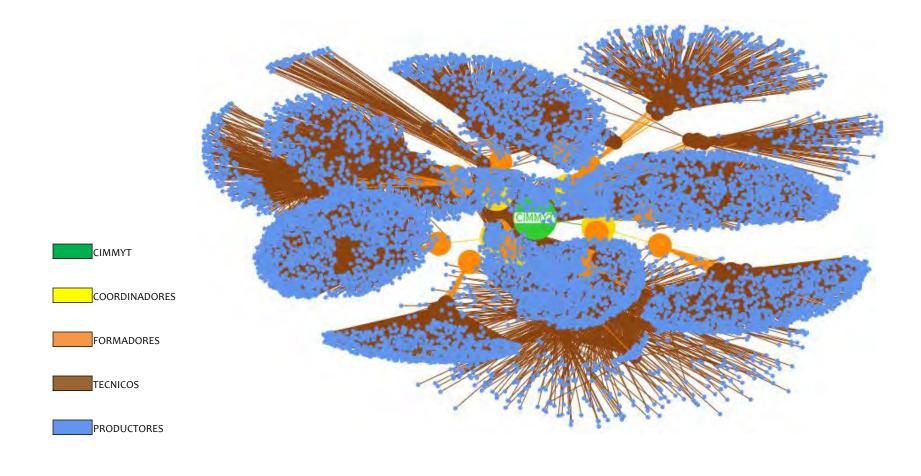








### **Evolution of a network**

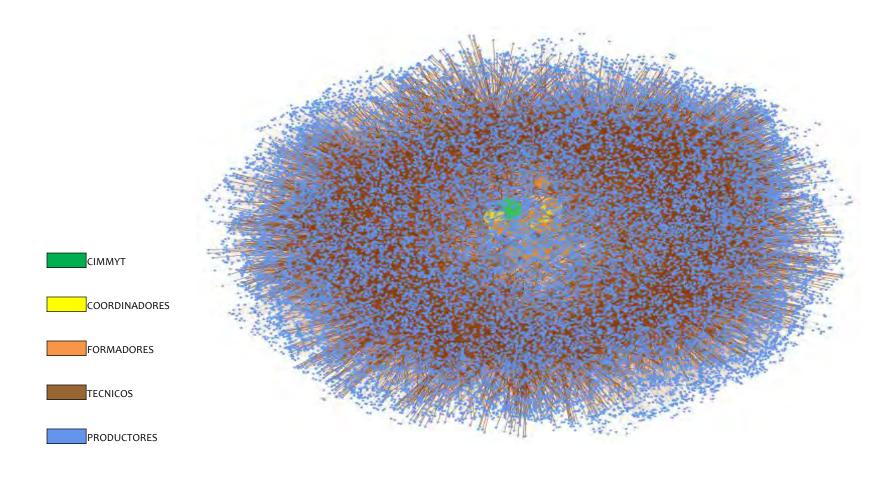


October 2017





### **Evolution of a network**



November 2017





## In this presentation

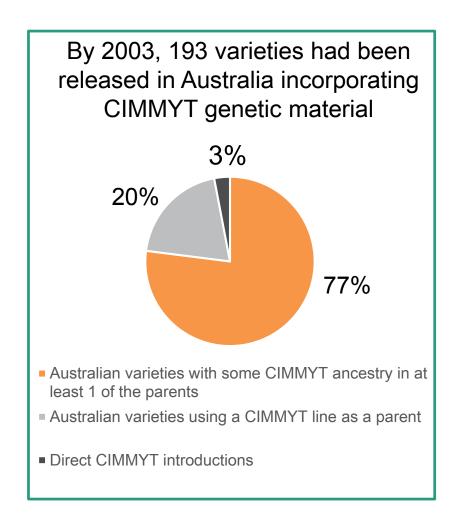
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## Germplasm exchange CIMMYT and Australia

- Net welfare gains for Australia from CIMMYT spillovers ~A\$30 million per year
- Australia has been importing CIMMYT material since the 1960s
- In most cases, CIMMYT lines used as parent lines in Australian wheat breeding programs







## notos: CAIGE

## CAIGE

- CIMMYT-Australia-ICARDA Germplasm Evaluation (CAIGE) project
- Every second year CAIGE participants visit CIMMYT or ICARDA and select wheat lines and import them to be tested in Australia









## Borlaug 100 – high yielding wheat

 Arrives in Australia in 2015 via CAIGE

 Success story: picked up by Rebel Seeds: "Has potential to replace any wheat going into the intensive livestock market."



Photo via graincentral.com

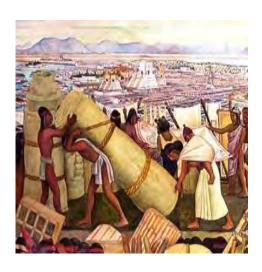




## **Diego Rivera Tlatelolco Market Mural**

















## Why organic farming is not the way forward

- an overview of significant findings

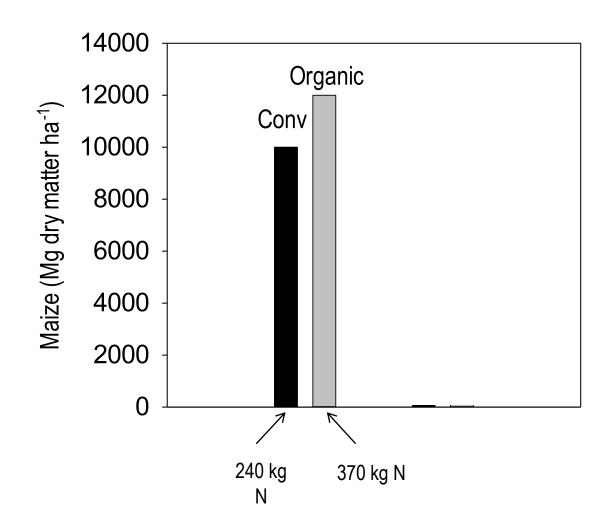


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Sciences (SLU)
Department of Soil and Environment,
750 07 Uppsala, Sweden
E-post: holger.kirchmann@slu.se

How are yields affected by conversion to organic farming?

### Yield data from conventional and organic experimental yields at the field and system level

Type of comparison	Relative organic yield (%)	Reference
META-ANALYSES		
Field level comparisons; n=382	80	De Pont et al. (2012) Agricultural Systems 108, 1-9.
Cropping system; n=316		
Legume production	95	Seufert et al. (2012) <i>Nature</i> 485, 229-234.
Best organic management	87	
Comparable system	66	
System and field level; n > 1000	81	Ponisio et al. (2015) Proceedings of the Royal
•		Society B. 2015. 218, 20141396.
Mean	<i>82</i>	

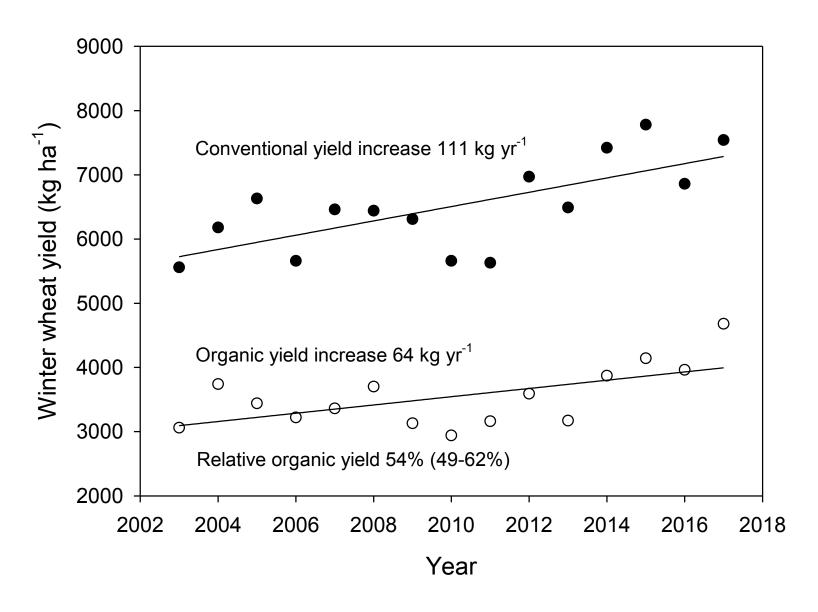


### Yields in organic and conventional long-term field experiments in Europe

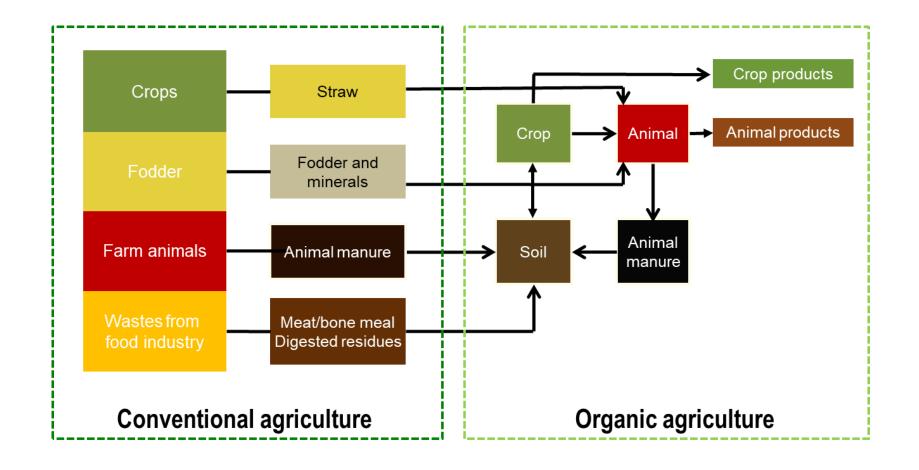
Long-term trials and crop	Yield (Mg h	na <sup>-1</sup> )	Decrease	N input (k	kg ha <sup>-1</sup> yr <sup>-1</sup> )	References
	Org.	Conv.	(%)	Org.	Conv.	
		Sys	tems with anim	nal husband	ry	
Norway Apelsvoll (8 yr)				121	227	Korsaeth & Eltun (2000)
Cerals	3.7	5.0	-26			Eltun <i>et al.</i> (2002)
Grass	8.3	10.7	-22			
Switzerland DOK (24 yr )				105	138	Spiess et al. (1993)
W-wheat	4.1	4.5	-10			Besson <i>et al.</i> (1999)
Grass	11.5	14.0	-18			Mäder <i>et al.</i> (2002)
Potatoes	30.0	48.0	-38			
Sweden Bjärröd (18 yr)				108	147	Kirchmann et al. (2007)
W-wheat	4.2	6.1	-31			
Mean			-24	111	170	
		Cro	op production s	systems only	y	
Sweden Mellby (6 yr)				71	97	Torstensson et al. (2006)
Oats	2.8	5.8	-52			
Sweden Lanna (6 yr)				84	134	Aronsson et al. (2007)
W-wheat	3.4	5.9	-42			
Mean			-47	77	115	

### Conventional and organic yields based on national statistics of Swedish agriculture for 2017

Type of Crop	Conventional yield (kg ha <sup>-1</sup> )	Organic yield (kg ha <sup>-1</sup> )	Relative organic yield (%)
Winter wheat	7540	4680	62
Spring wheat	4980	3140	63
Rye	6980	3910	56
Spring barley	5370	3180	59
Oats	4820	3130	65
Oil seed rape	3510	2310	66
Potato	32130	20230	63
Mean non-legumes			62
Legume-cereal forage	13170	12620	95
Peas	3560	2610	73
Beans	3890	2850	73
Grass-clover forage	6340	5570	88
Mean legumes			82



#### Transfer of nutrients from conventional to organic agriculture



When assessing organic yields, the contribution of nutrient inflows from conventional to organic farming are most often not considered

### Organic yields are partly relying on nutrient inflow from conventional farming

Conventional products	Import to mixed crop-animal production (n=35)	Import to organic crop production (n=11)
Concentrate and fodder	50 %	-
Straw	40%	-
Manure	10 %	27 %
Meat and bone-meal	-	10 %
Fodder minerals	26 %	-

Why are crop yields reduced when converting from conventional to organic production?

**Greater competition between crops and weeds** 

Lower mean nitrogen input at highly variable rates

Lower nutrient use efficiency



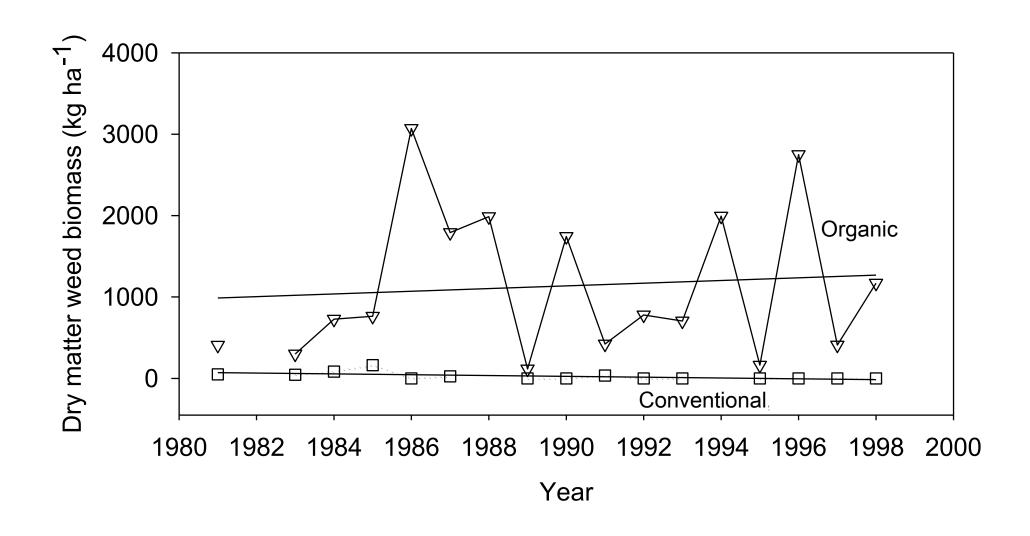




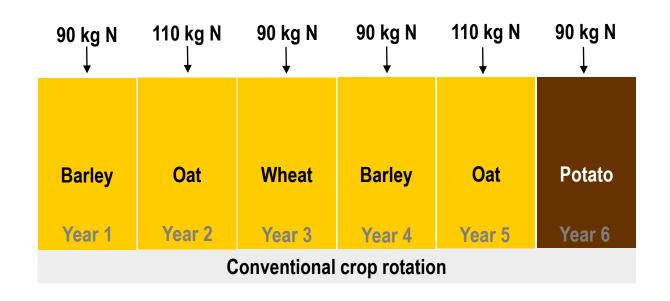


### Weed biomass development in the long-term trial at Bjärröd

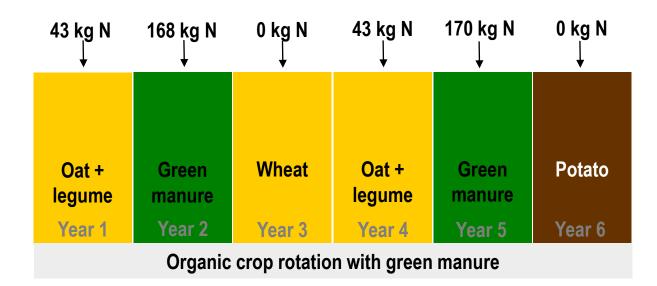
- intensive mechanical vs chemical treatment in the organic and conventional system, respectively



#### Nitrogen in- and output in an organic and conventional crop rotation (Mellby long-term study)



Mean N input 97 kg N ha<sup>-1</sup> yr<sup>-1</sup>
Mean N output 77 kg N ha<sup>-1</sup> yr<sup>-1</sup>
Utilization of N 79 %

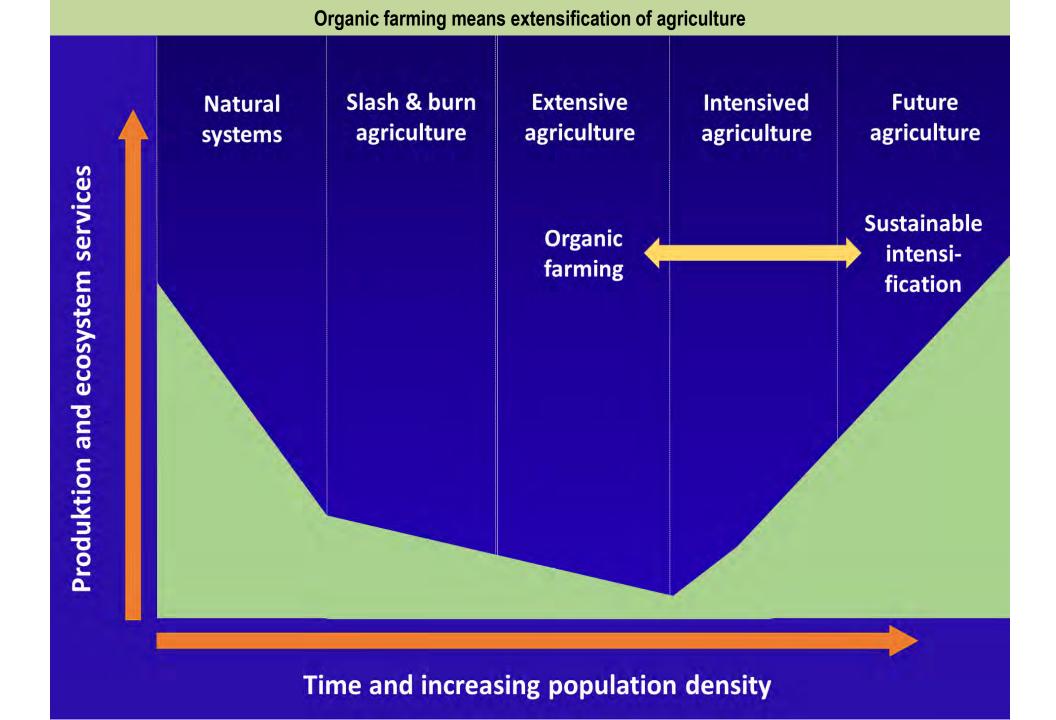


Mean N input
71 kg N ha-1 yr

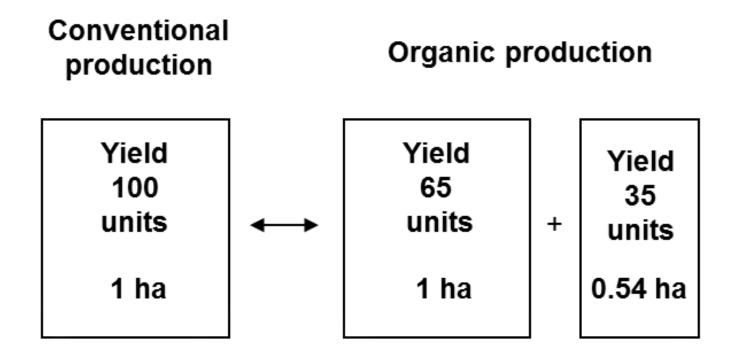
Mean N output
24 kg N ha-1 yr

Utilization of N 34 %

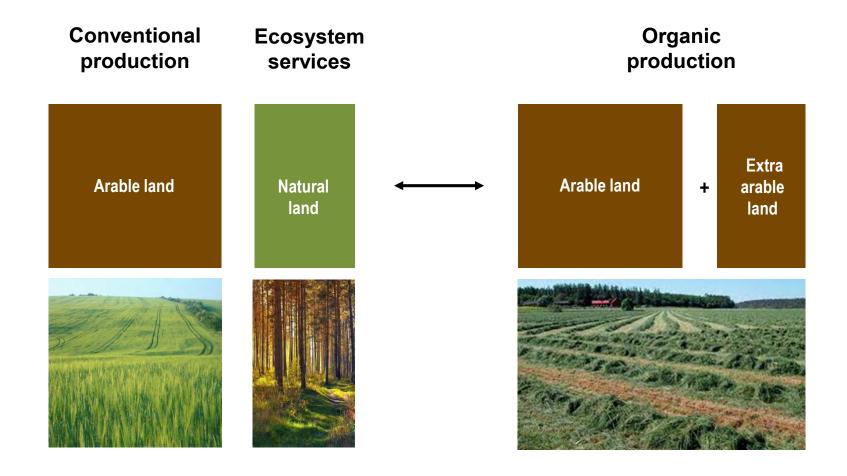
Torstensson et al. 2006. Agronomy Journal 98, 603-615.



Which are consequences of lower organic yields?



To produce the same amount of crops, a 35% yield reduction through organic farming requires about 50% more agricultural land.

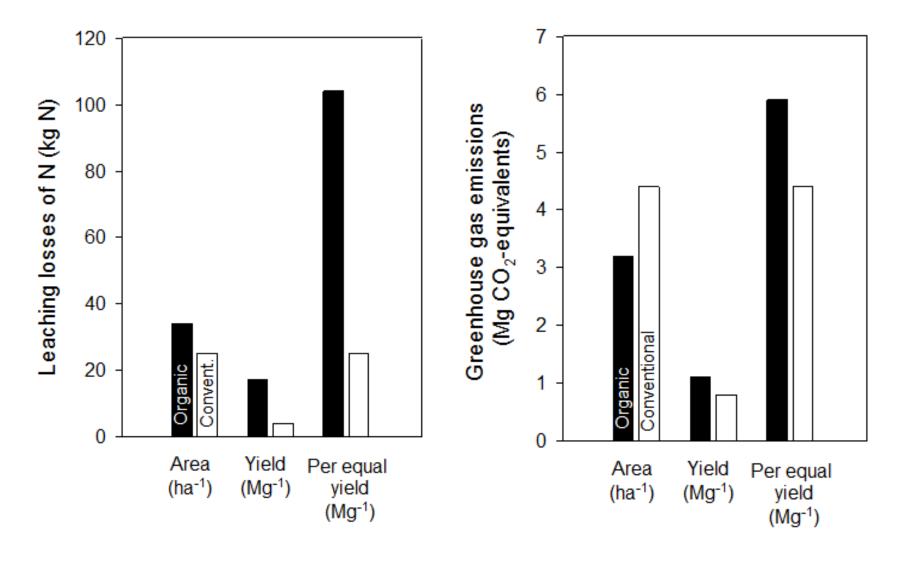


"Growing less food per acre leaving less land for nature." (Norman Borlaug)

# Impact of organic cultivation on supply of available crops (2017)

Crop	Conventional cultivation (% of arable la	Organic cultivation nd)	Relative areal difference (%)	Change of crops available due to organic conversion incl. yield reduction
Forage	49	63	+ 28	+ 11
Cereals	43	25	- 42	- 64
Oil seed rape	4	2	- 50	- 77
Peas and peas	1	3	+ 300	+ 120
Other crops	2	3	+ 33	-
Fallow	1	4	+ 400	

Does organic farming reduce nutrient leaching and is it climate smart?



Torstensson, et al. 2006. Agron. J. 98, 603-615.

Flessa et al. 2002. Agric. Ecosys. Environ. 91, 175-189.

### There is an opinion that organic farming sequesters more organic carbon in soil

(Gattinger et al., 2012)

"Meta-analysis from the farming systems database compiled for this study confirms higher SOC concentrations and stocks in top soils under organic farming".

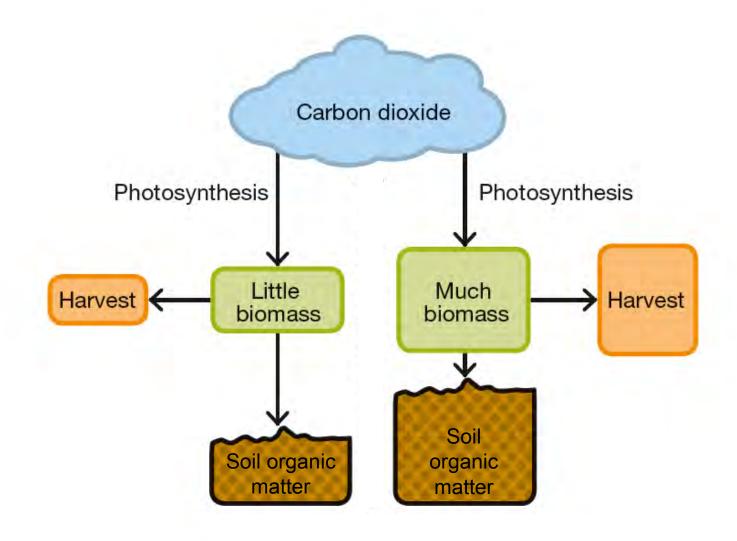
Reply to Gattinger et al. (2012) by Leifeld et al. (2013)

"we argue that their interpretation is biased. The bias mainly lies in a non-representative selection of conventional systems. In the study by Gattinger, 92% of the organic systems received external C inputs compared with only 27% of the conventional. The average external C input to organic farming was 4.14 times that of conventional farming for the full dataset...".

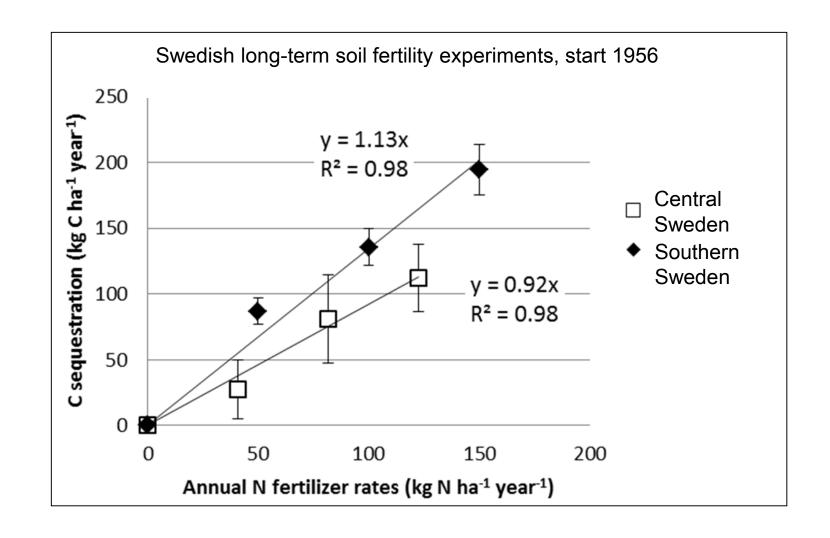
Gattinger, A. et al. 2012. Enhanced top soil carbon stocks under organic farming.

\*Proceedings of the National Academy of Sciences of the United States of America 109, 18226-18231.

Leifeld, J. et al., 2013. Organic farming gives no climate change benefit through soil carbon sequestration. *Proceedings of the National Academy of Sciences of the United States of America* 110, E984.

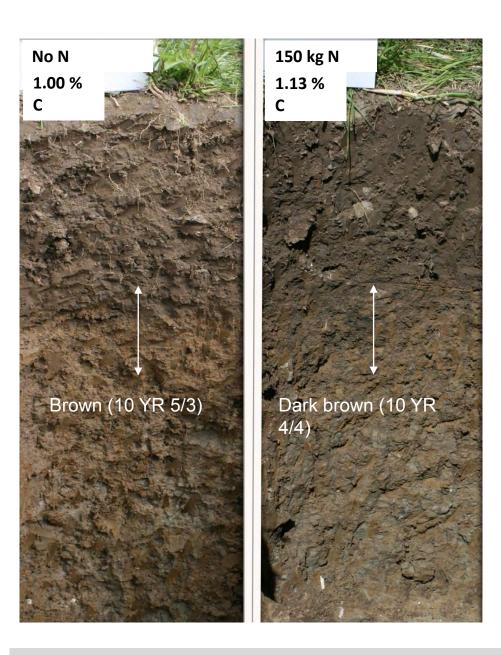


# Use of mineral N fertilizer increases the formation of soil organic matter

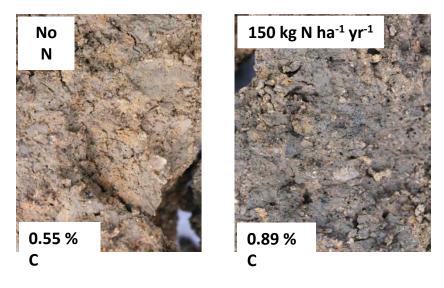


Kätterer, T. et al. 2012. Strategies for carbon sequestration in agricultural soils in northern Europe. Acta Agriculturae Scandinavica, Animal Science Section A, 62, 181-198.

# On average, 1 kg N fertilizer sequestered 1 kg soil organic C



Subsoil at 30 - 40 cm



Kirchmann, H. et al. 2013. Changes in subsoil properties after 50 years of nitrogen fertilizer application. Acta Agriculturae Scandinavica, Soil and Plant Science Section B 63, 25-36.

#### **Organic Cop Production – Ambitions and Limitations**

#### Free download of book chapters:

#### 1 Widespread Opinions About Organic Agriculture – Are They Supported by Scientific Evidence?

Lars Bergström, Holger Kirchmann and Gudni Thorvaldsson

http://pub.epsilon.slu.se/3508/

#### 2 Fundamentals of Organic Agriculture – Past and Present

Holger Kirchmann, Gudni Thorvaldsson, Lars Bergström, Martin Gerzabek, Olof Andrén, Lars-Olov Eriksson and Mikael Winninge

http://pub.epsilon.slu.se/3509/

#### 3 Can Organic Crop Production Feed the World?

Holger Kirchmann, Lars Bergström, Thomas Kätterer, Olof Andrén and Rune Andersson <a href="http://pub.epsilon.slu.se/3514/">http://pub.epsilon.slu.se/3514/</a>

#### **4 Plant Nutrients in Organic Farming**

Keith Goulding, Elizabeth Stockdale and Christine Watson

#### 5 Nutrient Supply in Organic Agriculture - Plant Availability, Sources and Recycling

Holger Kirchmann, Thomas Kätterer and Lars Bergström

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# 6 Synthesis of the Apelsvoll Cropping System Experiment in Norway – Nutrient Balances, Use Efficiencies and Leaching Audun Korsaeth and Ragnar Eltun

### 7 Use Efficiency and Leaching of Nutrients in Organic and Conventional Cropping Systems in Sweden

Lars Bergström, Holger Kirchmann, Helena Aronsson, Gunnar Torstensson and Lennart Mattsson <a href="http://pub.epsilon.slu.se/3511/">http://pub.epsilon.slu.se/3511/</a>

#### 8 How Will Conversion to Organic Cereal Production Affect Carbon Stocks in Swedish Agricultural Soils?

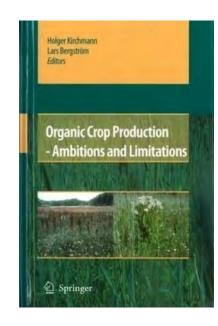
Olof Andrén, Thomas Kätterer and Holger Kirchmann

http://pub.epsilon.slu.se/3512/

#### 9 Energy Analysis of Organic and Conventional Agricultural Systems

Göte Bertilsson, Holger Kirchmann and Lars Bergström

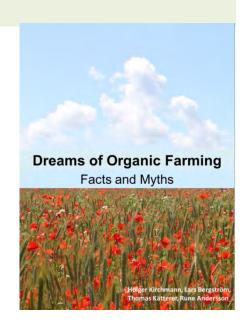
http://pub.epsilon.slu.se/3513/

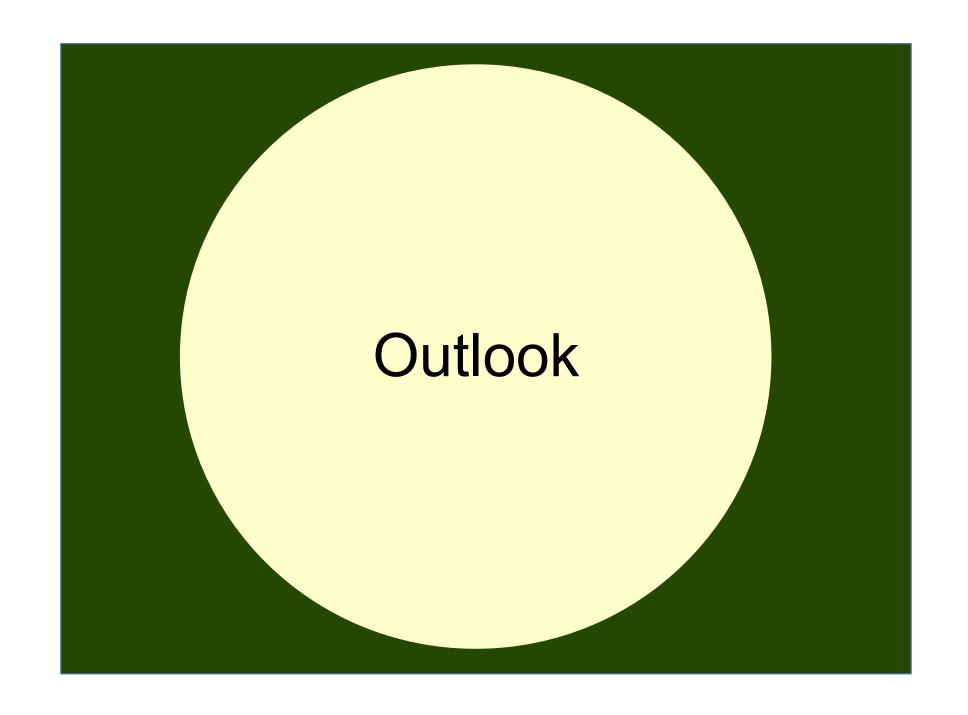


# **Dreams of Organic Farming – Facts and Myths**

Free book download <a href="http://pub.epsilon.slu.se/13967/">http://pub.epsilon.slu.se/13967/</a>

- 1. The rise of agriculture through the centuries
- 2. The roots of organic farming
- 3. Will we have enough food after converting to organic farming?
- 4. Is organic food healthier?
- 5. What about soil fertility and sustainable production capacity?
- 6. How does organic farming impact our waters?
- 7. Is organic farming climate smart?
- 8. Organic farming in practice
- 9. The road to a secure and environmentally friendly food production
- 10. Summary questions and answers



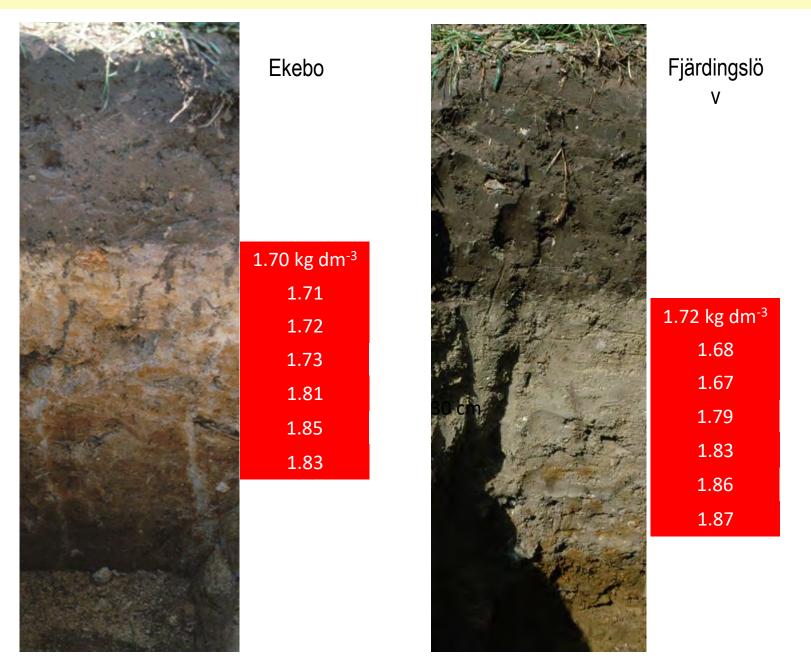


# **Examples of how to increase yields and make P fertilization sustainable**

> Improve subsoils for better root growth

Close the urban-rural nutrient cycle through new methods

# **Subsoil observation**



Bulk densities higher than 1.7 kg dm<sup>-3</sup> do not allow root growth

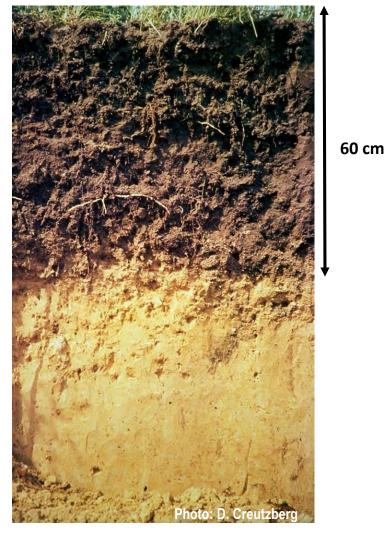
### Bulk density (kg dm<sup>-3</sup>) in subsoils of long-term soil fertility experiments in Sweden



# Are subsoils the key for higher yields?

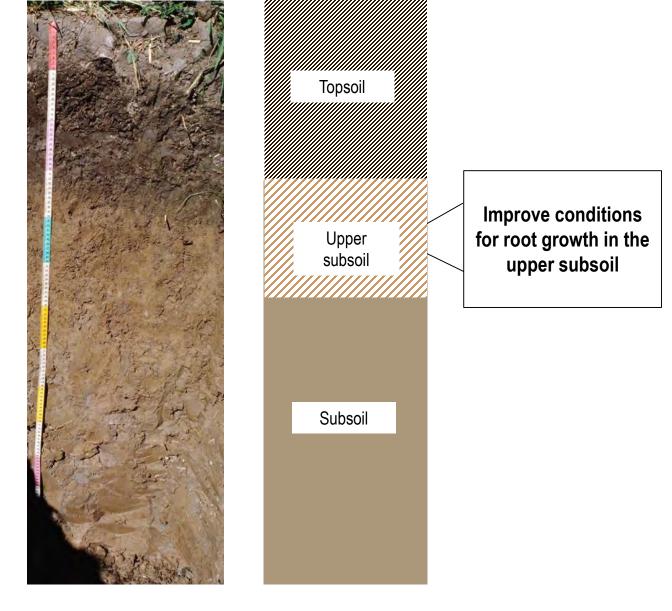


- Subsoils limit yields at several sites
- Subsoil development is a slow process
- Subsoil improvement is difficult



Haplic Chernozem, Germany

# The idea: subsoil improvement through incorporation of organic material



Typical profile

Subsoil melioration

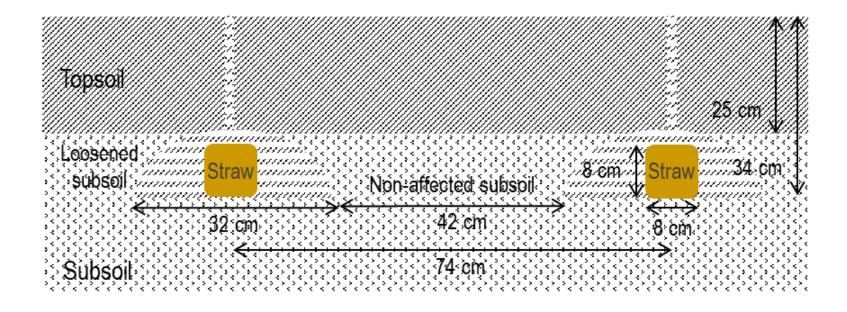
# Subtiller with outflow for straw slurry – first model











Straw application to subsoil: 237 kg straw per plot (23 700 kg ha<sup>-1</sup>) Revised estimate: 5-10% less (20 000 kg ha-1)

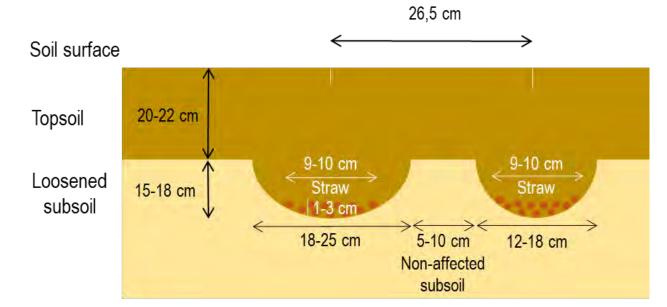
# **Preliminary results**

Treatment	Porosity (%)	Plant available water (mm in 29-34 cm layer)	Grain yield (Mg ha <sup>-1</sup> )
Control	47	14.5	4.65 (100)
Loosening	51	16.9	4.84 (104)
Lossening + straw	56	20.9	4.91 (106)

# Subtiller with outflow for pelletized organic material - second model







# A non-wanted nutrient flow in modern society

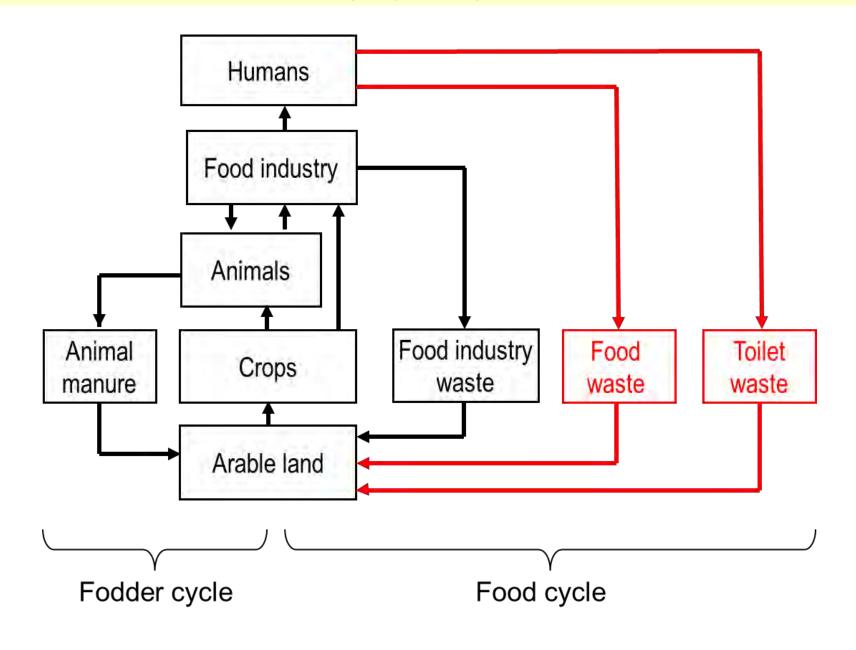
From fields to cities to disposal



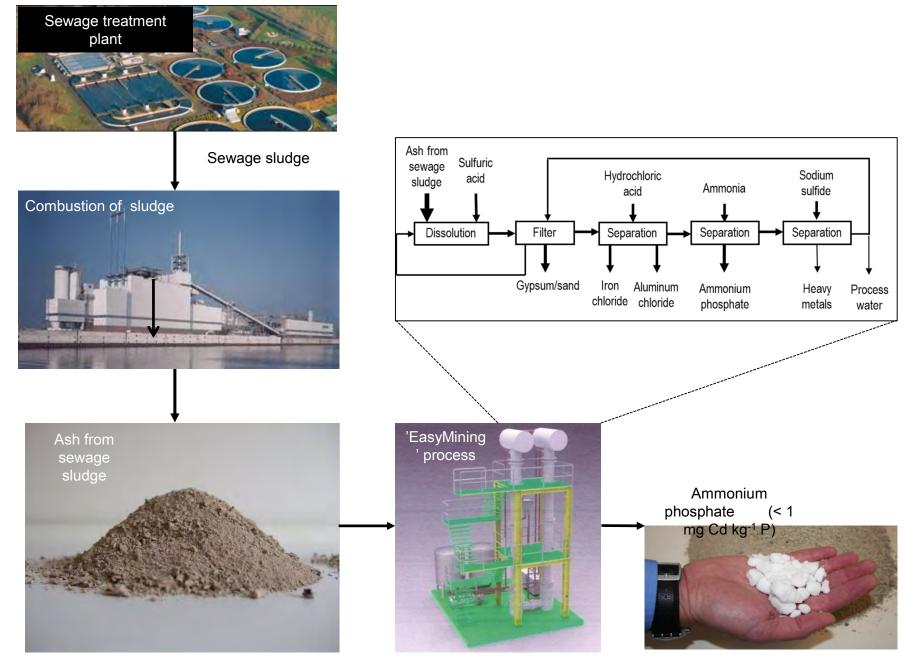




# Nutrient cycling in society is not closed



# Sustainable P fertilizer production from sewage sludge



Kirchmann et al. (2017) Ambio 46, 143-154. www.Easymining.se

# **Summary**

- Organic farming is characterized by lower yields due to greater weed competition, lower nutrient input and less efficient nutrient use.
- ➤ The challenge to use water, nutrients and energy most efficiently in crop production cannot be achieved through organic farming demanding use of natural means and methods only.
- ➤ Organic farming means extensification of agriculture requiring more arable land to produce the same amount of food.
- ➤ Organic farming has not shown to be able to decrease greenhouse gas emissons, increase carbon sequestration or reduce nitrogen leaching.
- ➤ Instead, developing methods that allow a sustainable intensification of agriculture with a minimum of environmental impact is the way forward.

Is the concept to exclude mineral fertilizer based on science?

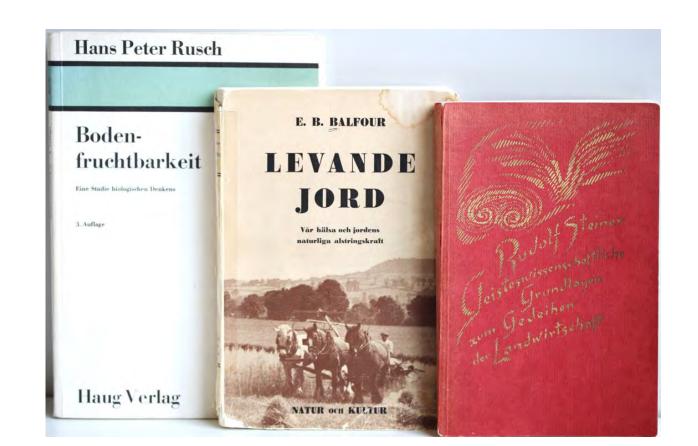
### Original European literature of organic agriculture

**Steiner, R. 1924.** *Geisteswissenschaftliche Grundlagen zum Gedeihen der Landwirtschaft.* Rudolf Steiner Verlag, Dornach, Schweiz, 1975.

Balfour, E.B. 1943. The Living Soil. Faber and Faber Ltd., London, England.

**Howard, A. 1947.** *The Soil and Health.* Devin-Adair Company. New York.

Rusch, H.P. 1978. Bodenfruchtbarkeit. Haug Verlag, Heidelberg, Germany.



### Citation of the original statement why to exclude mineral fertilizer in biodynamic agriculture

(Steiner, 1924)

page 12: "....die Produkte so degeneriert sein werden, dass sie noch im Laufe dieses Jahrhunderts nicht mehr zur Nahrung der Menschen dienen können."

.... the products will be so degenerated that these cannot be used as food for humans any more within this century.



**Rudolf Steiner** 

page 94: "Es weiss zum Beispiel kein Mensch heute, dass alle die mineralischen Dungarten gerade diejeningen sind, die zu dieser Degenerierung, von der ich gesprochen habe, zu diesem Schlechterwerden der landwirtschaftlichen Produkte das Wesentliche beitragen."

Nobody knows today that mineral fertilizers are those which significantly contribute to the degeneration of agricultural products I talked about.

Steiner, R. 1924. *Geisteswissenschaftliche Grundlagen zum Gedeihen der Landwirtschaft*. Rudolf Steiner Verlag, Dornach, Schweiz, 1975.

### The concept of biodynamic agriculture – manufacturing compounds to influence 'flow of forces'

(Steiner, 1924)

page 124: "Denn für die Pflanze sind viel wichtiger lebendige Kräfte als bloss die Substanzen" (Nährstoffe).

But for the plant, living forces are much more important than only substances (nutrients).

#### Preparation of compounds applied to soil

Cow manure put into cow horn buried in soil Powerded silica put into cow horn buried in soil

..... concentrates 'living forces'
..... concentrates 'cosmic forces'

### Prepration of compounds added to compost

Oak bark (Quercus robur) put into animal skull Yarrow flowers (Achillea millefolium) put into deer bladder Chamomile flowers (Anthemis cotula) put into cow intestine Stinging nettles (Urtica dioica) Dandelion (Taraxacum officinale) put into cow peritoneum Valerian flowers (Valeriana officinalis) ..... protects crops against diseases
..... enables correct cosmic deposition
..... have 'forces' stimulating plants

.... make soils reasonable

.... make soils take up cosmic silica

.... makes phosphorus to react properly

Steiner, R. 1924. *Geisteswissenschaftliche Grundlagen zum Gedeihen der Landwirtschaft*. Rudolf Steiner Verlag, Dornach, Schweiz, 1975.

# Citation of the original statement why to exclude mineral fertilizer by the British Soil Association

(Balfour, 1943)

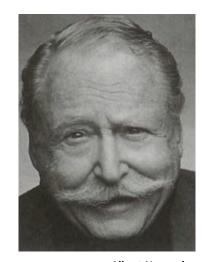
page 49: "Artificial fertilizers speed up the rate at which humus is exhausted".



Eve Balfour

(Howard, 1947)

page 26: "Humus is the most significant of all nature's reserves".



**Albert Howard** 

Balfour, E.B. 1943. *The Living Soil*. Faber and Faber Ltd., London, England. Howard, A. 1947. *The Soil and Health*. Devin-Adair Company. New York.

They postulated faster decomposition through use of mineral fertilizer.

Conservation and increase of organic matter in soil was regarded as being most important for healthy crops, animals and humans

### Is mineralization of soil organic matter accelerated by mineral N fertilizer?

Early <sup>15</sup>N isotopic studies revealed no significant impact of added mineral N on decomposition

Addition of mineral N fertilizer did not accelerate mineralization of soil organic N and the associated release of CO<sub>2</sub> under normal circumstances (Jansson, 1958).

Organic manures cause priming effect, not mineral fertilizer!!!

The priming effect (increased soil organic matter decomposition) is caused by an interaction of living and dead organic matter (Kuzyakov, 2010).

Jansson, S.L. 1958. Annals of Royal Agricultural College of Sweden 24, 101-361. Kuzyakov, Y. 2010. Soil Biology and Biochemistry 42, 1363-1371.

# Citation of the original statement why to exclude mineral fertilizer in biological-organic agriculture

(Rusch, 1978)

page 17: "... dass es sich bei der Kunstdüngung nicht um eine normale, physiologische und naturliche Pflanzenernährung handelt"

... that artificial fertilization is not a normal, physiological and natural form of plant nutrition.



Rusch, H.P. 1978. *Bodenfruchtbarkeit*. 3. Auflage. Haug Verlag, Heidelberg, Germany.

# **Concluding remarks**

- The statements of the founders of organic agriculture about mineral fertilizers were based on their view on nature - not observations or findings.
- Agricultural research has shown that their reasoning is not in accordance with our understanding of soil-crop-systems.
- There is no scientific evidence for the validity of the concept to exclude mineral fertilizer doctrine.
- The scientific community is obliged to follow rigorous scientific criteria - not biased views, prejudices or politically correct ideologies.

### Comments on biodynamic agriculture

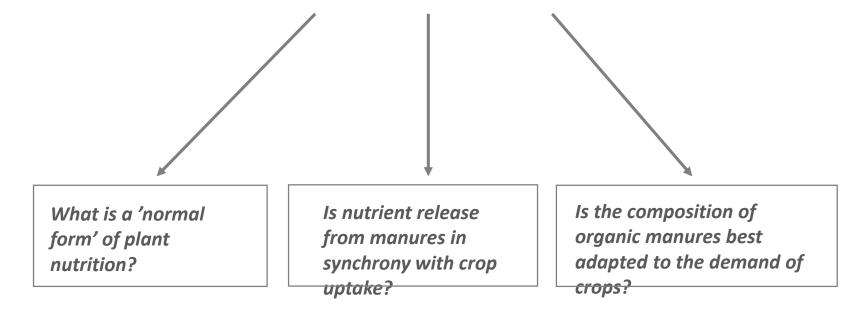
- Steiner's instructions to influence and control 'forces' were based on spiritual perception (clairvoyance).
- Steiner's statement on crop quality decline did not refer to scientific criteria: mineral, protein, carbohydrate or vitamin content.
- It has not been possible to test Steiner's instructions as no scientifically based hypotheses can be outlined.

Kirchmann, H. 1994. Biological dynamic farming – an occult form of alternative agriculture. *Agricultural and Environmental Ethic* 7, 173-187.

#### Are organic manures superior over artificial fertilizers?

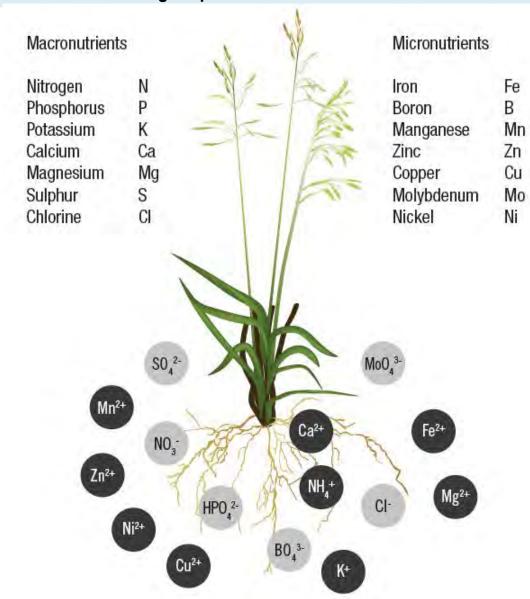
(Rusch, 1978)

"... that artificial fertilization is **not a normal, physiological and natural form** of plant nutrition".



Rusch, H.P. 1978. *Bodenfruchtbarkeit*. 3. Auflage. Haug Verlag, Heidelberg, Germany.

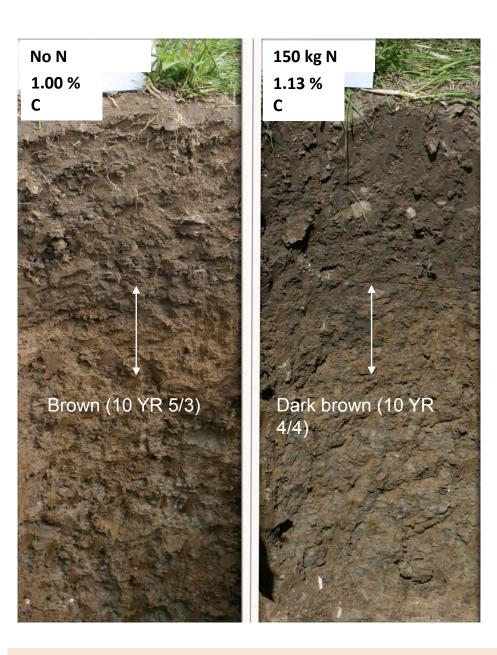
#### What is normal nutrition of higher plants?



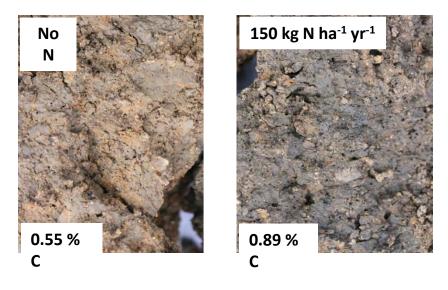
- Nutrients must be in water-soluble forms in order to be taken up by roots
- This refers to all nutrient sources urine, slurry, manures, compost or mineral fertilizers

Higher plants take up inorganic ions independent of their origin.

From the view of crops, nutrients in man-made fertilizers are as natural as nutrients added with manures, precipitation, irrigation, etc.



Subsoil at 30 - 40 cm



Kirchmann, H. et al. 2013. Changes in subsoil properties after 50 years of nitrogen fertilizer application. Acta Agriculturae Scandinavica, Soil and Plant Science Section B 63, 25-36.

### Even today, there is an opinion that chemical fertilizers have a negative impact on soil organic carbon - A recent controversy

(Gattinger et al., 2012)

"Metaanalysis from the farming systems database compiled for this study confirms higher SOC concentrations and stocks in top soils under organic farming".

Reply to Gattinger et al. (2012) by Leifeld et al. (2013)

"we argue that their interpretation is biased. The bias mainly lies in a non-representative selection of conventional systems. In the study by Gattinger, 92% of the organic systems received external C inputs compared with only 27% of the conventional. The average external C input to organic farming was 4.14 times that of conventional farming for the full dataset...".

Gattinger, A. et al. 2012. Enhanced top soil carbon stocks under organic farming.

\*Proceedings of the National Academy of Sciences of the United States of America 109, 18226-18231.

Leifeld, J. et al., 2013. Organic farming gives no climate change benefit through soil carbon sequestration.

Proceedings of the National Academy of Sciences of the United States of America 110, E984.

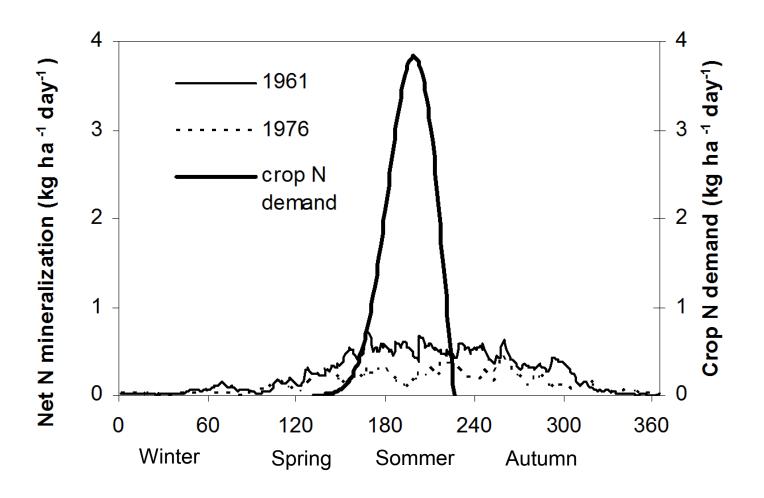
It is a myth that mineral fertilizers lead to lower soil organic matter in conventional farming

#### Organic manures and mineral fertilizers fulfil different functions in the soil-plant-system

Functions	Organic manures	Mineral fertilizers
Soil biological	Provide organic matter; affect mineralization/immobilzation	Increase SOM formation from residues
Soil chemical	Recycle plant nutrients; increase adsoprtion, buffering	Replenish nutrient depletion
Soil physical	Improve soil structure, water infiltration/retention	None
Plant physiological	Affect biomass and yield; influence crop composition	Splitted application determines biomass and yield formation; allow quality improvment; enable foliar application

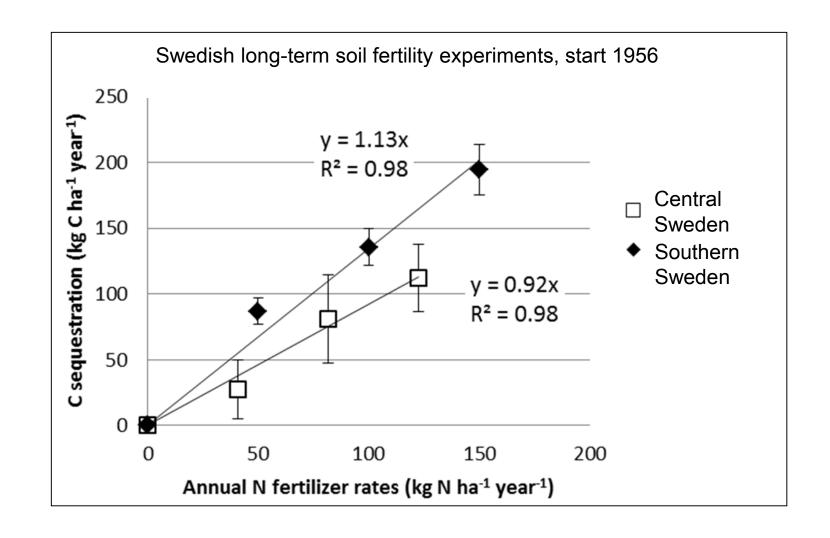
Organic manures provide water-soluble compounds, precipitates and organic matter mainly improving the soil.

Mineral fertilizers contain water-soluble plant nutrients feeding the crop. They are complementing each other



Kirchmann, H. et al., 2008. Organic Crop Production – Ambitions and Limitations. Springer Verlag.

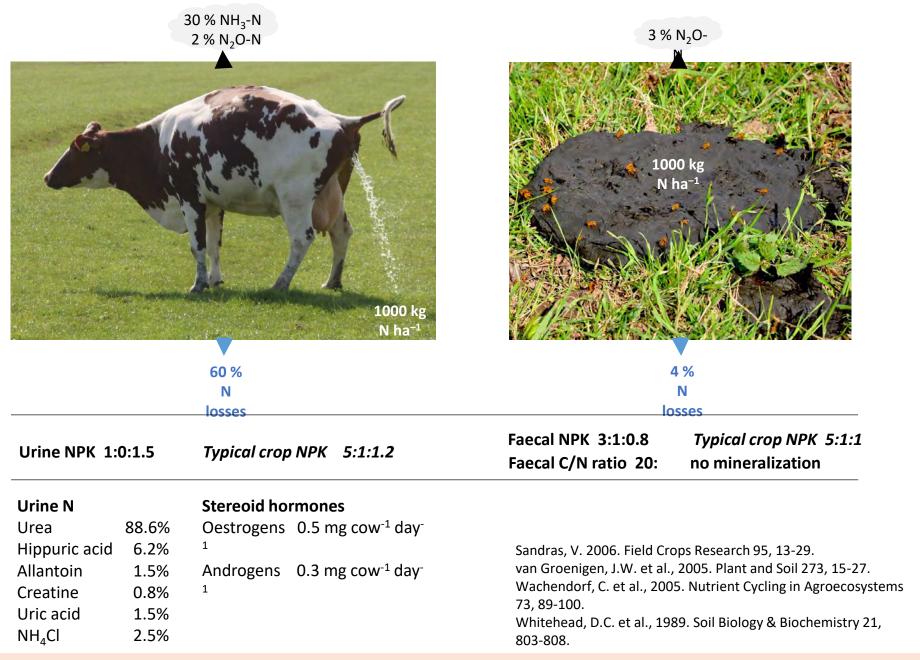
#### Use of mineral N fertilizer increases the formation of soil organic matter



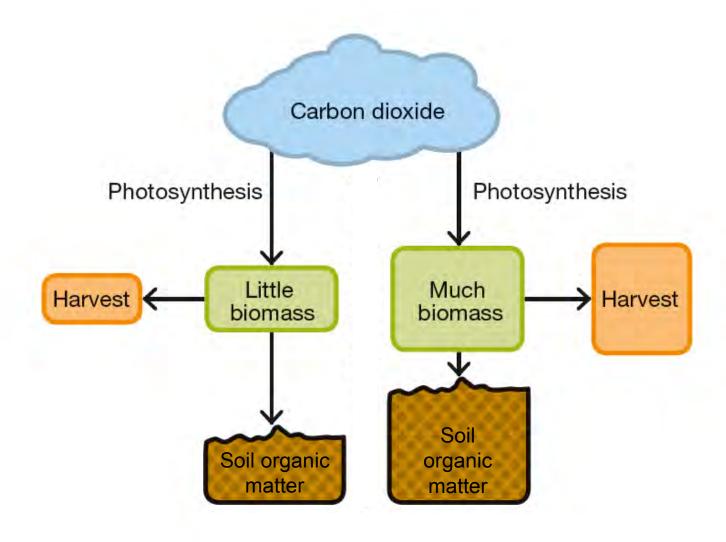
Kätterer, T. et al. 2012. Strategies for carbon sequestration in agricultural soils in northern Europe. Acta Agriculturae Scandinavica, Animal Science Section A, 62, 181-198.

#### On average, 1 kg N fertilizer sequestered 1 kg soil organic C

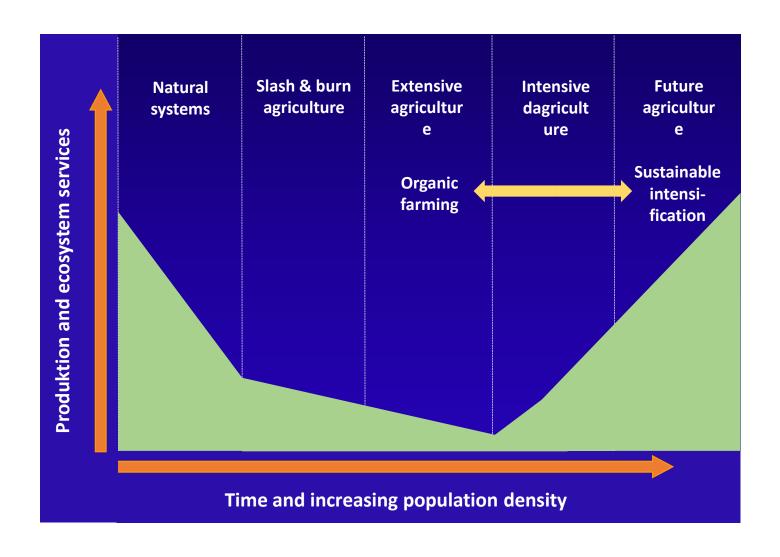
#### Grazing cows put the fertilizer right onto the ground where it belongs – but is it ideal fertilization?



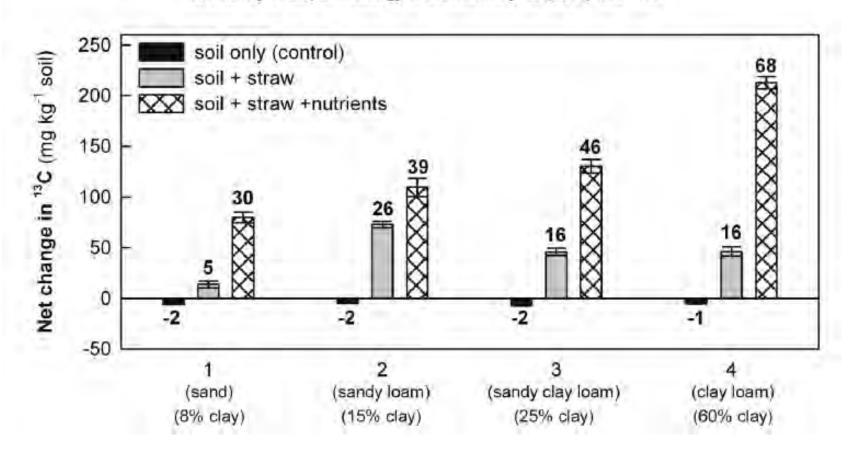
Excreted compounds do not match crop demand and are not necessarily environmentally friendly



#### Organic farming means moving back to extensive production

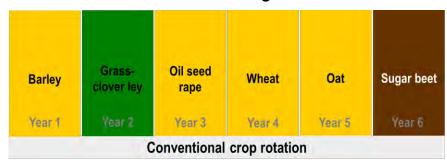


C.A. Kirkby et al. / Soil Biology & Biochemistry 68 (2014) 402-409



Kirkby et al. 2014. Soil Biology and Biochemistry 68, 402-409.

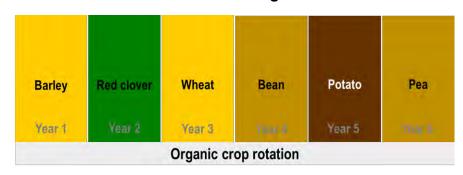
Mean 147 kg N



# Characteristics of cropping experiments

- N supply in organic systems: 75% of conventional addition
- Different crops in rotation, maximum use of legumes in organic rotations

Mean 111 kg N



Agronomic efficiency	
(kg yield increase kg <sup>-1</sup> N)	

	Barley	Winter-wheat
Conventional	18	16
Organic	9	10



# How to increase impact from research on the soil biota?

Arbuscular mycorrhizal fungi (AMF) as a case study

Dogma/group-think/soil health approach

Drivers of this approach

Importance of a systems agronomy approach

Megan Ryan and John Kirkegaard

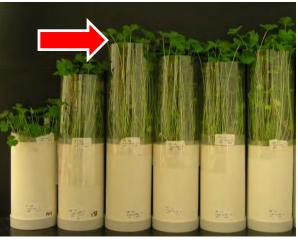
### Arbuscular mycorrhizal fungi



- Ubiquitous (does level of colonisation matter?)
- Easy to quantify abundance
- Close symbiotic relationship with plants (similar to rhizobia?)
- Clear benefits (in glasshouse)
  - Uptake of P and other nutrients (biofortification)
  - Soil structure
  - Drought and disease tolerance



With AMF



No AMF

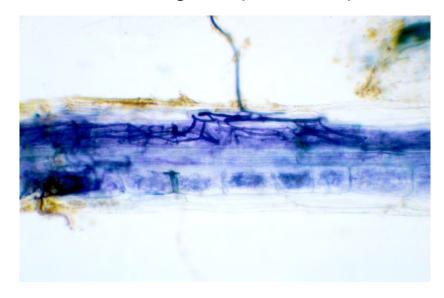


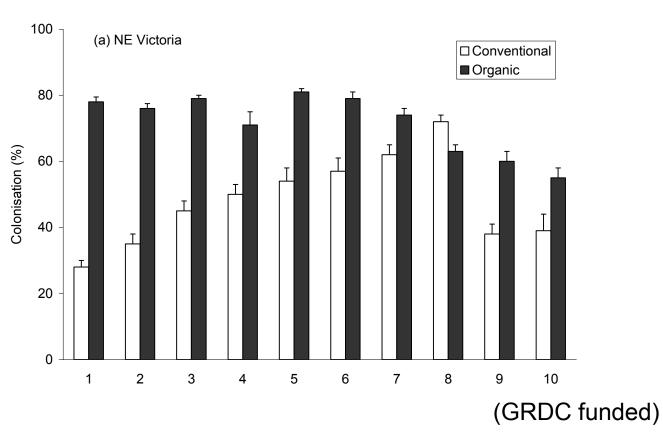
Increasing P →

## Biodynamic farming and AMF



- 20 farms paired
- Biodynamic no P or N fertiliser for up to 40 years
- Conventional average 27 kg/ha P and 17 kg/ha N as fertiliser
- Permanent, irrigated perennial pastures





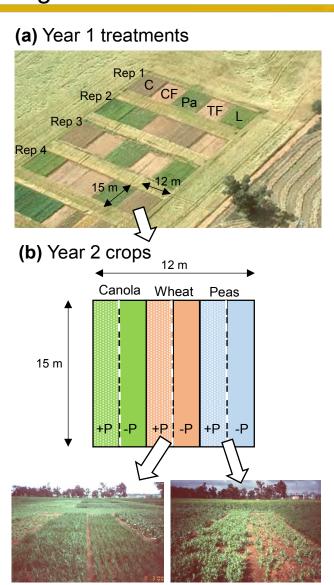
(Ryan et al., 2000; Burkitt et al 2007a, b)

# Should farmers manage AMF<sub>Fi</sub>(in Australia)?

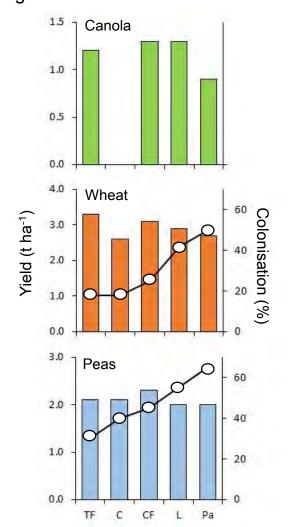


- Northern (subtropical Australia) long fallow disorder
- QUESTION: Southern Australia will canola induce long fallow disorder?
- Series of field trials
- ANSWER: No evidence that low AMF impacts crop yield (even if P limiting)
- Summarised in Ryan & Kirkegaard (2012)
- Higher wheat yield following canola

(GRDC funded; Ryan and Angus 2003 redrawn in Ryan and Graham 2018)



**(c)** Yield and mycorrhizal colonisation of Year 2 crops grown without P fertiliser



### Northern vs Southern

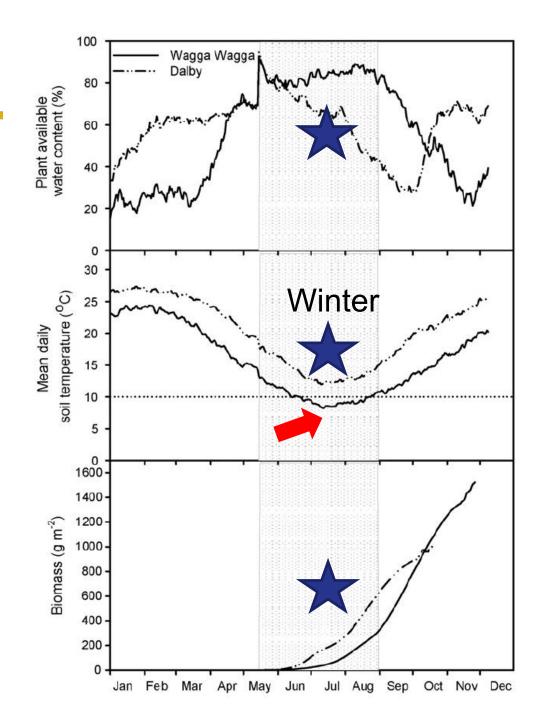
APSIM modelling for autumn sown wheat

Fast growth in north

Warmer soil temperature in north

10°C - root length colonised by AMF high (40%), but no external hyphae (Gavito et al. 2003)

Faster crop growth in north



(Ryan and Kirkegaard, 2012)

### Optimistic literature



**OPEN** 

The ISME Journal (2015) 9, 1053-1061

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**PERSPECTIVE** 

www.nature.com/ismej

The role of community and population ecology in applying mycorrhizal fungi for improved food security

Trends in Plant Science

#### Opinion

Soil Biodiversity Effects from Field to Fork

Towards an Integrated Mycorrhizal Technology: Harnessing Mycorrhiza for Sustainable Intensification in Agriculture

in Plant Science

#### Journal of Ecology

Journal of Ecology 2017, 105, 921-929

dei: 10.1111/136

Are mycorrhizal fungi our sustainable saviours?

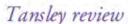
Considerations for achieving food security

## Should farmers manage AMF?



 Ryan and Graham (2018) conclude "no" (generally; will be exceptions)





Little evidence that farmers should consider abundance or diversity of arbuscular mycorrhizal fungi when managing crops

- Find that literature is "over-optimistic"
  - Glasshouse results assumed relevant to field
  - 2. Agronomic and AMF literature not consistent
  - Meta-analyses biased and lack agronomic context
  - 4. Co-occurrence of high colonisation and high yield assumed to be causal (and vice versa)
  - 5. Poor rigour with design and data analysis and interpretation of results in agronomic context

### Megan H. Ryan 1 1 and James H. Graham 2

Note – debate in NP letters (Rillig et al., in press; Ryan et al. in press)

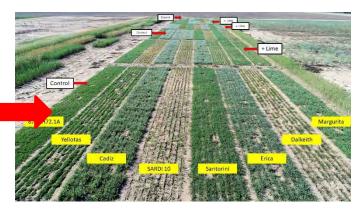
### Glasshouse experiments



- Poor field relevance
  - Lack cold temperatures
  - Regular watering
  - Small pots
  - No soil profile, homogenous
  - Lack environmental variation and extremes
  - Plant densities lack of sward







(MLA funded)





- Shoot DM decreased 10-30%
- Root DM decreased 40-60%
- Total rhizosphere carboxylates increased 2-6 fold (Jefferies et al. 2017)

### Research on AMF

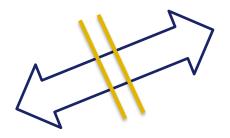


#### **AMF**

Increasing complexity of knowledge and (molecular) tools

Impact of AMF on plants differs with:

- AM species/strain
- Other soil biota
- Soil nutrients and ratios
- Environment



Agronomy

Knowledge and techniques

### Double the complexity!

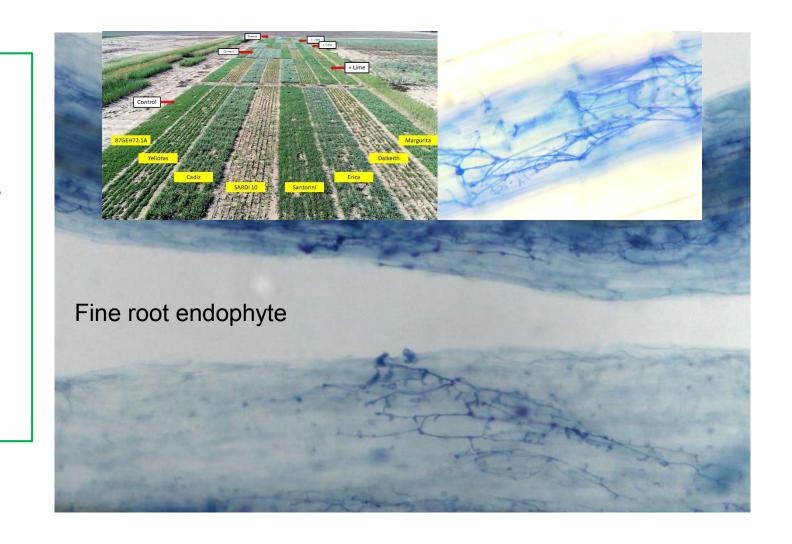


#### **AMF**

Increasing complexity of knowledge and (molecular) tools

Impact of AMF on plants differs with:

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### Research on soil biota



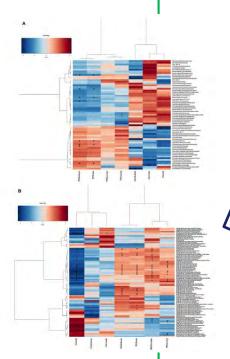
#### All soil biota

**AMF** 

Increasing complexity of knowledge and (molecular) tools

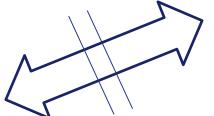
Impact of AMF on plants differs with:

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Agronomy

Knowledge and techniques



### "Soil biota approach"



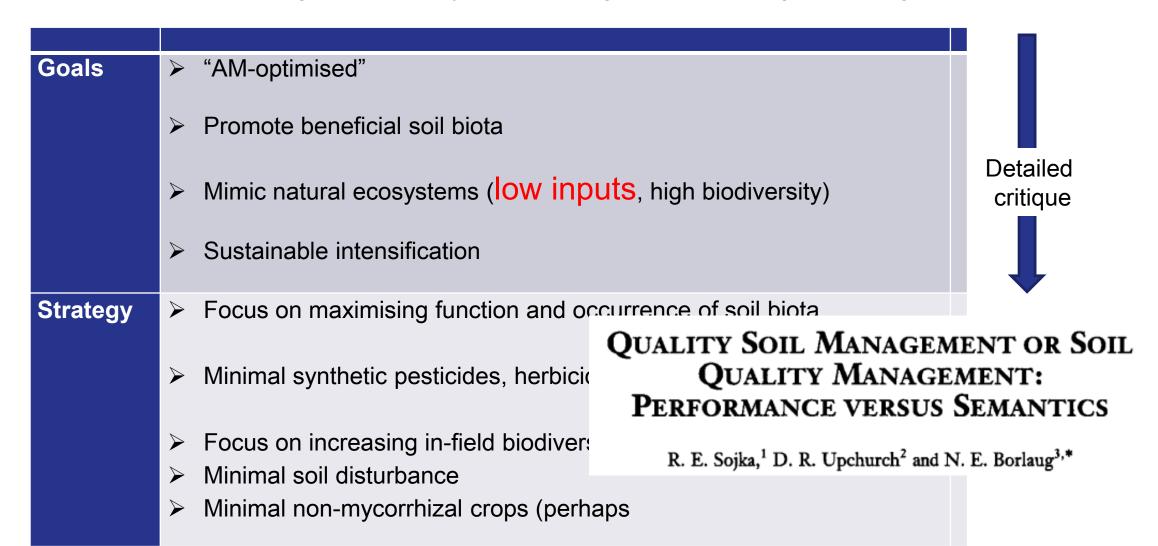
Arises from/interlinked with organic and biodynamic farming/"soil health" dogma/paradigm/approach

Goals	s "AM-optimised"	
	Promote beneficial soil biota	
	Mimic natural ecosystems (low inputs, high biodiversity)	
	> Sustainable intensification	
Strategy	> Focus on maximising function and occurrence of soil biota	
	Minimal synthetic pesticides, herbicides and inorganic fertilisers	
	<ul> <li>Focus on increasing in-field biodiversity</li> <li>Minimal soil disturbance</li> <li>Minimal non-mycorrhizal crops (perhaps</li> </ul>	

### "Soil biota approach"



Arises from/interlinked with organic and biodynamic farming/"soil health" dogma/paradigm/approach



## Low inputs leads to low outputs



		Biodynamic	Conventional
Soil	Extractable P (mg/kg Olsen)	8	19
Production	Milk (L/ha/year)	6814	10619
Soil biology	AMF colonisation (%)	71	48
	Rhizobium nodules (/ 10 cm root)	3.9	5.7
	Microbial biomass (mg/g)	538	510
	Earthworm biomass (g/m²)	59	87

- Soil biota can become nutrient limited
- Simple measures do not proxy "soil health"
- High AMF cannot replace P fertiliser

### Drivers for soil biota approach



- Prevalence of support for organic farming/soil health dogma
- University and funding bodies (e.g. ARC) assess capacity on journal impact factors: agronomy
  journals low impact
- Traditional journals for soil biology not agronomic → poor rigour in review and meta-analyses
- Reviewers and editors have insufficient agronomic knowledge to assess claims of agricultural relevance
  - "This conclusion [that AMF are crucial to yield in ag systems] comes from hundreds of experiments with plants in pots and there is no reason why in the field the situation will be different."
- No-one wants to rock the boat
- Everyone has a stake in getting more funding

### Journal impact factors



OPEN

The ISME Journal (2015) 9, 1053-1061

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**PERSPECTIVE** 

www.nature.com/ismej

The role of community and population ecology in applying mycorrhizal fungi for improved food security

Impact factor = 9.5

Trends in Plant Science

Impact factor = 12.2

Opinion

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in Plant Science

Impact factor = 3.7

Impact factor = 5.2

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Are mycorrhizal fungi our sustainable saviours?

Considerations for achieving food security

# Systems agronomy approach WESTERN AUSTRALIA



	AM-centric (soil health) approach	Systems agronomy approach
Goals	<ul> <li>"AM-optimised"</li> <li>Promote beneficial soil biota</li> <li>Mimic natural ecosystems (low inputs, high biodiversity)</li> <li>Sustainable intensification</li> </ul>	<ul> <li>Close yield gap while improving resource-use efficiency</li> <li>Sustainable intensification</li> </ul>
Strategy	<ul> <li>Focus on maximising function and occurrence of soil biota</li> <li>Minimal synthetic pesticides, herbicides and inorganic fertilisers</li> <li>Focus on increasing in-field biodiversity</li> <li>Minimal soil disturbance</li> <li>Minimal non-mycorrhizal crops (perhaps)</li> </ul>	<ul> <li>Benchmark current yield against physiologically determined potential</li> <li>Identify factors limiting yield or reducing resource use efficiency, and determine how to best address them, using modelling and field experimentation based on rigorous agronomic methodology. Inclusion of the principles of phosphorus-efficient farming systems</li> </ul>
		Address in a farming systems context using stepwise or simultaneous multiple (synergistic) practice changes

### Case study 1. P-efficient pastures



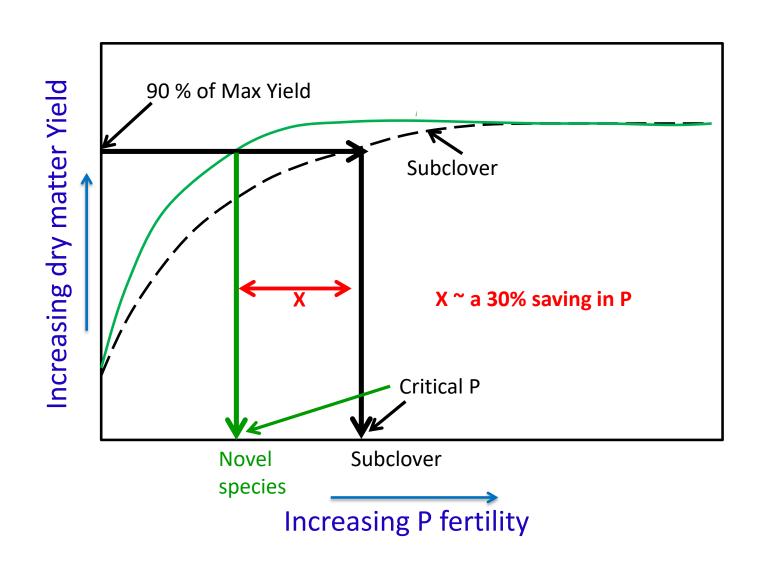
QUESTION: how do we make Australian pastures more P efficient?

Richard Simpson CSIRO

Funding: AWI, MLA, Rural Research and Dev for Profit

Collaborators: CSIRO, UWA, NSW DPI, Murdoch,

famer groups





## Used P-response curves to calculate external critical P requirements

#### Subterranean clover

- High external critical P requirement (field)
- Due to thick roots and short root hairs (large root hair cylinder volume) (glasshouse)
- Screened core collection
- Linked genomics platform

#### - Serradellas

- Low critical P requirement
- Maintain yield at lower available soil P

#### First - field



(AMF colonised)

Field soil

Not pasteurised (usually)

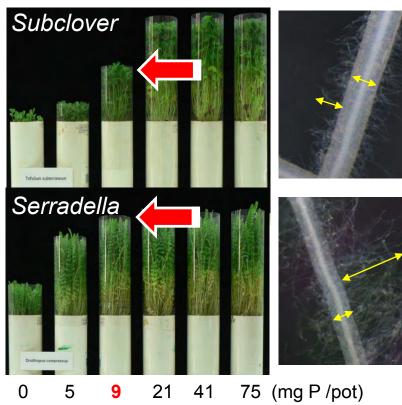
P stratified

Sward conditions

Grow for 6 weeks only

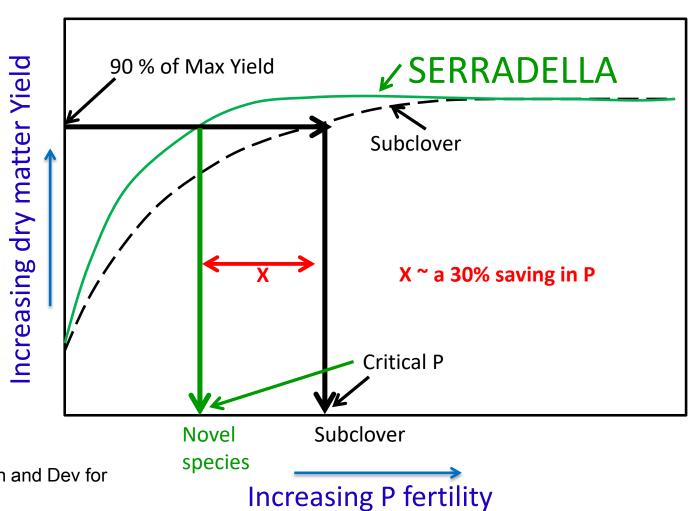
Density influences response

#### Second - glasshouse



(Ryan et al. 2016; Kidd et al. 2016, Haling et al 2017a, b, Sandral et al in press, etc)





Funding: AWI, MLA, Rural Research and Dev for Profit

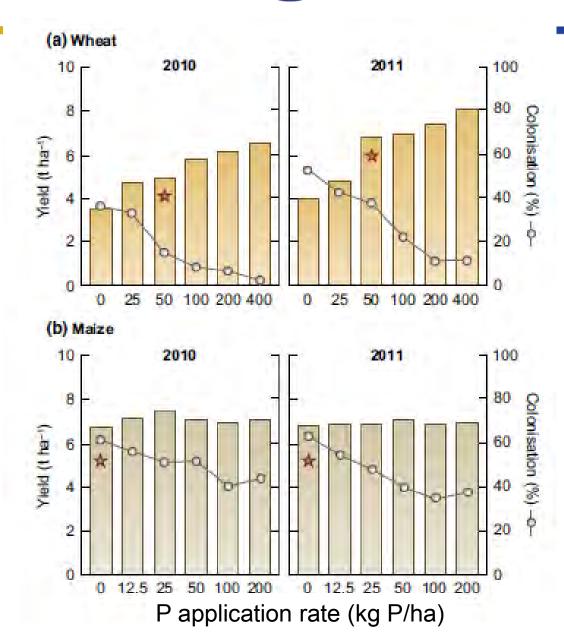
Collaborators: CSIRO (Richard Simpson), NSW

DPI, Murdoch, famer groups

### P-efficient farming systems

WESTERN AUSTRALIA

- Manage soil P to meet crop critical external P requirement
- For example: Deng et al. 2017 (China)
- The critical soil-extractable P was 22 mg/kg
- To optimise yields of wheat and maize, it was calculated that this could be maintained through application of 45– 50 kg P/ha in each wheat–maize rotation with application to the wheat (stars)
- AMF colonisation is reasonably high
- Contribution of AMF to plant growth remains unknown!
- AMF-benefits gained, but not "AM-optimised"
- No need to manage AMF in a P-efficient farming system



## Case study 2. No-till farming



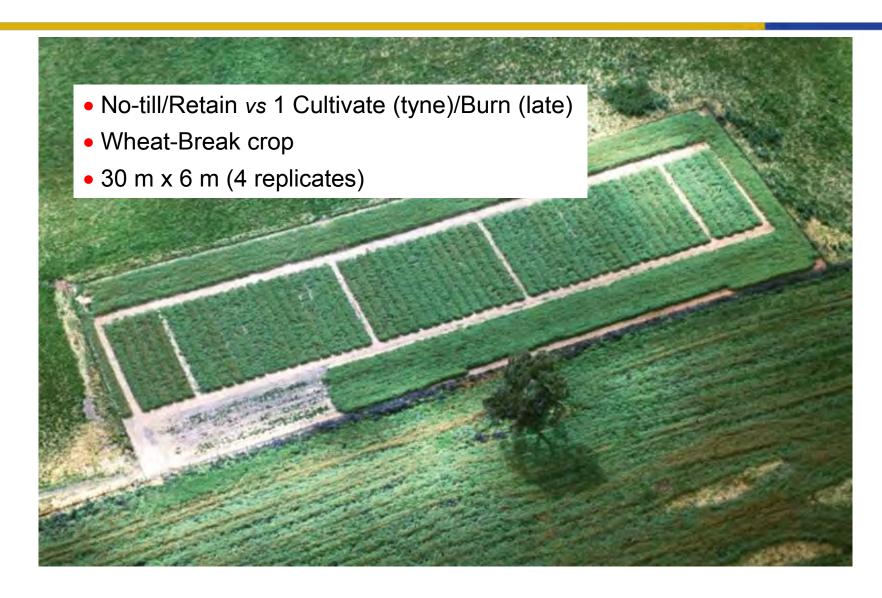


### Harden long term study



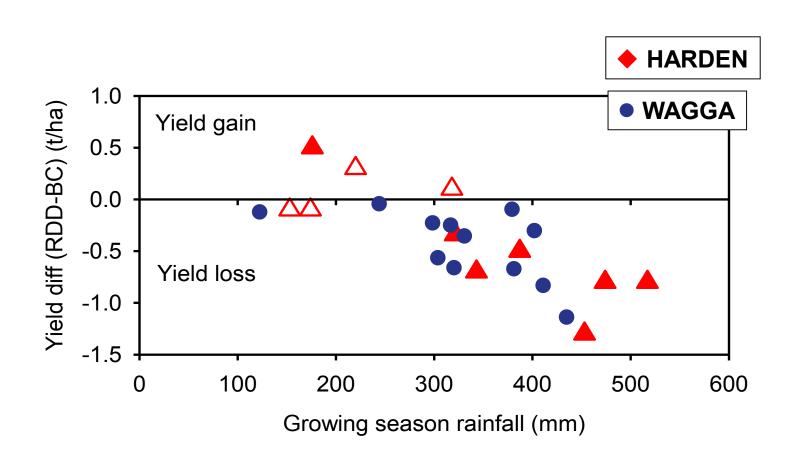






#### No till = lower yields

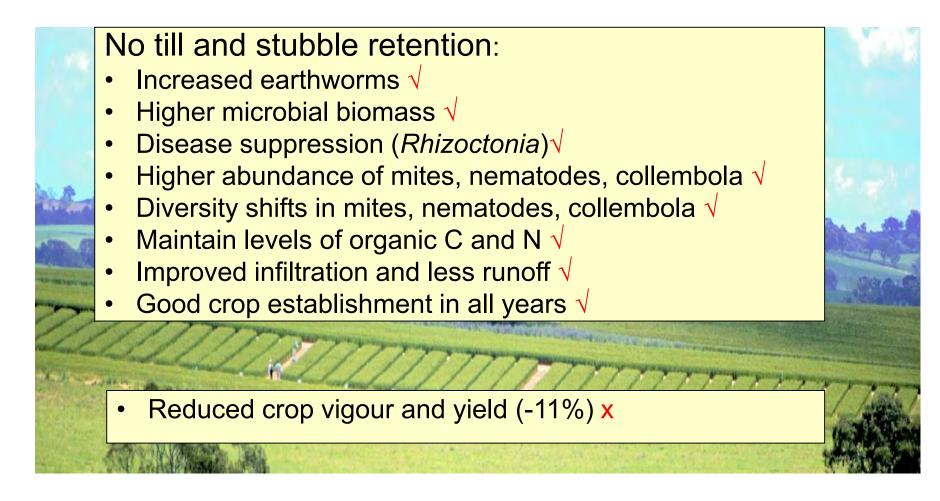




#### No till and soil health



(Harden NSW, commenced 1990)



#### Biological yield constraint

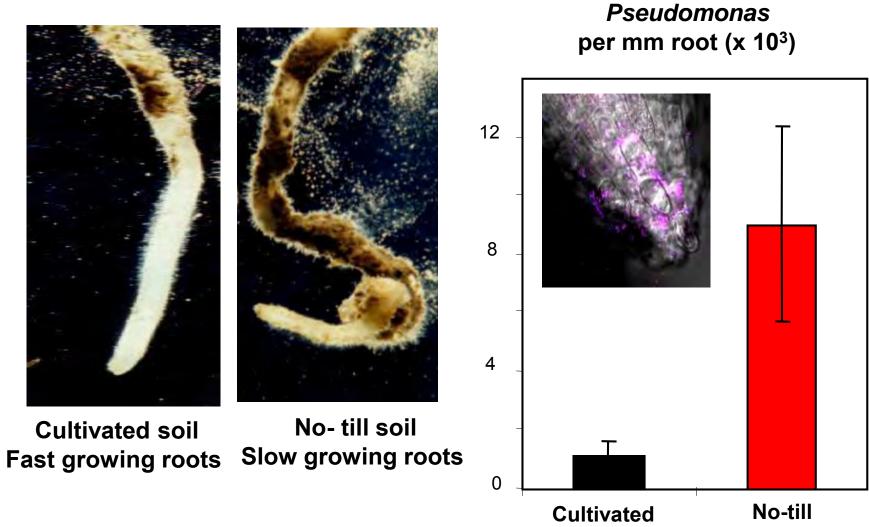




(inhibitory Pseudomonas, Simpfendorfer et al., 2002)

#### Inhibitory bacteria on root tips





(Watt et al 2005, 2006)

#### Solution: improve root vigour



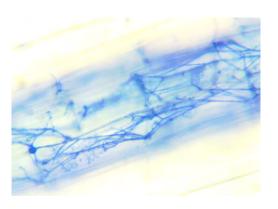
#### **Encourage rapid root growth**

 Sow early into warm soil ed using deep points Optimising "soil health" had no relationship with yield et al 2005) 30 years of field work to understand system

### How to increase impact from research on the soil biota?



- No simple measures of soil (biota) health
- "Soil biota approach" leads to research that is an "expensive distraction"
- Soil biota research need to address clear questions using a systems agronomy approach
- Well managed field trials using contemporary agronomy are essential
- Glasshouse trials should be field-relevant
- It's important to LOOK!









#### The multi-dimensionality of water use. Simple indicators, society concerns, and scientific rigour: the example of the water footprint

#### M. Inés Mínguez and Francisco J. Villalobos

(ines.minguez@upm.es and ag1vimaf@uco.es)

Making science useful to agriculture Adelaide, 26-29 Nov 2018







#### Outline

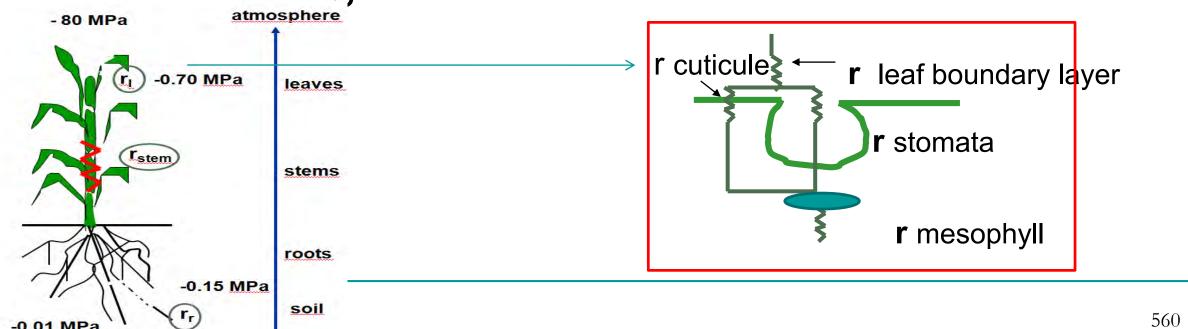
- Processes: water use and canopies
- Crop water productivity (WP) WUE
  - The attraction of oversimplification and the water footprint WF
  - The multi dimensionality of water use
- Bottlenecks in water use research: smallholder farmers
- Summarising



scale 2

#### Processes: water use and canopies

- CO<sub>2</sub> diffuses from air through stomata into leaf mesophyll as a result of concentration gradient
- In parallel, the water potential gradient between leaves and the atmosphere results in evaporation from stomata of crops or natural vegetation



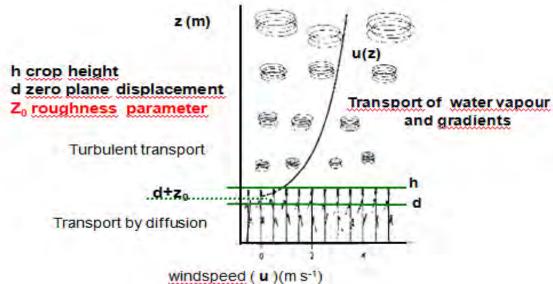
#### Processes: water use and canopies

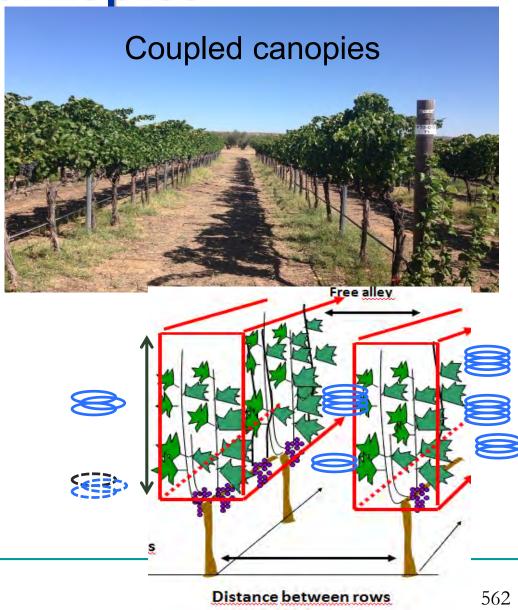
- The atmosphere is an enormous water vapour sink
- Evaporation from soil and leaves (transpiration) is a passive process, f(energy, water and vapour gradient)
- If water is available, arid and semiarid regions will have larger evaporation than regions with conditions such as those of northern Europe

 Not all crops behave similarly as a consequence of their canopy conductance

#### Processes: water use and canopies



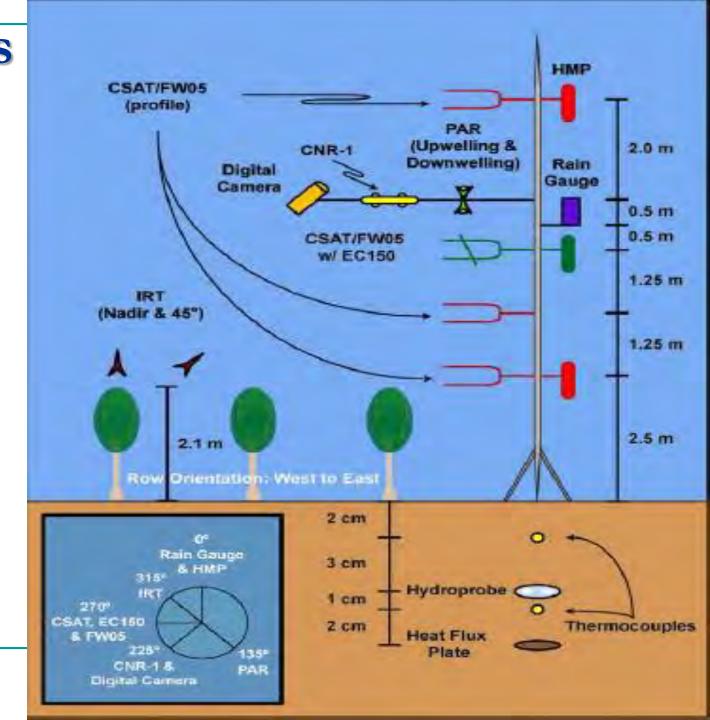




# Monitoring processes GRAPEX project Central Valley, CA

- Understand E & mass transfers
- Monitor Ta, Tc, wind, vapour,
   & CO<sub>2</sub> profiles
- Monitor soil moisture, Ts,& heat fluxes
- Vine water use via sap flow
- High resolution airborne imagery

(J.G. Alfieri. Hydrology & Remote Sensing Lab. and J.H. Prueger. National Lab. for Agriculture & Environment, USDA ARS)



### Processes: water use and canopies Scale 1

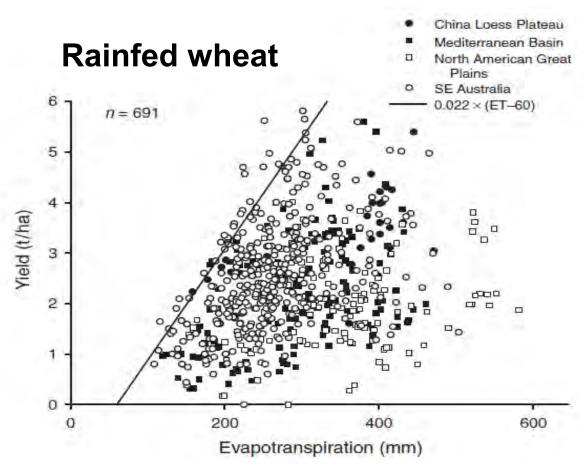
- In highly technified agriculture <u>small decreases in WU</u> represent large irrigation savings in large areas such as ca 25000 ha GRAPEX (350 000 ha of vines in California)
  - Changes in row orientation, in d (zero displacement plane), zo (roughness length) linked to vegetation height and LAI, may have an impact on WU
  - Vine monitoring for improving irrigation scheduling
  - A further step to add to Control Deficit Irrigation

#### Crop water productivity (WP)

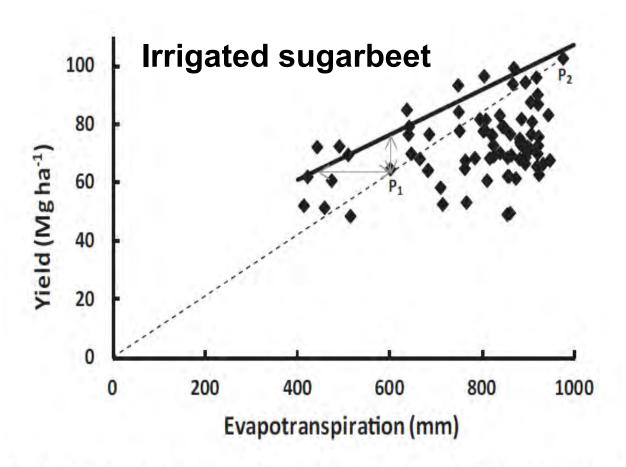
- WP: yield / WU or € / m³) show large variations among crops, locations, and time scale,
  - Diurnal and seasonal variations (WUE)
  - Variations between fields, farms, and years
- Leaks in WU research: the attraction of oversimplification and the water footprint WF

The multi dimensionality of WU

#### WP at field level: scattered and variable



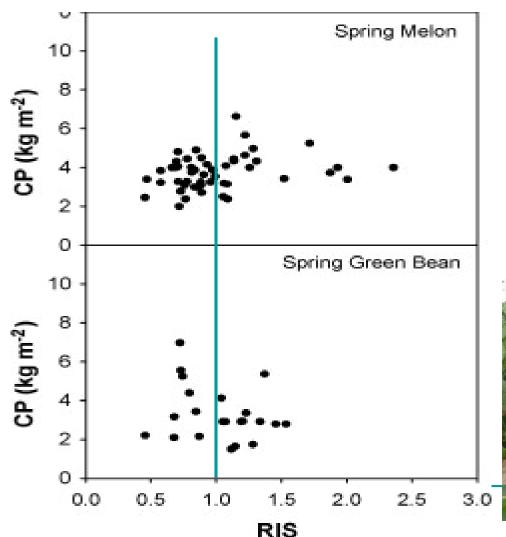
Scatter plot of rainfed wheat grain yield and seasonal ET in 4 mega-environments (Sadras and Angus 2006, based on others).



**Fig. 3.** Scatter plot of sugarbeet yield vs. remote sensing-estimated evapotranspiration and experimentally-derived yield-ET function.

Mateos and Araus, 2016

### WP at field level: scattered and variable. Irrigation management



Relationship between values of <u>crop</u> <u>productivity</u> (CP) and relative irrigation supply (RIS) for <u>greenhouse crops</u> on the Almería coast.

The vertical line (RIS=1) indicates when actual irrigation = Irrig. Requirement



#### The attraction of oversimplification: WF

The water footprint WF is L of water / kg of produce

- Footprint implies human intervention (as in Carbon F)
- The large variations in WP among locations, time scales and crops should be reflected in WF
  - WF has 3 independent components: GWF, BWF, GWF
  - Green WF: supplied by stored soil water
    - BlueWF: supplied by stored water resources
    - GreyWF: amount of fresh water required to assimilate or dilute
    - pollutants (Hoekstra and Mekonnen, 2012)

#### The attraction of oversimplification: WF

The two main flaws of the WF are:

1) The GWF of a crop can be less than the water consumption of native vegetation and downstream water availability is actually increased by rainfed agriculture

2) The total water consumption of a crop ("blue" + "green") is computed as the maximum potential crop ET, which is often significantly higher than actual crop ET. This error is serious for rainfed systems with low productivity

(Fereres et al., 2017)

#### The attraction of oversimplification: WF

- Publications on WF of irrigated crops (climate +crop models) or on the WF of Mediterranean diet are multiplying
- WF for decision makers and politicians as a "measurable indicator that may support European water governance" (Gobin et al., 2017)
- WF along with Carbon Footprint is proposed to be inserted on food packages to inform discerning consumers

#### Corrected water footprint WF\*

- An "Ecological water footprint" could be established against a reference natural vegetation (ET\*)
- WF\* = increase in consumed water / yield
- WF\* = (ETactual ET\*) / yield
  - ETactual in rainfed or irrigated conditions
  - □ ET\* =  $\sum$  ETo during crop growth
  - Where the sum of ETo is greater than seasonal rainfall then ET\*= rainfall in order to not overestimate the use of water by natural vegetation

#### WF vs WF\* in rainfed wheat (North High Plateau, Spain)

- Rainfed wheat yields based on 7-year yield statistics
- Yavg Valladolid: 2759 kg/ha ± 842; Burgos: 3804 kg/ha ± 411
- ETcrop = seasonal rainfall; ET\*= rainfall

WF =	ETc rainfed/yield (L/kg)	Avg	SD
Valladolid	(2006-07 to 2012-13)	998	494
Burgos	(2006-07 to 2012-13)	1090	242
WF*= (ETc rainfed-ET*)/yield (L/kg)			
WF*= (	ETc rainfed-ET*)/yield (L/kg)	Avg	SD
WF*= (I	ETc rainfed-ET*)/yield (L/kg) (2006-07 to 2012-13)	Avg 0	<b>SD</b> 0

#### WFvsWF\* in irrig fababeans ETmax;Ymax 6200-6800 kg/ha

WF = ETmax/yield (L/kg)	1986-1987	1987-1988
Faba bean cv Alameda Irrig +N	858	820
Faba bean cv Alameda Irrig N2	924	856

WF*=(ETmax- ET*)/yield (L/kg)	1986-1987	1987-1988
Faba bean cv Alameda Irrig +N	363	116
Faba bean cv Alameda Irrig N2	398	121
ET (mm)	1986-1987	1987-1988
ETmax = kc x ETo	555	538
$ET^* = \sum (ETo Dec-Apr) + \sum rainfall (May - June)$	306	462

## The multi dimensionality of water use in agriculture: GWF and BWF are not independent

Watershed scale: hydrological pathways

Field level: physiological, agronomic and engineering pathways

Mateos and Araus, 2016

#### The multi dimensionality of water use

 Watershed scale: hydrological pathways. Effective use of water involves water being captured, retained, and used efficiently to produce benefits

- Dams and groundwater recharge increase water capture and storage
- Water can be reused many times while only a fraction of the water is consumed in each reutilization cycle
- The water that enters a water use unit may come from a primary water source or it may be return flow from upstream units

#### The multi dimensionality of water use

Field level: Engineering pathways. WP improvements in irrigation (irrigation efficiency):

- Water conservation measures: modernizing irrigation systems to apply water more uniformly and development of irrigation scheduling methods
- Access to technologies and capital by farmers
- Small-holder farmers: 70% of food production

### Bottlenecks in water use research: Smallholder farmers Scale 2

- The majority of the 570 million farms in the world are small.
- The main challenge is the improvement of WP of smallholders in developed and developing countries





### Bottlenecks in water use research: Smallholder farmers Scale 2

- What can science and engineering do for smallholders from developed and developing countries?
- Socio-economic issues are critical and disrupt improvement efforts (from infrastructure and transport, maintenance of water distribution systems to untimely arrival of credits to the farmer)
- Nevertheless:

### Bottlenecks in water use research: Smallholder farmers Scale 2

- Extension services, cheaper sensors or tools to measure water supply, can be complemented by ICT support
- ICT: smart phones are bypassing the need for farm size and capital. Innovative applications allow gathering, disseminating information easily and allow better access from global to micro level.
  - Access to weather forecasts
  - Apps to improve irrigation, N mgt, pest, disease, weed control
  - (Access to markets)

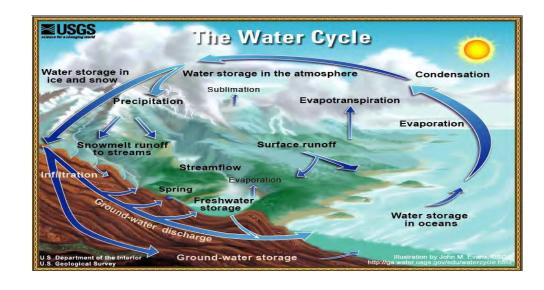
#### Summarising

- Crops are grown at a field scale which determines the relevance and impact of physiological traits
- Good agricultural practices and crop monitoring are bases of yield and WP increases. Non-destructive methods to determine WP in the field have yet to be improved
  - Improving WP relies on breeding and agronomy, efforts to change cropping to periods of lower evaporative demand, reducing water losses, and improving irrigation practice with better above and below-ground monitoring

#### Summarising

- Small gains: small decreases in water use or small WP improvements, represent significant water savings when applied to large areas
- Big gains: tools and technologies to improve water management, in particular irrigation by smallholder farmers, are essential to increase WP
- Leaks in funding: Simplicity of WF attracts decision makers and politicians but also researchers that generate an increasing number of papers and then citations which then give "objective" scientific support to the idea

#### Thank you ....



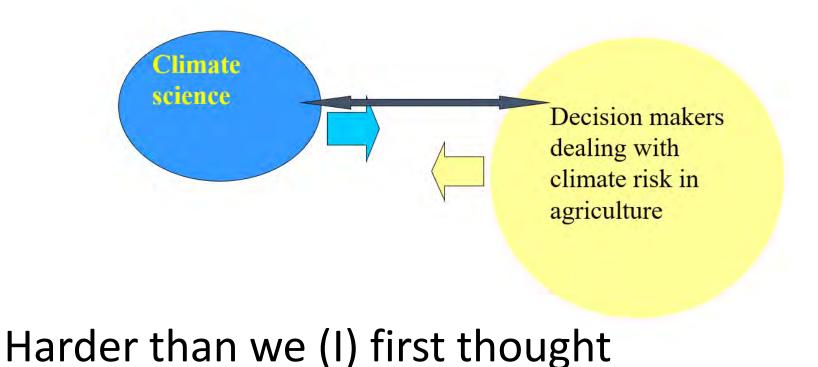


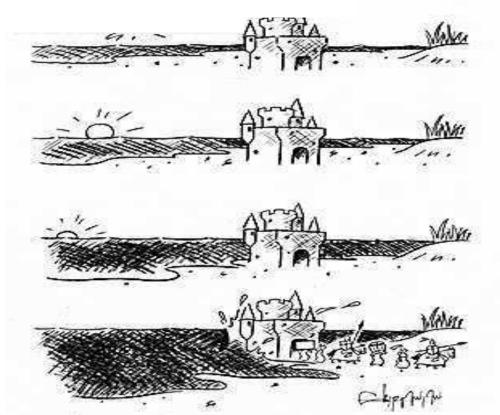


## Making *climate* science useful to agriculture

Peter Hayman SARDI Climate Applications

### Applying the advances in climate science to agriculture







What destroyed the sand castle? The wave or the tide?

Researching and managing agricultural systems in a nonstationary climate



"The climate system is an angry beast and we are poking it with sticks." - Dr. Wallace Broecker

Risk, uncertainty, non stationarity, ambiguity...

#### CLIMATE COMMISSION







Home > News & Events > Industry news > Red meat industry can be carbon neutral by 2030

**INDUSTRY NEWS** 

**PUBLICATIONS** 

MLA'S E-NEWSLETTERS

EVENTS, SPONSORSHIP & SPEAKERS

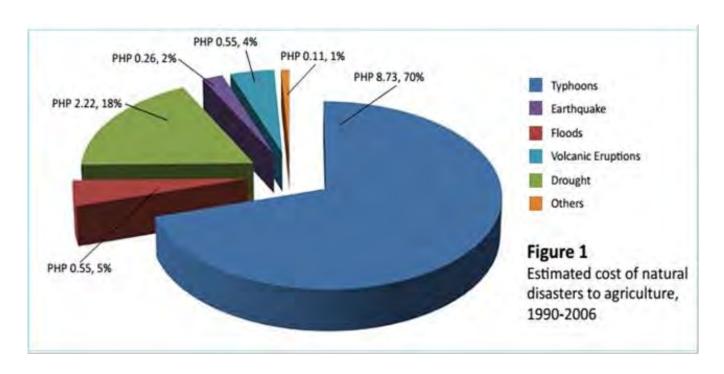
#### Red meat industry can be carbon neutral by 2030

22 November 2017

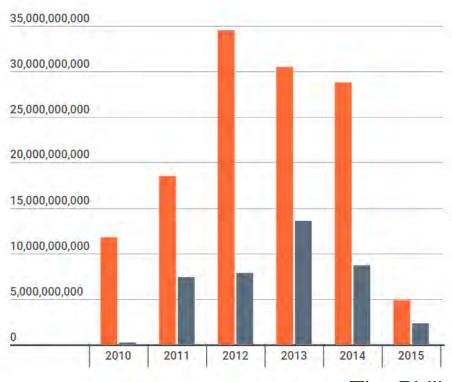
Australia's red meat industry can be carbon neutral by 2030, Managing Director of Meat & Livestock Australia (MLA) Richard Norton told the company's annual general meeting in Alice Springs today.

Mr Norton said achieving the goal would put Australia head and shoulders above its competitors, giving consumers even more confidence in the quality and integrity of Australian red meat and turning environmental criticism of the industry on its head.

### The cost of climate variability



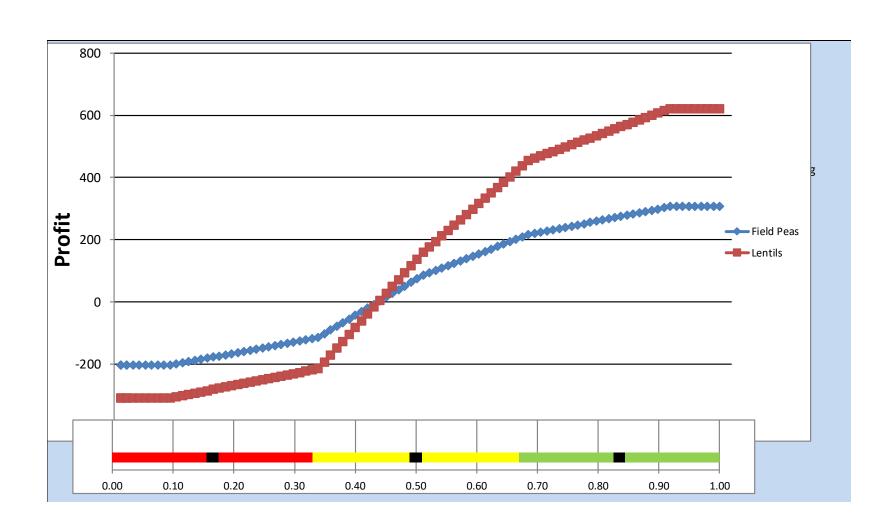
# Total cost of damage in agriculture and infrastructure (2010-2015)



Agriculture Infrastructure

The Philippines is visited by an average of 22 tropical cyclones a year, with at least six having a significant impact that require relief efforts. Eight or nine of these make landfall.

#### Unavoidable regret



# Some challenges/mistakes from climate applications community in Australia

1 Failure to acknowledge uncertainty – especially the over attribution of millennium drought (2002-2009?). Finding appropriate confidence?

- 2. Need to go beyond damage report understand adaptation Climate change as only issue - Time matters with adaptation (and is different to urgency for GHG reduction)
- 3. Being comfortable with uncertainty

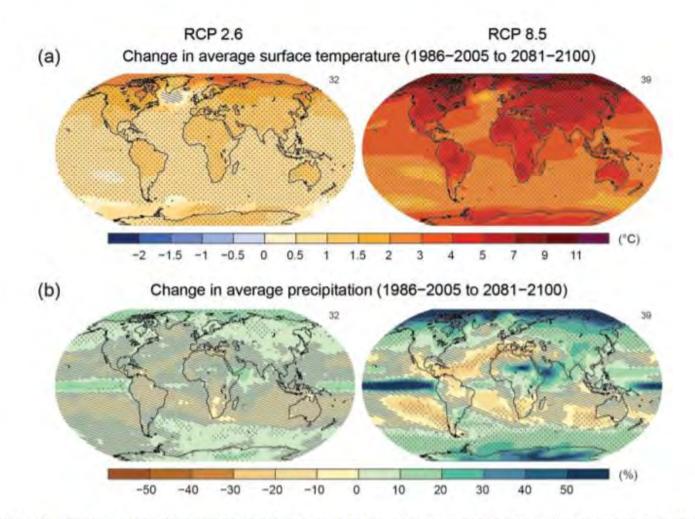
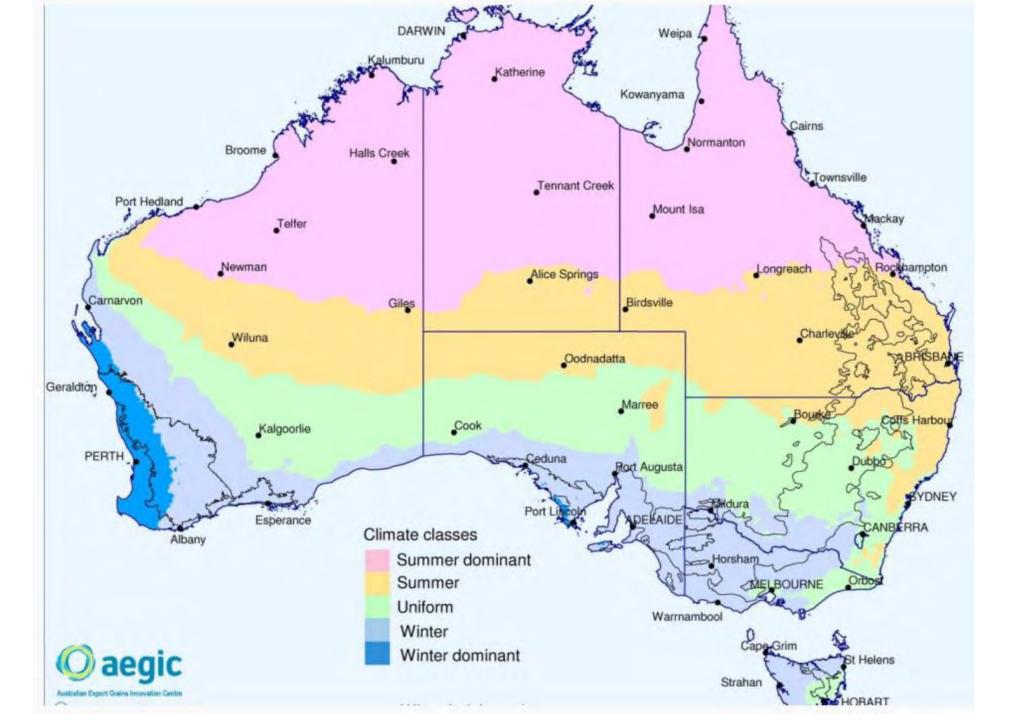
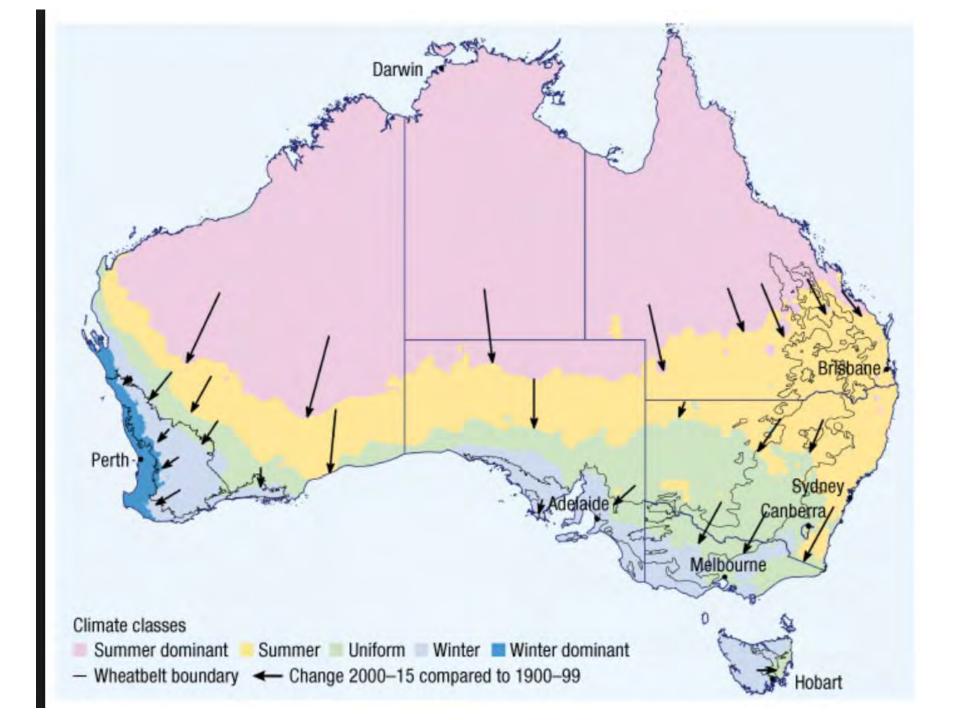


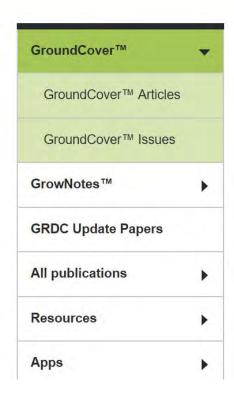
FIGURE 3.5.2: MAPS OF CMIP5 MULTI-MODEL MEAN RESULTS FOR THE SCENARIOS RCP2.6 AND RCP8.5 IN 2081-2100 OF (A) ANNUAL MEAN SURFACE TEMPERATURE CHANGE AND (B) AVERAGE PER CENT CHANGE IN ANNUAL MEAN PRECIPITATION. CHANGES ARE SHOWN RELATIVE TO 1986-2005. THE NUMBER OF CMIP5 MODELS USED TO CALCULATE THE MULTI-MODEL MEAN IS INDICATED IN THE UPPER RIGHT CORNER OF EACH PANEL. HATCHING INDICATES REGIONS WHERE THE MULTI-MODEL MEAN IS SMALL COMPARED TO INTERNAL VARIABILITY (I.E. LESS THAN ONE STANDARD DEVIATION OF INTERNAL VARIABILITY IN 20-YEAR MEANS). STIPPLING INDICATES REGIONS WHERE THE MULTI-MODEL MEAN IS LARGE COMPARED TO INTERNAL VARIABILITY (I.E. GREATER THAN TWO STANDARD DEVIATIONS OF INTERNAL VARIABILITY IN 20-YEAR MEANS) AND WHERE 90 % OF MODELS AGREE ON THE SIGN OF CHANGE (SOURCE: FIGURE SPM.8 IN IPCC, 2013).





# Early Sowing The Symptom Of A New Climate

Home → Resources and publications → GroundCover™ → Early sowing the symptom of a new climate

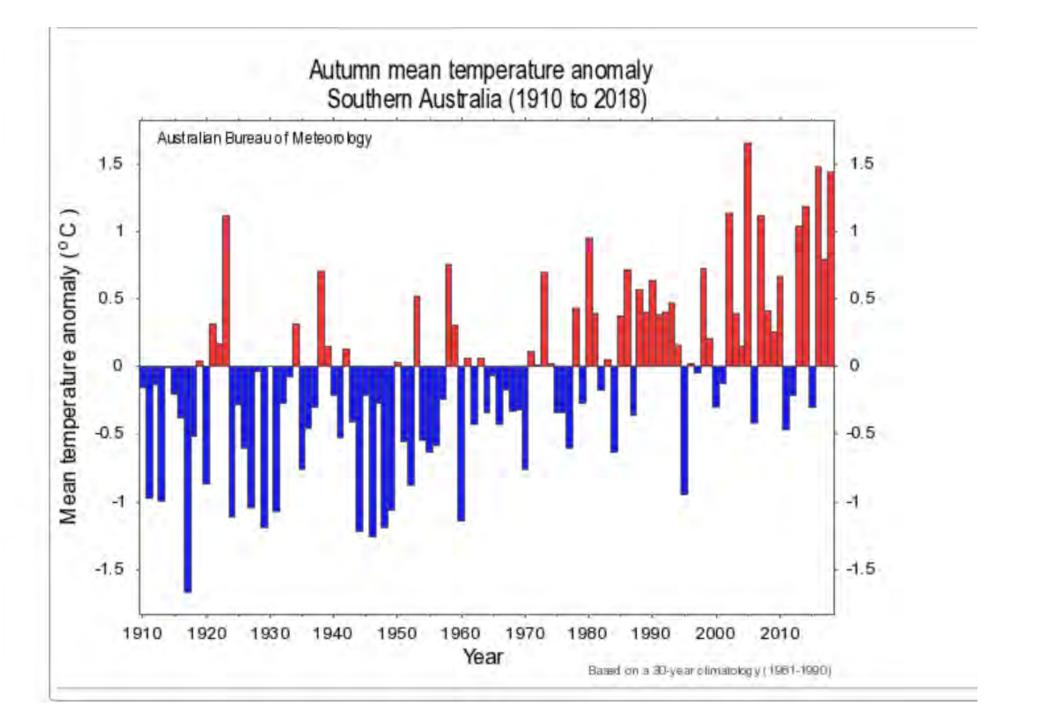


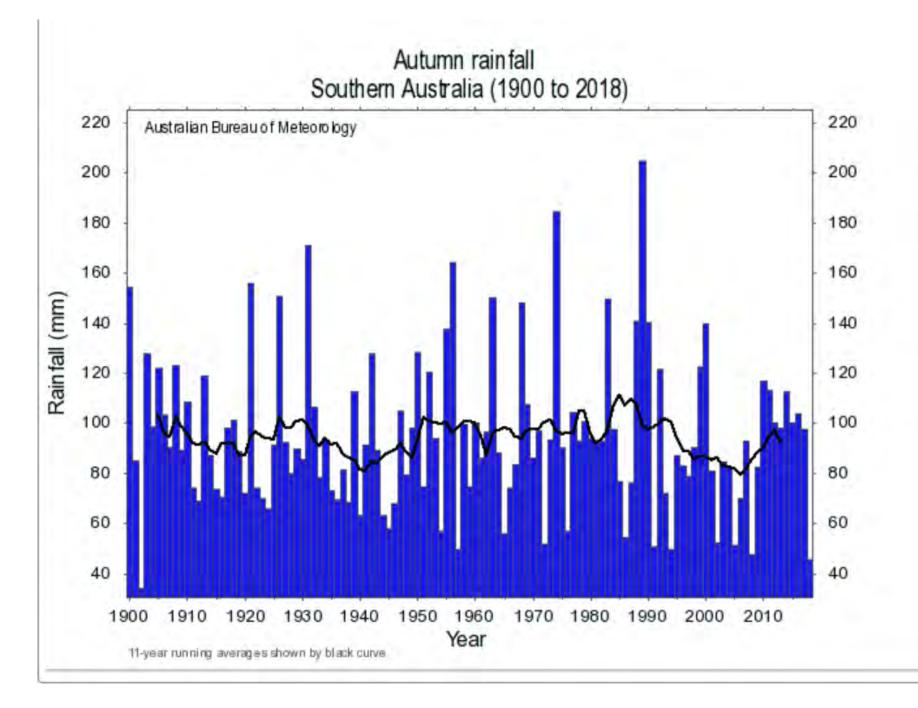
GroundCover™ Issue: 122 | 02 May 2016 | Author: Brad Colli:

#### **Key Points**

- A new Australian climate is developing
- Seasonal rainfall zones have shifted across Australia since 2000
- There are clear implications for farming systems and management

Early Sowing Has Become The Norm In Many Grain-Growing Areas, But Only Now Are Some People Openly Saying Why: Our Climate Has Changed





### Projections for relative precipitation change from 1950-2005 to 2080-99 according to RCP8.5

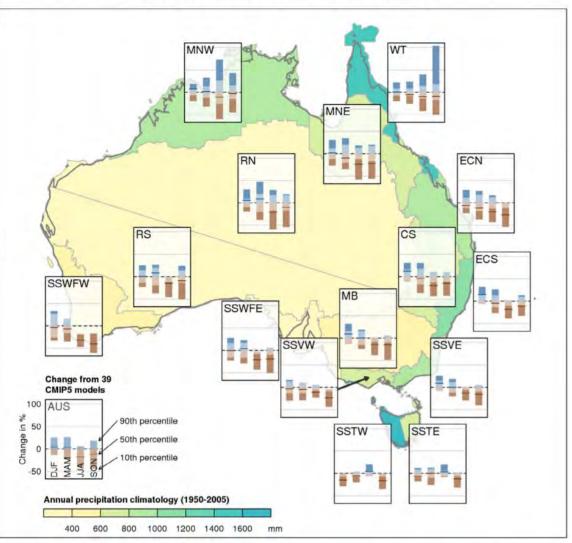


Fig. 4. Example of the presentation of rainfall projections from the CSIRO and Bureau of Meteorology (2015) release showing the focus on ranges of change from CMIP5 as charts for discrete regions within Australia: the figure shows 10th, 50th and 90th percentile of the 39 CMIP5 models in projected rainfall change (%) by 2090 for each calen season for each 'sub-cluster' of Australia (shown in the map). The paler colours indicates the 10th to 90th percentile expected from natural variability. See CSIRO and Burn of Meteorology (2015) for further explanation of the figure and a legend of the codes for the sub-cluster regions. (For interpretation of the references to colour in this fig legend, the reader is referred to the web version of this article.)

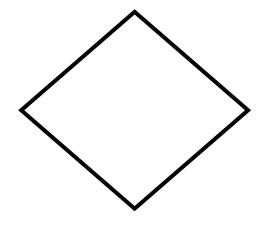
# 4 ways of thinking about the future

### Thinking about future climates

Climate change projections from GCMS

Temporal analogues

– eg drought



Spatial analogues – study a warmer & drier site

Sensitivity analysis: 1,1.5, 2 degrees warming; 5%, 10%,

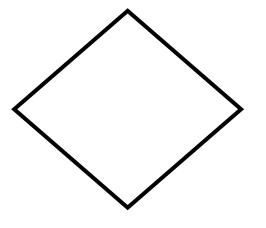
20% rainfall decline

## Thinking about future climates Quantification is powerful in this discussion

Climate change projections from GCMS

Temporal analogues

- eg drought



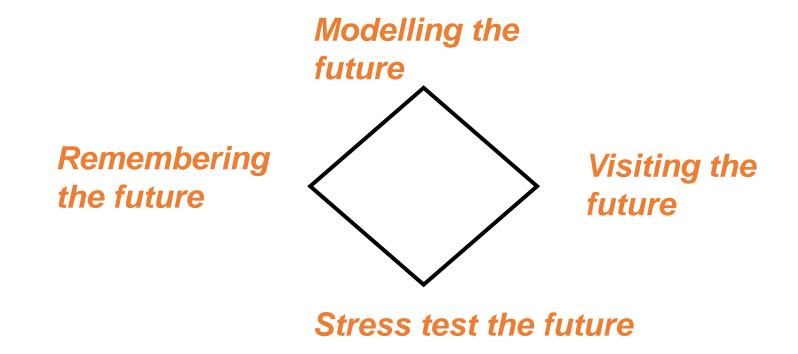
Spatial analogues – study a warmer & drier site

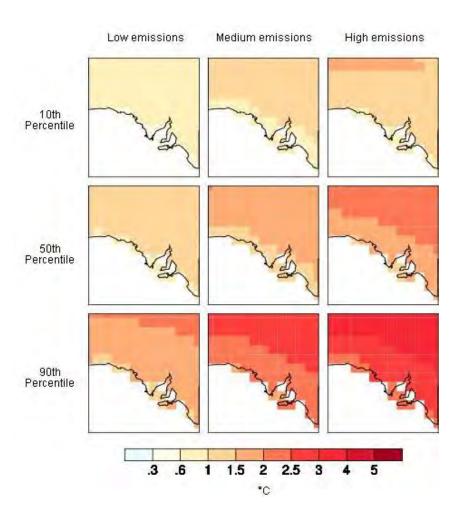
Sensitivity analysis: 1,1.5, 2

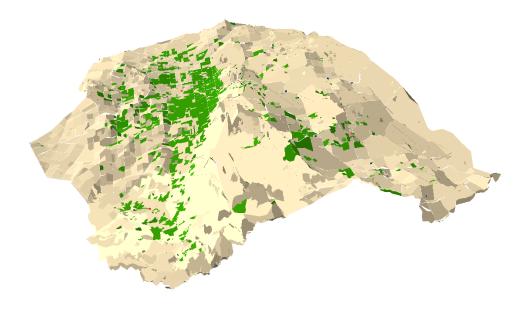
degrees warming; 5%, 10%, 20%

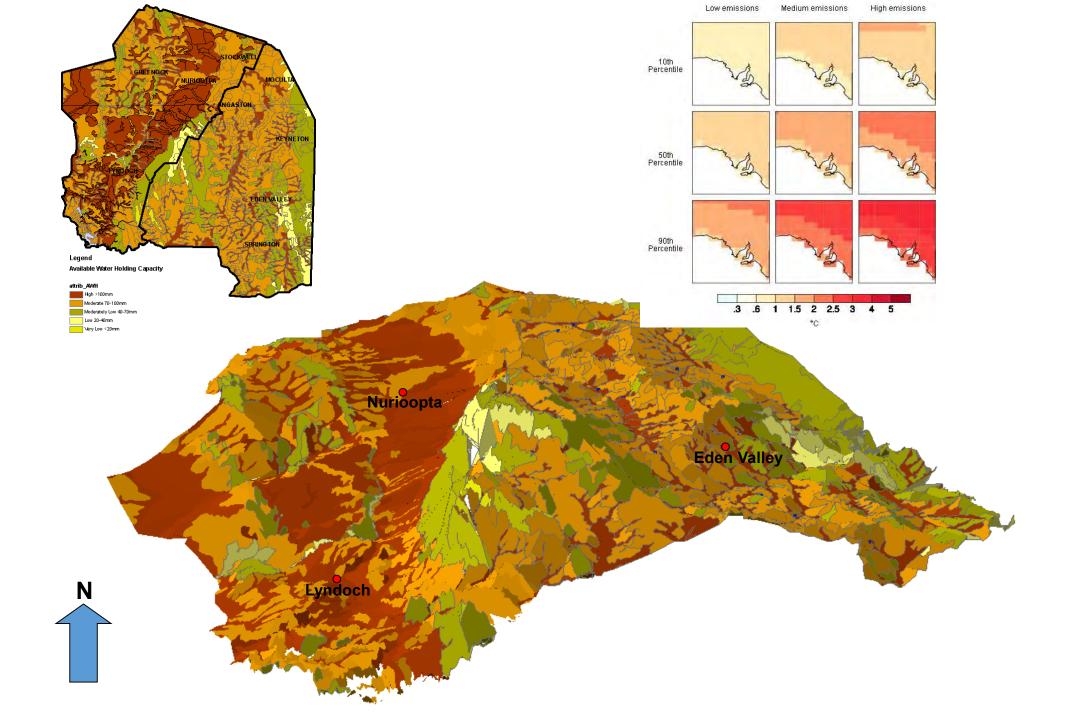
rainfall decline

### Thinking about future climates









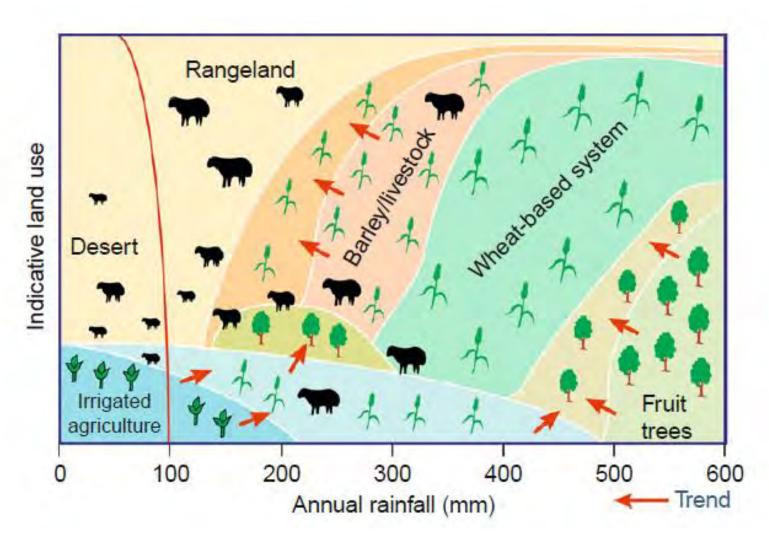
Perhaps more than any other species, we are in a very real sense adapted for adaptation, and few would question that this overarching capacity for adaptation is a *sine qua non* of the human condition.

Everett et al 2016 Language evolution and climate

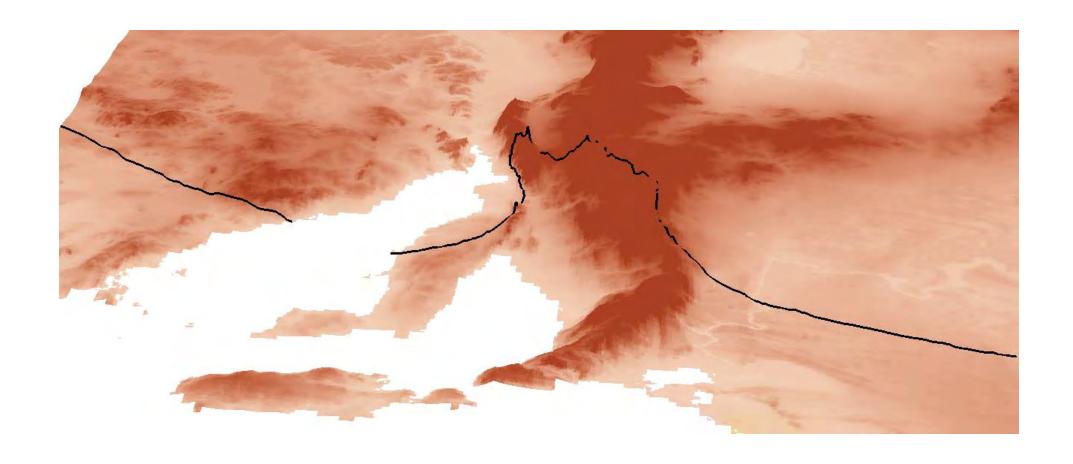
# What are farmers doing in a nearby warmer drier location?

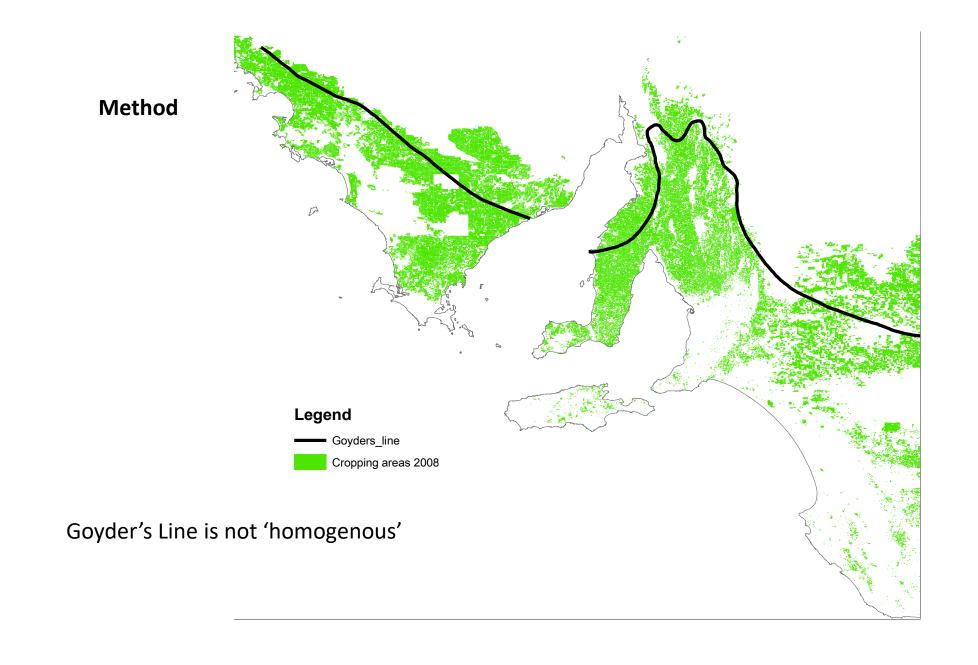
- Near term future (2016-2035) for primary industries
- Space as a proxy for time has long tradition in ecology and is common in adaptation planning. Howden, Webb, Ramirez-Villegas et al 2011 Finding tomorrow's agriculture today (CGIAR)

Farmers and agronomists naturally think this way...especially in South Australia



Ryan et al 2010





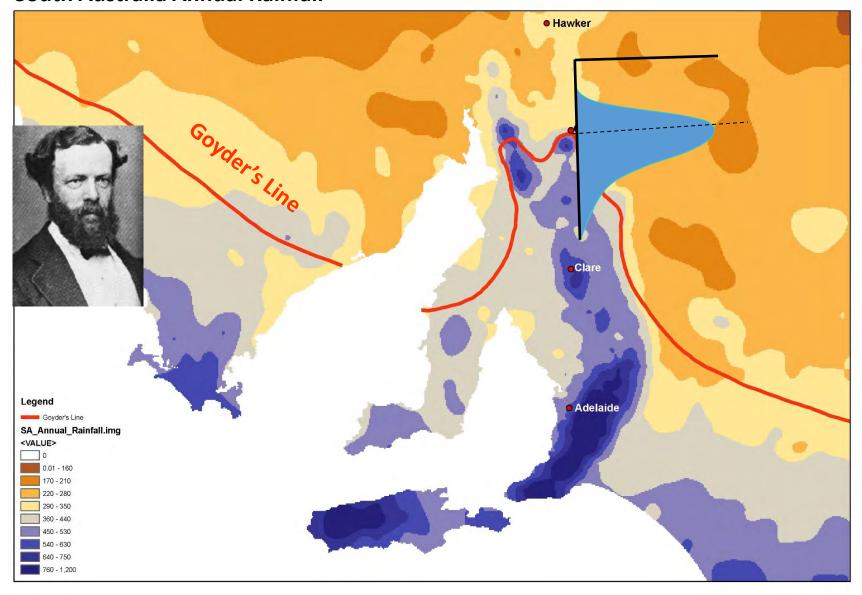
### History of Goyder's line

- Following settlement of SA in 1836, agriculture rapidly expanded northwards
- After severe drought during 1863-1866 the Surveyor-General Goyder established a line of reliable rainfall
- Farming expanded again 1870 to 1882 over the line but retreated again during the late 1880's and 1890's
- Expansion again occurred 1906-1926 but retreated again in the 1930's
- In each retreat there was major economic, social and environmental cost

Janis Sheldrick. Goyder's Line: The unreliable history of the line of reliable rainfall *in* Sheratt et al 2004

- 1857 as Assistant Surveyor General exploring between Flinder's Ranges and Lake Torrens, found Lake Blanche full of fresh water
- Surveyor General Freeling took 6 m long galvinised boat and folding iron punt to find mud
- Freeling rebuked Goyder "for not having paid closer attention to the generagl character of the country"

#### **South Australia Annual Rainfall**

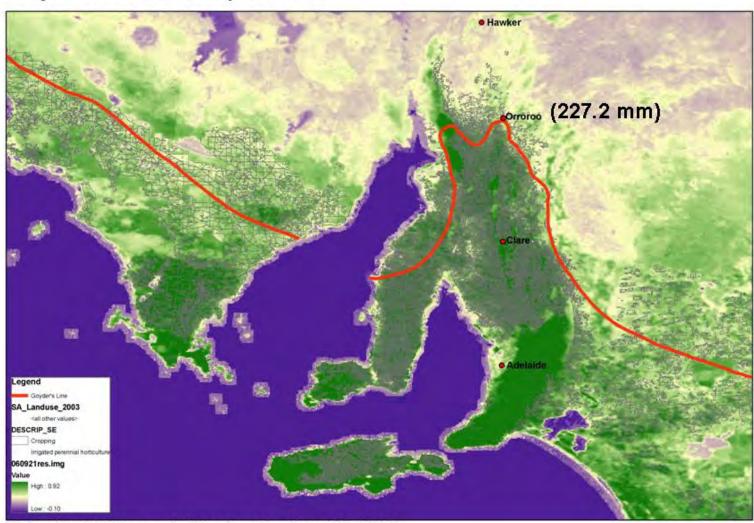






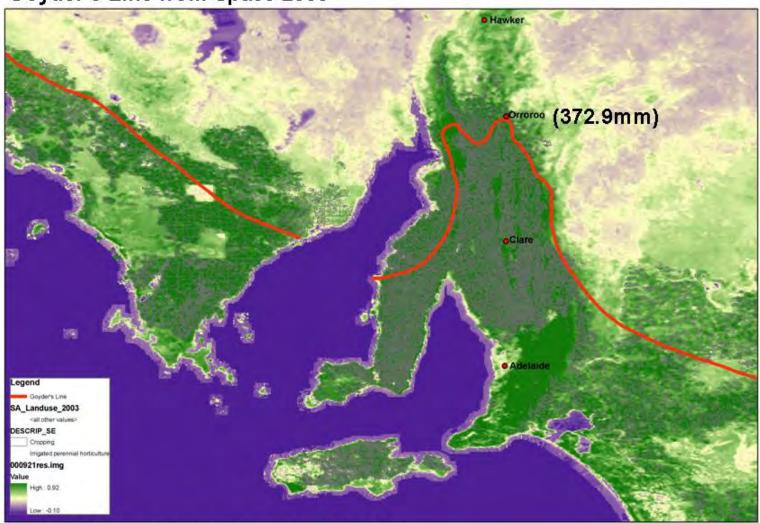


#### Goyder's Line from Space 2006

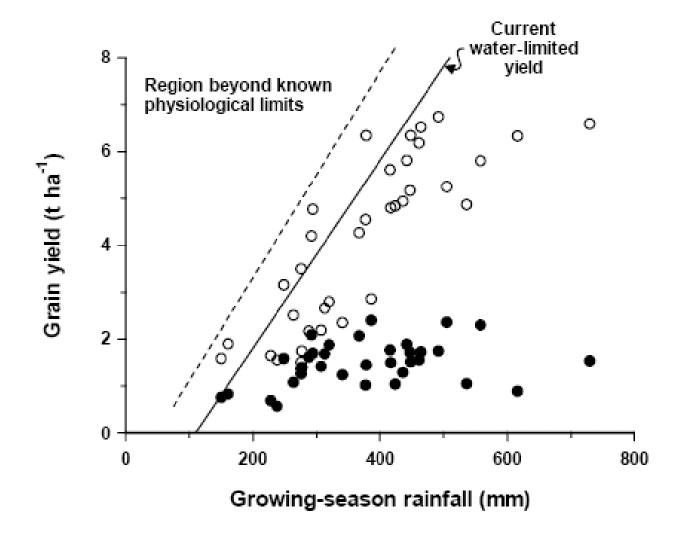


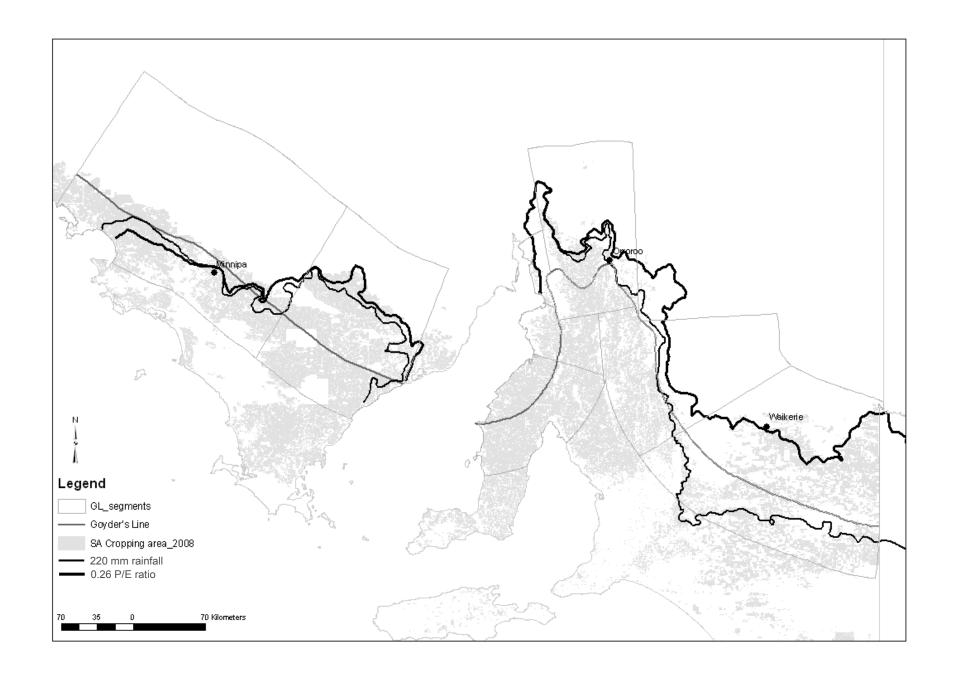
Data: SPOT Veg satellite, September 21, 2006

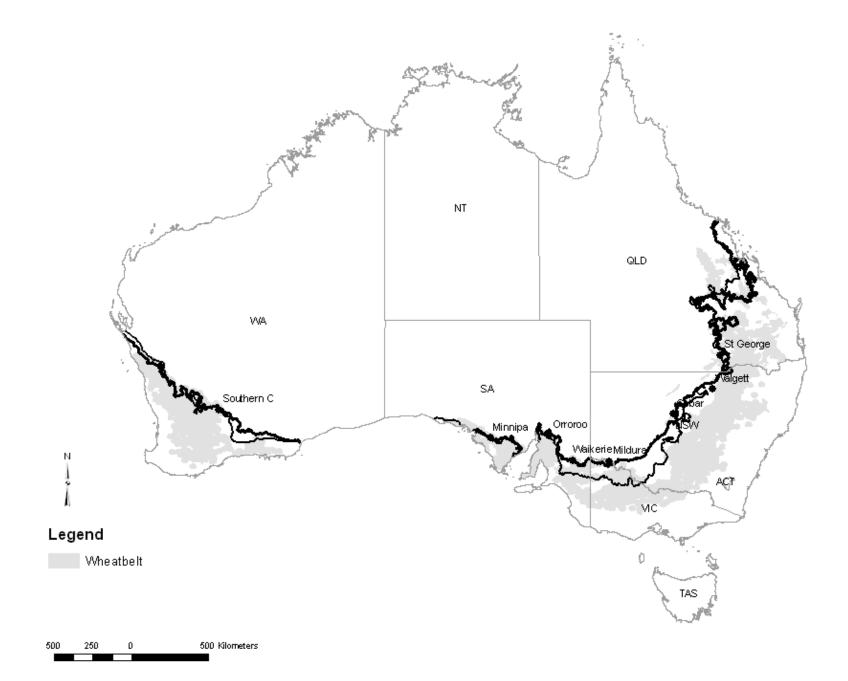
#### Goyder's Line from Space 2000

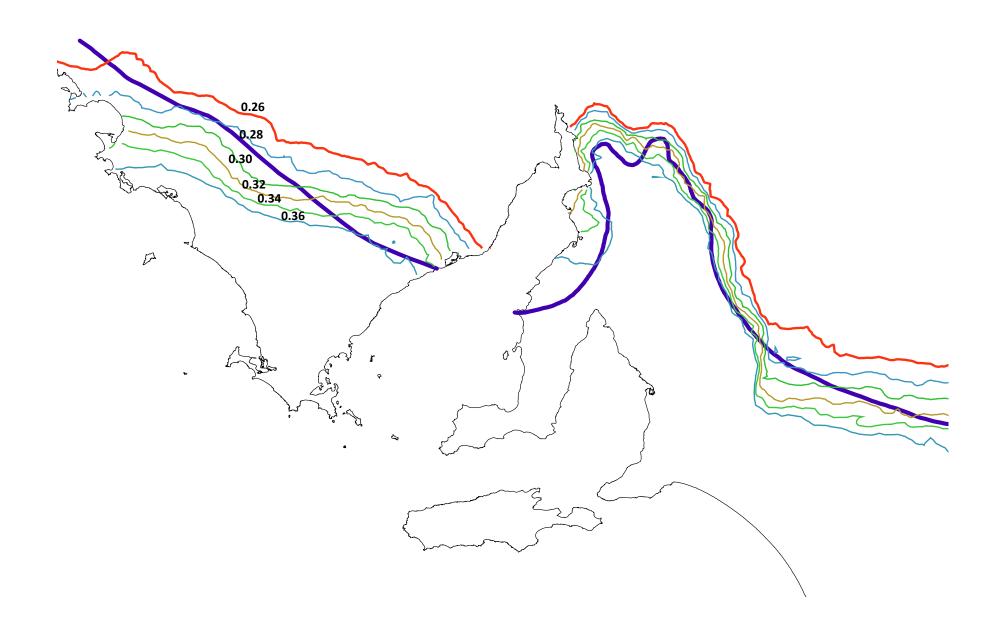


Data: SPOT Veg satellite, September 21, 2000





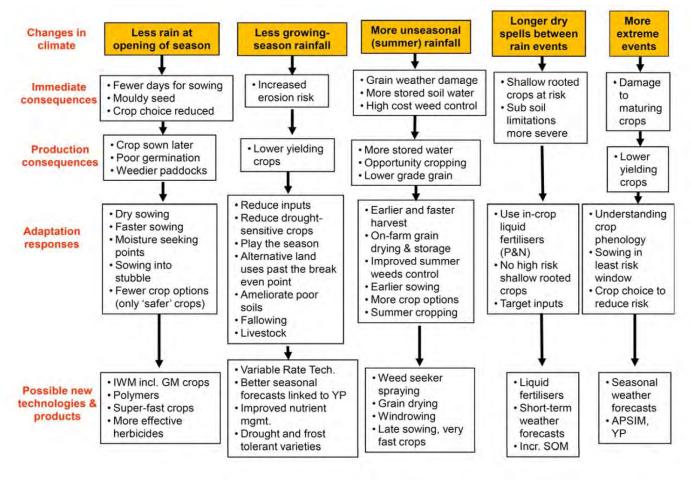




### Climate change

Howden et al 2010

# Climate change adaptations suggested by famers

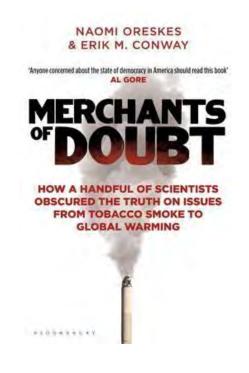


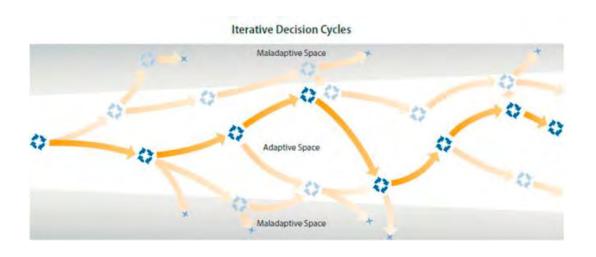
van Rees et al. 2012

Addressing drivers of vulnerability.	Building Capacity.	Managing Climate Risk.	Confronting Climate Change.
Activities increasing human development, reducing poverty, and addressing factors that make people vulnerable. Activities do not consider climate change and its impacts, but can buffer households, communities and societies from the impacts of climate change by reducing vulnerability to nearly all stresses.	Activities laying the foundation for more targeted actions. Tend to involve institution-building and technological approaches adapted from development approaches/ tools/methods. Activities in this category tend to occur in sectors directly affected or sensitive to climate change.	Successful climate risk management and reduction activities that may lead to strong development benefits, but are distinguished from typical development efforts through the use of climate information.	Activities focusing almost exclusively on addressing climate change impacts. Tend to target climate risks that are clearly outsid of historic climate variability and stem from climate change.
Examples: Economic development policies, education and health policies, gender initiatives, livelihood diversification efforts and literacy promotion, etc.	Examples: Awareness raising on climate-development linkages at national, sectoral, local and project level, participatory reforestation efforts to combat flood-induced landslides, natural resource management practices and weather monitoring.	Examples: Integration of climate change in national, sectoral, and local planning and strategies, climate risk screening, climate risk assessment, climate proofing, disaster response planning activities and technological approaches, such as drought resistant crops.	Examples: Relocation of communities in response to sea-level rise and glacial melting. Radical or costly policies and technological approaches that explicitly address unprecedented levels of climate risk including infrastructure, e.g. dikes, harnessin harbors, etc.

# Nature of uncertainty and urgency for GHG reduction and adaptation

• Extreme urgency to reduce GHG. Adaptation is important and path dependent, but do we sometimes overstate the urgency?





# "adaptation needs to slow down and have a process that we trust".

 "expert accounts of a distant and discontinuous future contrast strongly with the continuity anticipated by residents across their remembered pasts, lived presents, and imagined futures"

Fincher Barnett and Graham 2015

DOI: 10.1080/00045608.2014.988101

#### Action bias

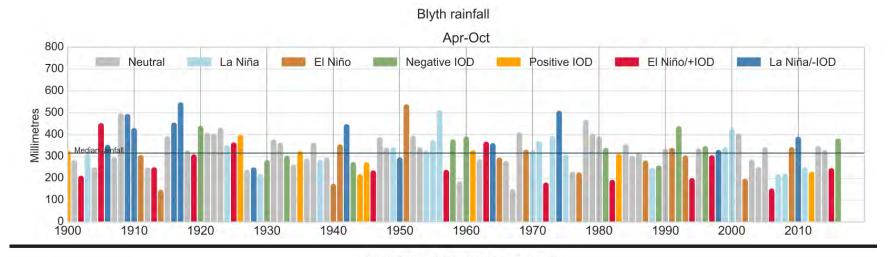


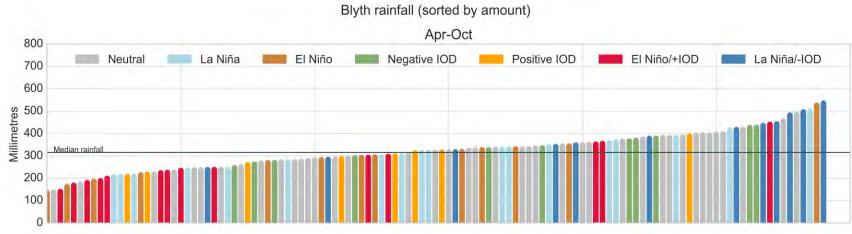
286 top goal keepers
Jump right 12% chance of save
Jump left 14% chance
Stay in middle 33% chance

But 94% of time jump left or right

Why? Better be seen to do something

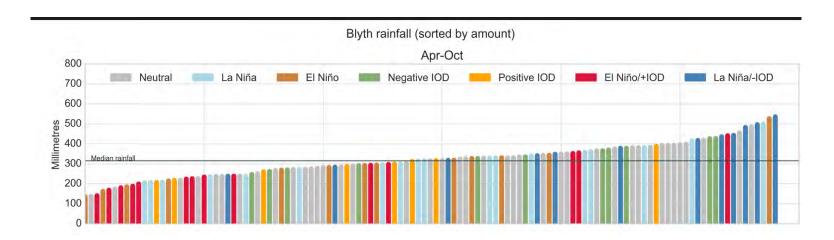
Bar-Eli, M., Azar, O.H., Ritov, I., Keidar-Levin, Y. & Schein, G. (2007). *Action Bias Among Elite Soccer Goalkeepers: The Case of Penalty Kicks.* Journal of Economic Psychology, 28, 606-621





# El Nino = Drought?

- If we define drought as driest 10% of years
- There have been about 25 El Nino events
- So there have been more El Nino events than droughts
- El Nino means increased chance of drought and this is a challenge for communication



# If\_Then\_Else

- *IF* the season is going to be dry *THEN* plant low risk crops *ELSE* high risk crops.
- If the end point is better risk management, misunderstanding forecasts as categorical will result in poorer risk management than if people never heard of the forecast

Thinking in bets, making smarter decisions when you don't have all the facts.

• Annie Duke – cognitive decision making and poker champion.

- Farmers have deep understanding of risky decision making....
- But in giving advice we all like certainty
- Distinguish between wise and lucky decisions





Skill and Chance



Chance

#### Chess vs Poker vs Pokies

- Chess vs Backgammon
- Go vs Ma-hjong



#### Camden (NSW)

34.04S, 150.69E

### Black line: The observed 90<sup>th</sup> percentile threshold of daily T<sub>mean</sub>

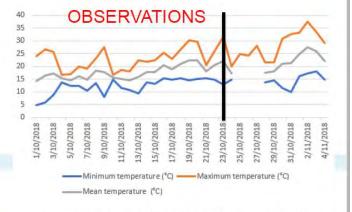
 Calculated by looking back over the historical period for the particular time of year. 10% of days are hotter than this threshold for the given time of year.

#### The "plume" is the forecast

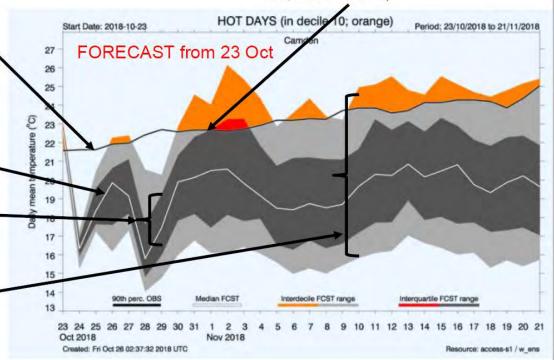
- White line: middle (median)
   value of the forecast ensemble
- Dark grey: interquartile range (between the 25<sup>th</sup> and 75<sup>th</sup> percentiles of the forecast ensemble). 50% of the forecast distribution have values in this range.
- Light grey: interdecile range (between the 10<sup>th</sup> and 90<sup>th</sup> percentiles of the forecast ensemble). 80% of the forecast distribution have values in this range.

#### Increased hot day risk:

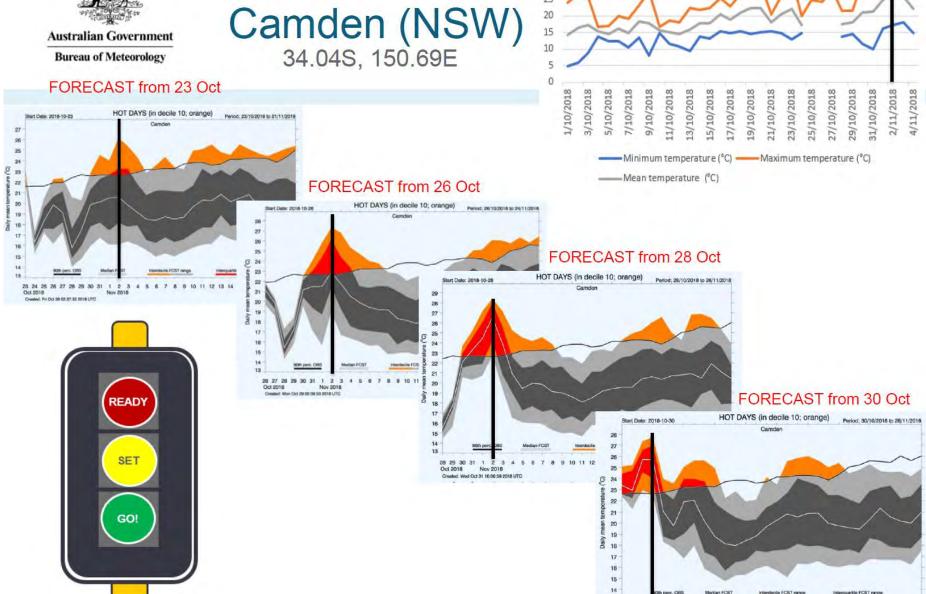
"Orange" if some of the forecast ensemble are forecasting temperatures exceeding the historical (climatology) 90th percentile



This is the 75<sup>th</sup> percentile i.e. more than 25% of the ensemble are forecasting temps > historical (climatology) 90<sup>th</sup> percentile. The chance of "hot days" is 25% (i.e., more than double the normal risk, which is 10%)







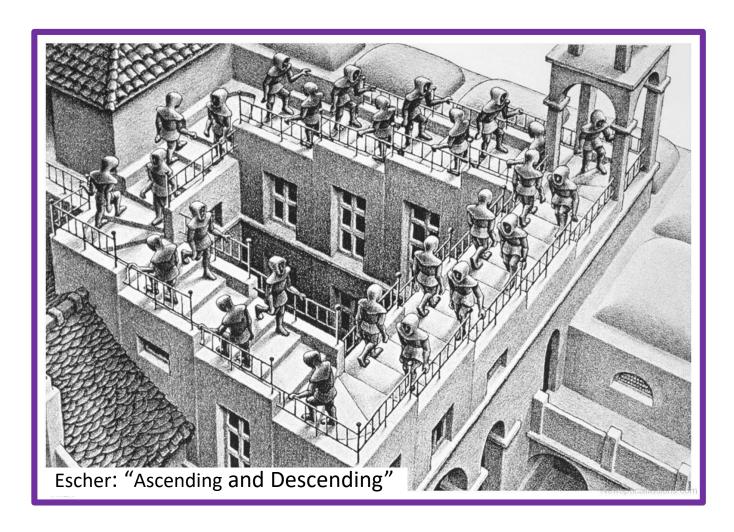
**OBSERVATIONS** 

30

# Understanding decision context

- False precision...Measure with a micrometer, mark with a piece of chalk and cut with an axe
- Purposeful procrastination Real Options
- Active users asking better questions. For example seasonality rather than very high spatial resolution.

## Translational Research? Which Way?



John Passioura CSIRO

#### Levels of organization

A nested hierarchy
Each level has specific
features, processes, terms

<u>Crop</u> (yield, LAI, WUE)

<u>Plant</u> (phenology, RGR, sink)

Organ (leaf, root, flower)

Tissue (stele, mesophyll, xylem)

Cell (wall, protoplast, plasmodesmata)

Organelle (mitochondrion, chloroplast)

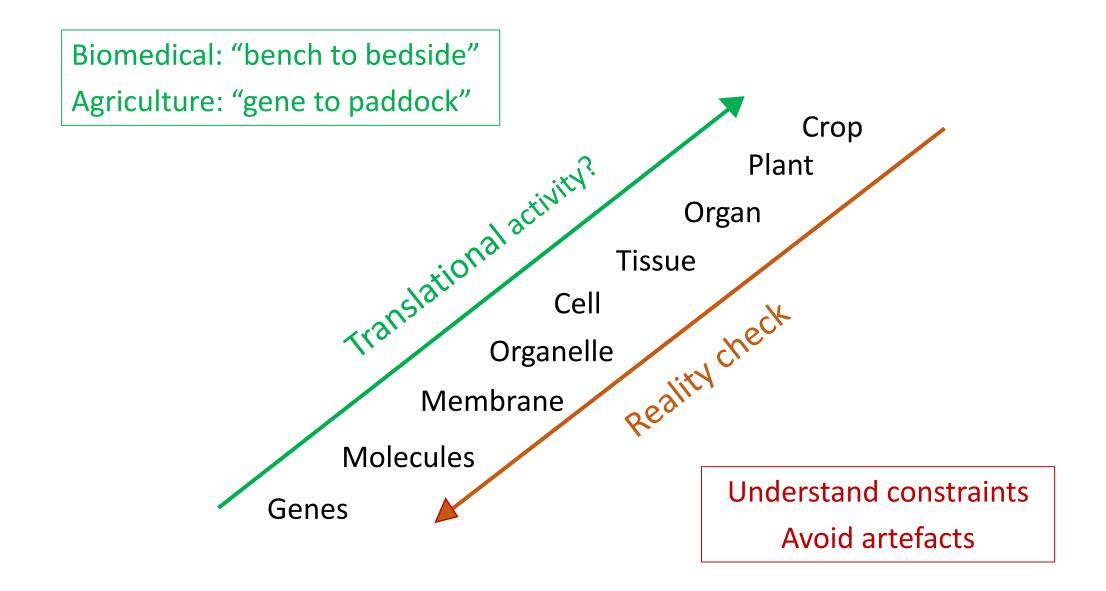
Membrane (plasmalemma, transporter, vesicle)

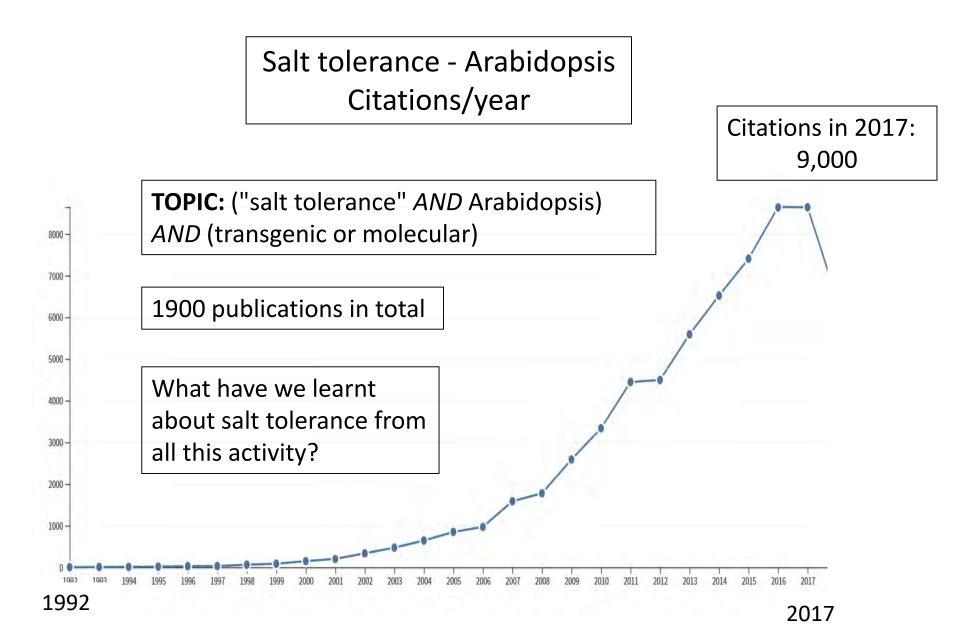
Molecules (proteins, nucleic acids, metabolites)

Genes (promoter, intron, exon)

# Interactions between levels of organisation

Level	Role
N+1	Biological significance
N	Phenomenon of interest
N-1	Mechanistic understanding



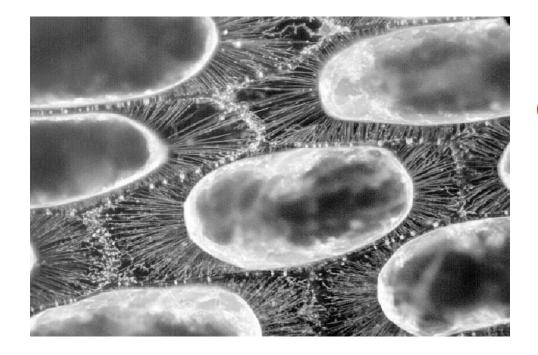


Source: Web of Science 640

# Contributions to salt tolerance? Reality Checks:

- 1. Treatments often use osmotic shock that plasmolyses the cells
- 2. Genetic variation in salt tolerance is invisible for days to weeks:

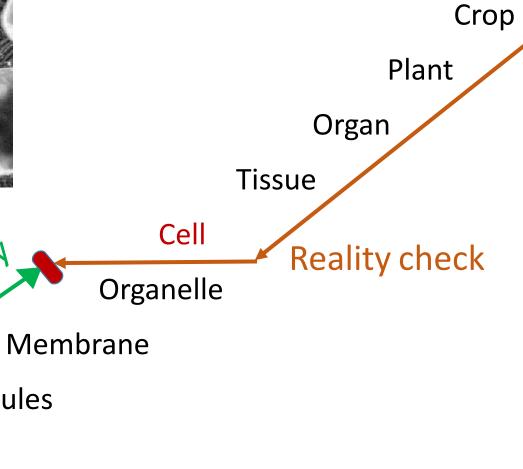
for It depends on how slowly sodium accumulates in the leaves.



Molecules

Genes

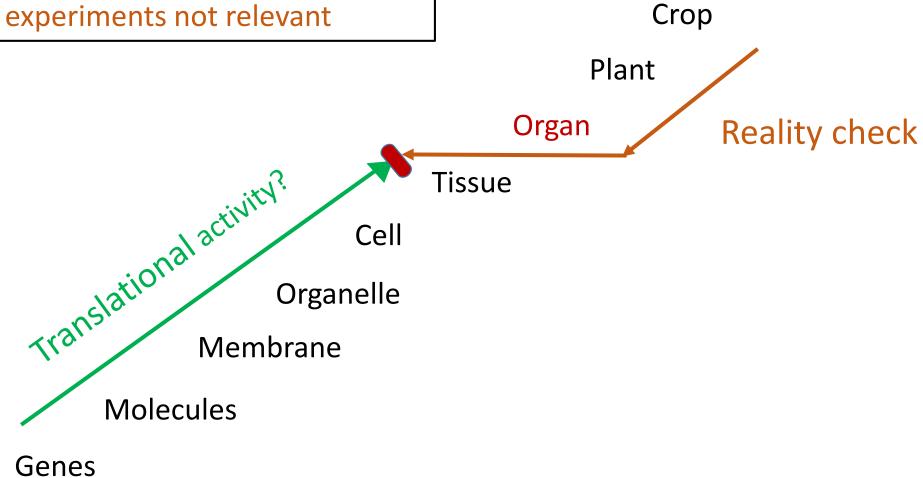
#### Plasmolysis from sudden exposure to 200mM NaCl



Source: Brian Gunning, ANU Translational activity

- 1. Roots exclude 96-98% of salt
- 2. Salt builds up in leaves slowly (days to weeks)
- 3. More exclusion = more tolerance

➤ Short term experiments not relevant



Reality checks are absent in most papers on salt tolerance in Arabidopsis:

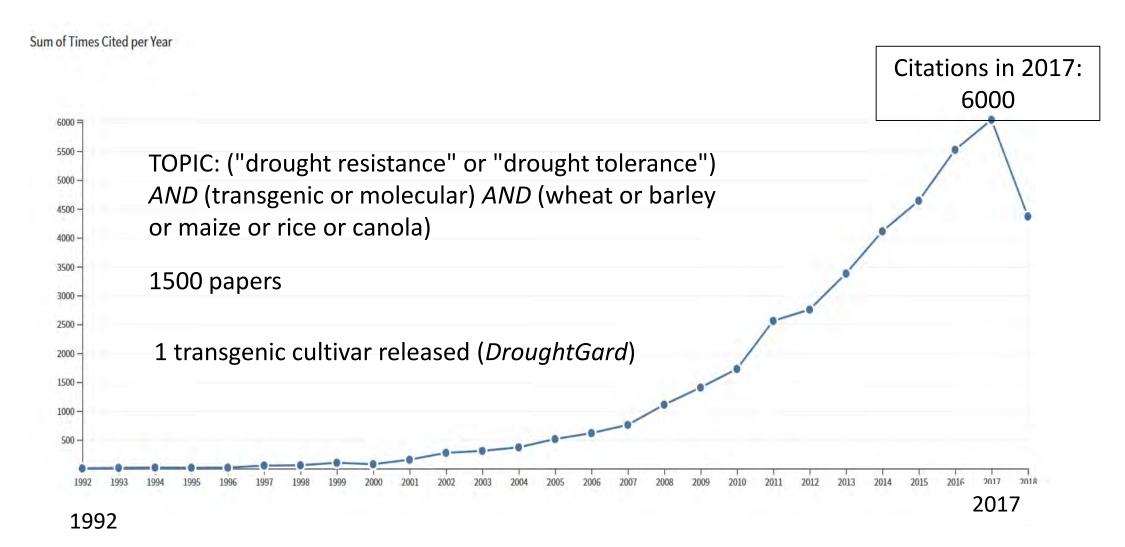
Only 1 of 9,000 citations mentions plasmolysis

3% mention exclusion

<u>Simultaneous translation</u> in both directions has proven to be essential (<u>aspirational utility</u> and <u>reality checks</u>):

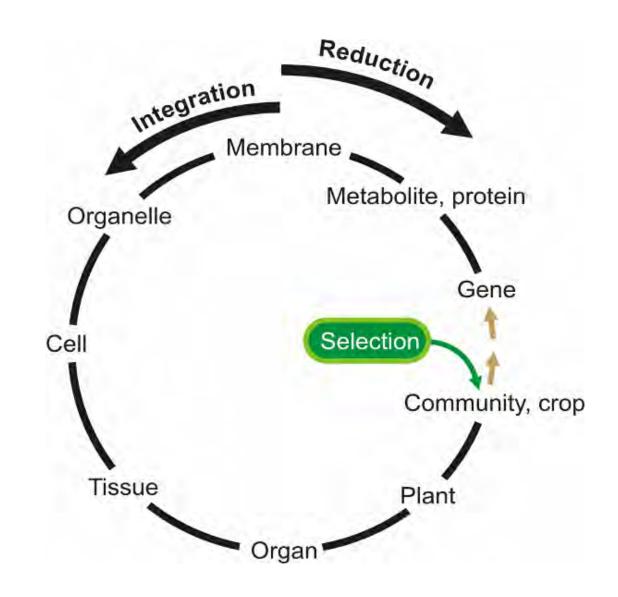
It has resulted in 2 genes for exclusion being discovered in a rare landrace of durum that was salt tolerant

#### "Drought resistance", Several crops Citations/year



Source: Web of Science

#### Biological organization is cyclic

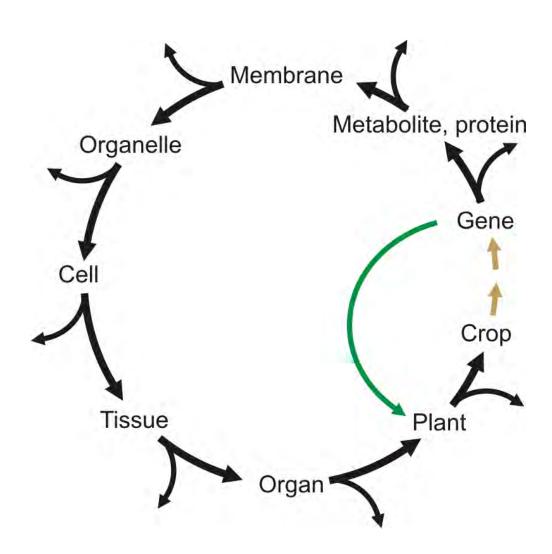


Passioura (2010) Scaling up: the essence of effective agricultural research. Functional Plant Biology

#### Translation from gene to plant

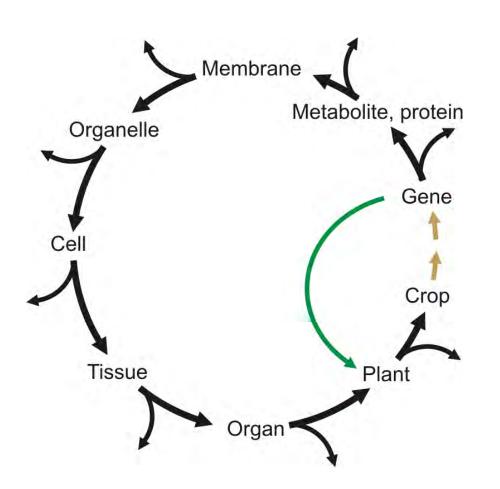
....successful scaling up... or oblivion?





#### The direct route from gene to better crop plant

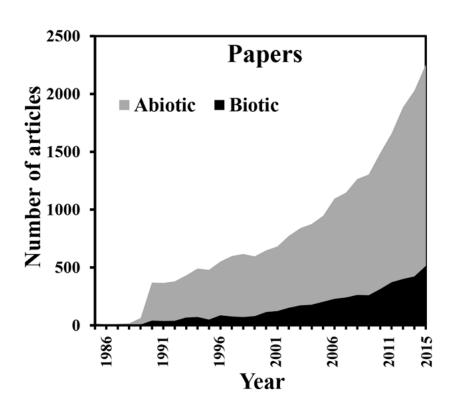
#### What works?

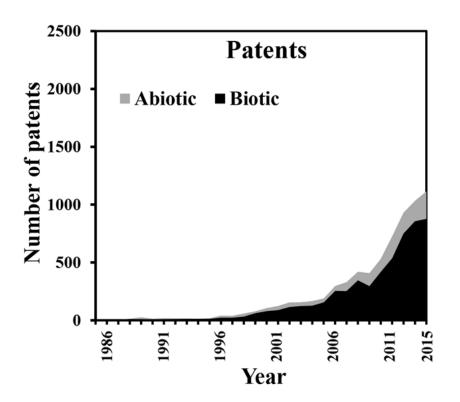


Pest resistance	<b>✓ ✓</b>
Herbicide resistance	<b>✓ ✓</b>
Grain quality	<b>✓ ✓</b>
Disease resistance	√?
Drought resistance (water-limited yield)	*

#### Transgenic successes (or not)

Trait		Reason for effectiveness
		(or not)
Pest resistance	<b>✓</b> ✓	No metabolic interference
Herbicide resistance	<b>√</b> √	No metabolic interference
Grain quality	<b>✓</b> ✓	End-product metabolism
Disease resistance	√ ?	No metabolic interference?
Drought resistance (water-limited yield)	*	Yield is the culmination of a whole season with many influences





**Products:** numbers of genotypes sold for biotic stresses were 13 times more than those sold for abiotic stresses

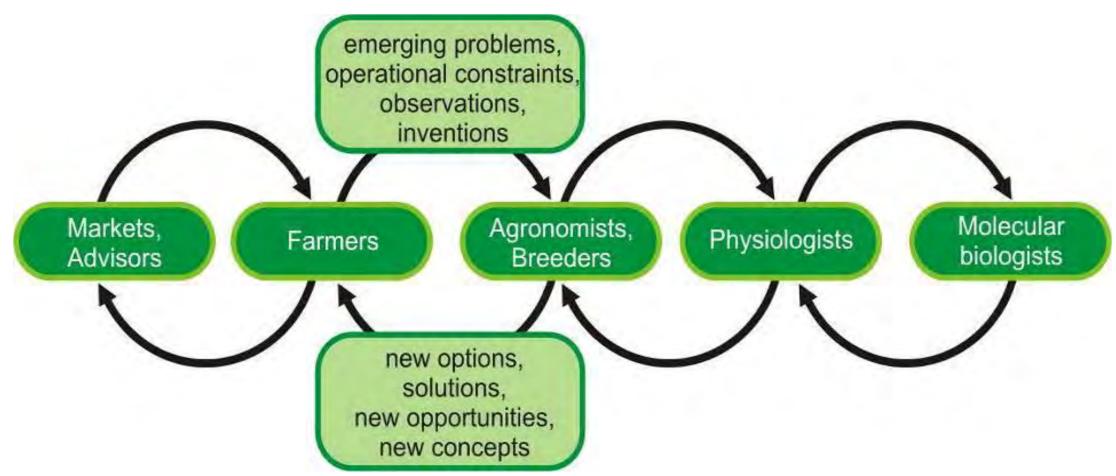
Source: Dalal etal 2017 Frontiers in Plant Science

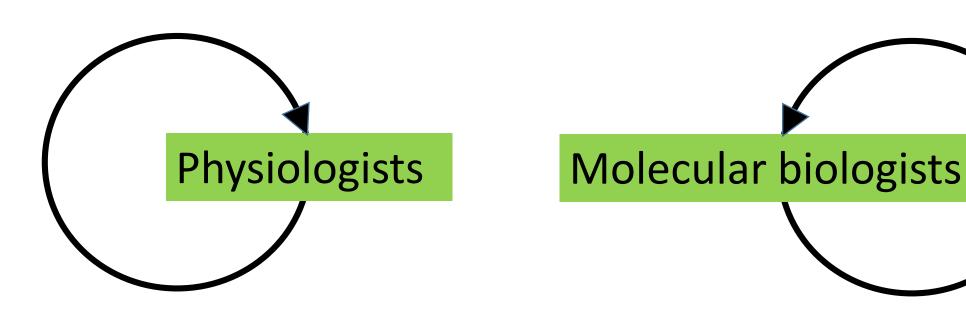
#### The linear language of agricultural R&D

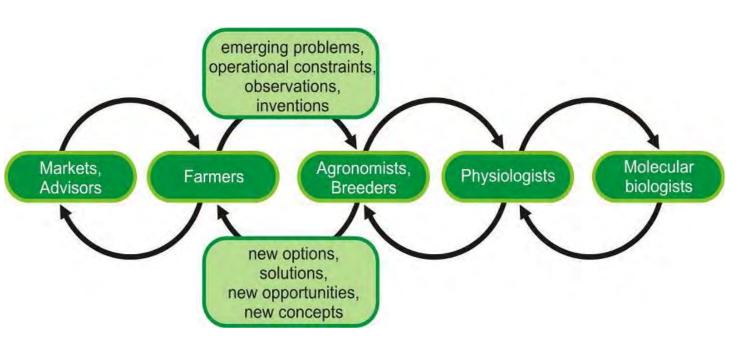
- extension
- technology transfer
- input, output, outcome, impact
- delivering outcomes ( = impact?)
- translational research
- transformational research

#### A common successful pattern:

Scaling down from the field as far as necessary, then back up again







#### Possible solutions....

Expand the definition of peer:

Use reviewers of papers and proposals who can assess claims of utility as well as the quality of the work.

Foster conversations across levels of organization, both formal and spontaneous.

Ensure that there is enough scientific leisure for this to happen.

# Pasteur's quadrant



Donald Stokes

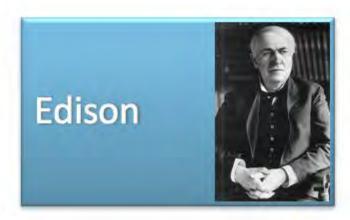




Bohr







**Consideration of Use** 

Source: Bob Williamson, ANU



### **Incremental transformation:**

Science and agriculture learning together

CSIRO AGRICULTURE AND FOOD www.csiro.au





#### Talk outline

- Increments can transform through synergy
- Recent Australian examples...
  - success factors?
- Rigour Relevance Reality
   collective enquiry
- Concluding remarks



#### Agricultural (r)evolutions.....

The **Norfolk** system (Young 1771)

- (1) enclosures without Government assistance
- (2) use of marl (lime) and clay (known to Romans)
- (3) rotation of crops (Ancient Greeks)
- (4) culture of turnips, hand hoed (in rows) (Chinese in 6th century)
- (5) culture of clover and rye (Ancient Greeks)
- (6) long leases
- (7) large farms

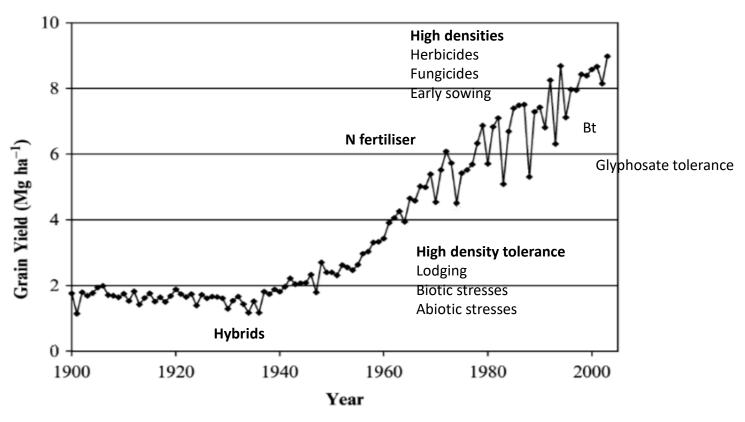
4 course rotation [turnips (for fodder) - wheat/barley - clover/rye - wheat/barley]

"individual components of the revolution had a long history but the **synergistic interactions** in the Norfolk system made it such an effective agent of improvement"

in Evans LT (1998) Feeding the 10 Billion



#### US Maize – a modern agricultural revolution..



"On average, about 50% of the increase is due to management and 50% to breeding. The two tools interact so closely that neither of them could have produced such progress alone."



### **Synergy**

#### Genetics, breeding

Agronomy, systems

**G** x E

E x M

Molecular biology Plant cell biology Crop physiology







Farmers Consultants Input resellers







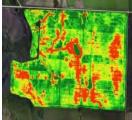


GxExM

Crops for the systems of the future

Physiology Modelling











#### What are the obstacles?

Conceptual - just how we think about things?

Structural - how we organise ourselves?

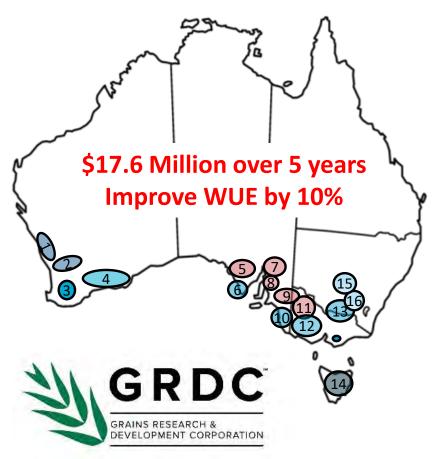
Cultural - how we approach research?

Statistical - how we analyse data?

Institutional - how we are rewarded?



### National WUE Initiative (2009-2014)

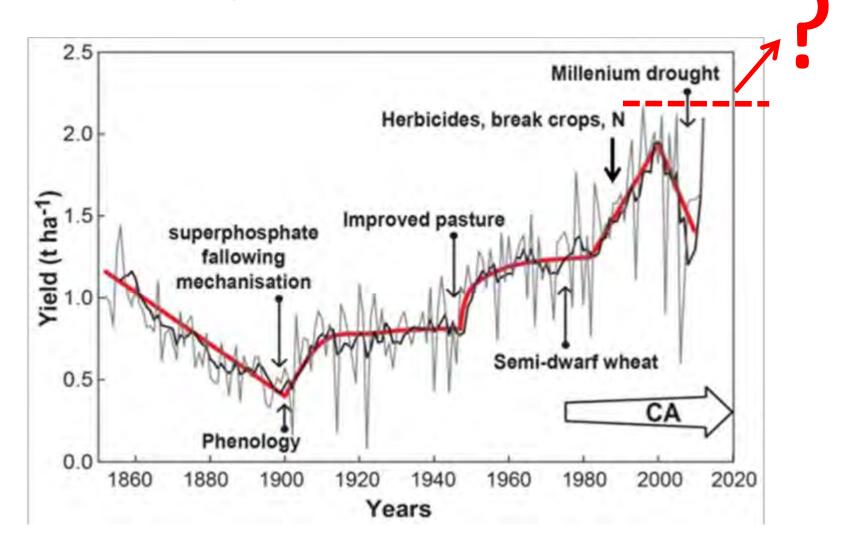


#### 16 regional farmer groups





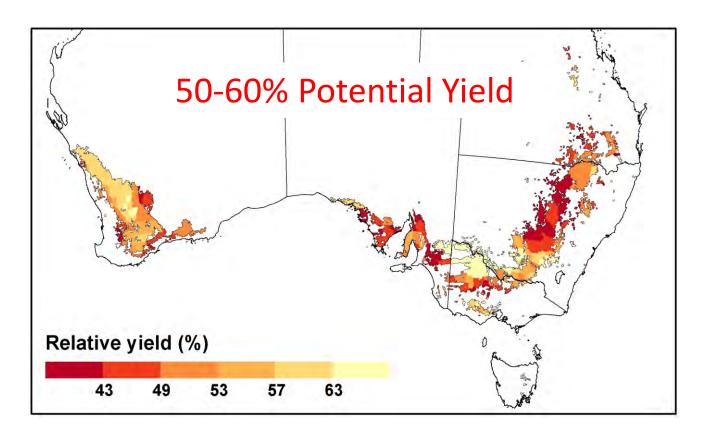
### **Australian dryland wheat**





#### Yield Gaps - potential vs actual wheat yield

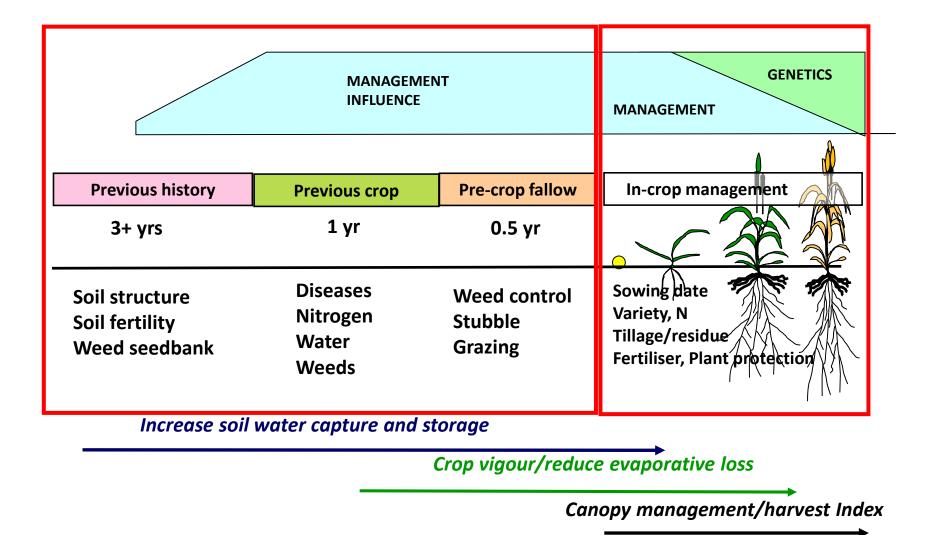
15 year average 1996-2010



www.yieldgapaustralia.com



### Using rainfall more efficiently





#### Four linked research Themes



1. Break crops and crop sequence

2. Summer fallow management







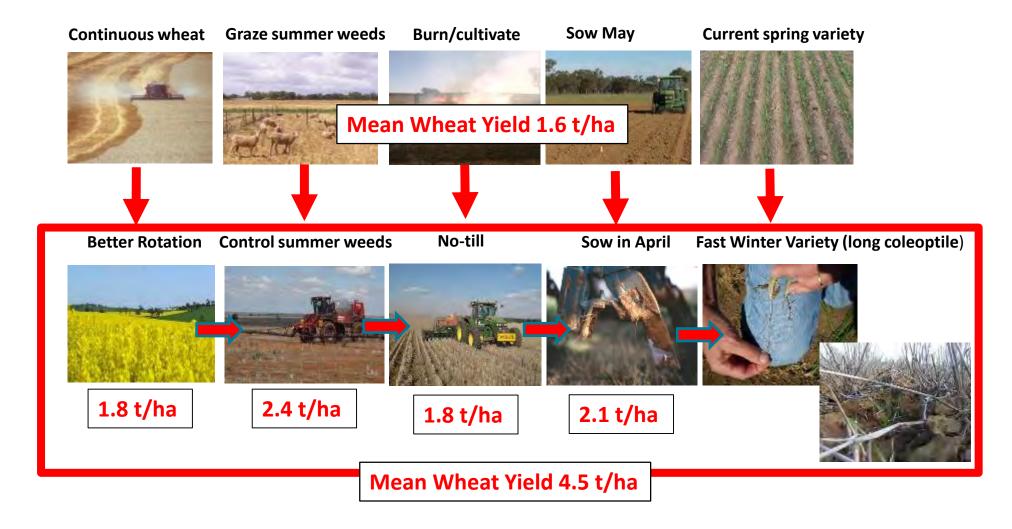
3. Managing in-season water-use

4. Managing variable or constrained soils





#### **Novel system-level innovations**





#### **Demonstrated benefits of Innovations – (10%?)**

	Theme	Innovation	WUE Increase
	1	Break crops	16 to 83%
	2	Summer weed control	60%
	3	Early sowing	21 to 32%
	3	Wider rows	-6 to -13%
	3	Irrigation timing	12 to 23%
	3	Disease control	20 to 25%
	4	Variable N rates	up to 91%
	4	Responsive systems	22%
4		Gypsum	15 to 54%
	4	Subsoil manuring	28%
	4	Mouldboard/spade	20 to 80%









#### Wider adoption and impact

- Independent ex post economic analysis ROI 18.5%; BC ratio 3.7:1
- Consultant feedback

"A unique aspect of this project has been the speed of adoption by growers.

After just 3 seasons there has been widespread practice change across the industry"

Tim Condon, Agricultural Consultant, NSW

"The uptake of many of the aspects of this research program have been outstanding.

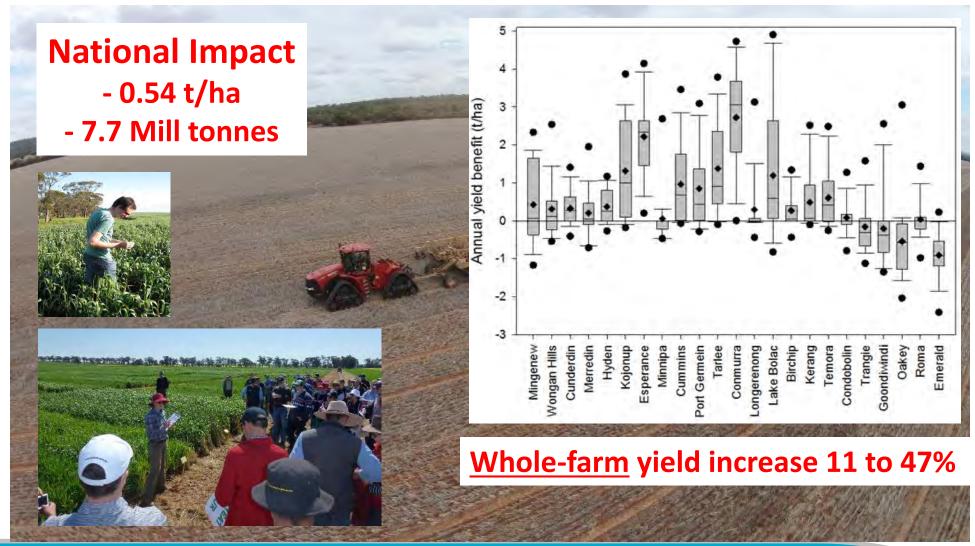
Farmers no longer debate the benefits and costs of summer weed control"

Bill Long, Agricultural Consultant, South Australia

Commercial breeding companies pursuing slower-maturing wheat



#### Farm-scale benefits and flow-on projects





#### Early sowing systems in canola



~ 1M ha suitable

Yield ~ 6%/week Oil ~ 1%/week

Worth \$40/ha/week



"My clients now plan to finish rather than start sowing canola on 25 April and I estimate a 0.3 t/ha yield increase"

Greg Condon
Consultant (manages 10,000 ha canola)





### Dual-purpose (grazing) canola

Grain only

Jan F M A M J J A S O N Dec

Dual-purpose crop — graze and grain

Jan F M A M J J A S O N Dec

Winter Grazing









#### **Dual-purpose canola research**

2004 to 2006 Proof of concept ("CDK") (CSIRO)

2007 to 2009 Best-bet G x M (eConcept) (GRDC-CSIRO)

2009 to 2012 Whole-farm integration (GRDC-CSIRO-DPIs)

2012 to 2015 Refine graze-grain trade-off (GRDC/MLA)

2013 to 2018 Expanded animal studies (MLA)









### **Dual-purpose canola research (on farm)**





**Pathology** 

**Crop physiology** 





**Grazing management and animal nutrition** 





**Consultants and growers** 





**Genetics and adaptation** Farming systems

**Simulation** 



#### Impact on-farm – existing and new farming areas



"We increased crop area by 10% and winter stocking rate from 12 to 18 animals/ha (worth \$1 Mill pa to business)"

• Whole-farm productivity/profitability increases of 25-75% (~\$100 per farm ha)

"A decade ago we only grew fine wool...now we grow crops for forage, silage, hay and grain, and meat from sheep and cattle"





#### **Elements of success**

- Industry and growers involved from the outset
- Adopted a G x E x M approach at system level
- Multi-disciplinary, but linked to a non-disciplinary goal
- Effective "integrators" needed; valued for broad knowledge
- Longer-term? funding horizons (5 years)
- Working across borders, disciplines, crops









#### Latest farming systems research

- New "systems research" projects supported
   Sequence x sowing time (+graze) x nitrogen]
- Grower Group connections have been lost....







#### Rice revolution in Latin America

#### Latin American Fund for Irrigated Rice (FLAR)

(Commenced 1995)

• Farmers, Millers, Seed Companies, Public

Breeding, Agronomy, Economics and markets

Annual fee related to production

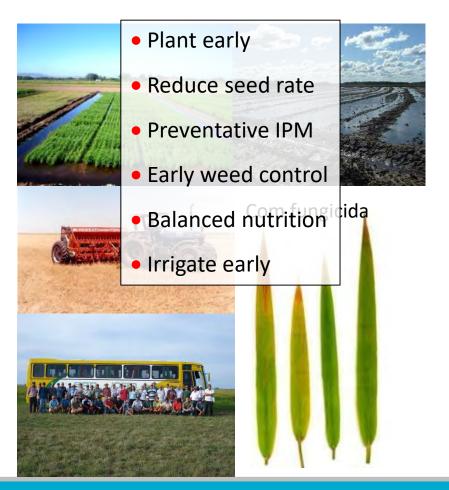


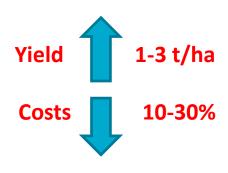




#### Rice revolution in Latin America

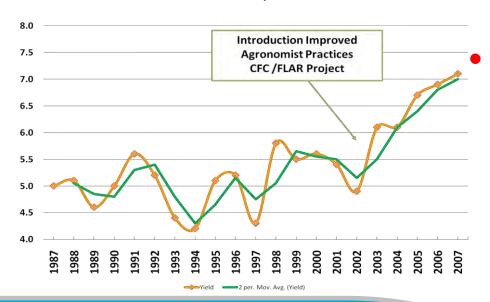
6 Strategic principles NOT site-specific







Rice Yields - RS Brazil 1987 - 2007, IRGA





#### **Key elements of success**

- Systematic agronomy approach not fragmented "product-centric"
- Common goal and <u>agronomic principles</u> (easily communicated)
- Large-scale technology solutions that match farmers' needs
- Focus on farmer-to-farmer extension
- Extension support mechanisms

Motivated field agronomists (IRGA, private consultants) Local partnerships (technical working groups) Focused applied research program (IRGA)

- Self-sustained: paid and driven by farmers
- Teamwork





# Rigour Relevance - Reality





### Stubble retention and carbon sequestration?



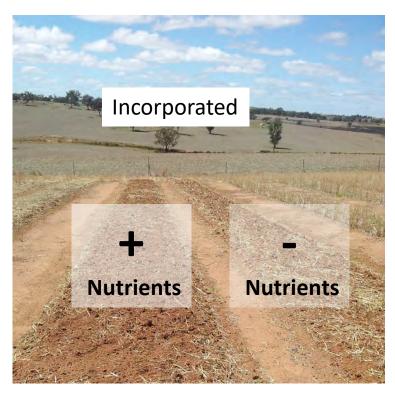
- Soil carbon changes slow or absent [Rumpel et al. (2008); Luo et al.(2010)]
- No significant change at Harden Site
- Clive Kirkby PhD
  - nutrients, not C, limit organic matter

- Target is stable organic matter SOM
- SOM has a constant ratio of C:N:P:S
- Nutrients (not C) limit humus formation





#### Change in humus carbon 2006 to 2012



2006 Wheat 2007 Wheat 2008 Wheat 2009 Wheat 2010 Canola 2011 Wheat 2012 Wheat 2013 Wheat 2014 Lupin 2015 Canola





#### **Change in Humus C**

- Nutrients 3.2 t/ha C
- + Nutrients + 5.5 t/ha C

Net Diff 8.7 t/ha

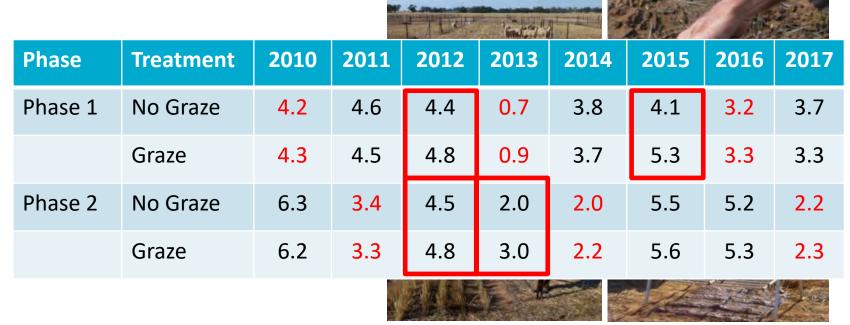


### Sheep on no-till soils – synergy or sinners?









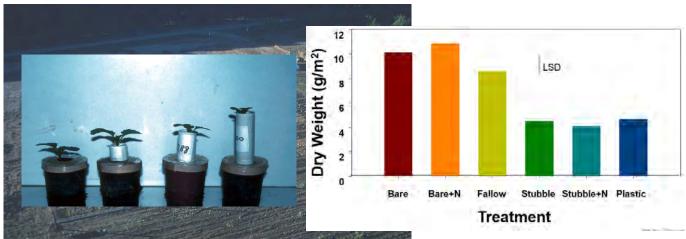


#### Allellopathy - wheat residue on canola?





- Poor emergence
- Poor vigour
- 25% yield loss
- Allelopathy?



Stubble on inter-row











#### Strategic tillage...



Does occasional tillage do irreparable damage to soil?

"Years of soil regeneration can be lost to a single tillage event" (Grandy et al. 2006).

#### Method

- Four sites on diverse soils, 10 to 25 years no-till
- Cultivated <u>once</u> in 2011, returned to no-till cropping
- Soil conditions and crop growth monitored for 5 years

#### Result

- Impacts on soil structure minor, and short-lived (1-2 years)
- Few effects on crop biomass or yield (mostly positive)
- Soil C redistributed not reduced; reduced pH and P stratification



#### Summer rainfall <u>IS</u> important in southern Australia

- Value of summer fallow rain (modelling)
  - 33% (3 72%) of yield
  - 1 t/ha (0.1 to 2.0 t/ha)
- 9 on-farm experiments (2010 to 2012)
  - extra 37 mm water
  - extra 44 kg N/ha
  - yield increase **0.8 t/ha**
  - ROI \$5.60 for each \$ spent
- Rapid adoption, now standard practice







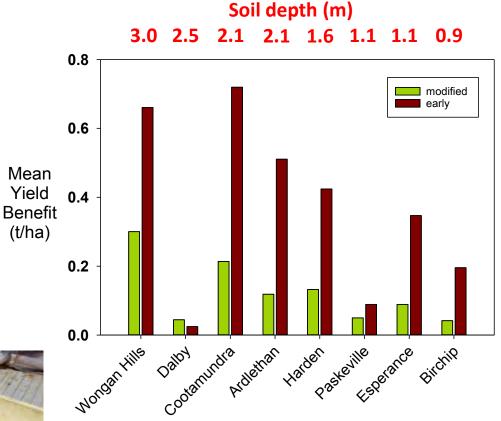


#### Deep and meaningful - value of deep roots?



Innovation	Yield benefit (t/ha)	
Modified roots	0 to 0.3	
Early sowing	0 to 0.7	
Both	0.1 to 1.0	



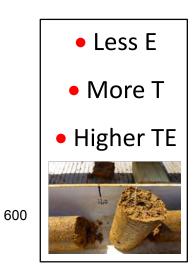


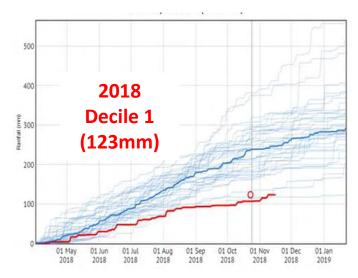


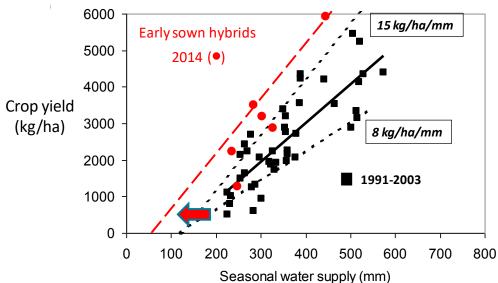


### Earty-sown, vigorous canola crops don't "crash"









Karoonda, SA Mallee





### Cover crops...in need of rigour!

- Diverse, multi-species cover crops (tillage radish etc....)
   expensive distraction???
- Rolled oat cover crops in western Australia
   pasture better option
- Legume brown manure in SE Australia
   resistant weeds, water and N benefit
- Millet inter-row cover crop for sorghum
  - water benefit and soil protection







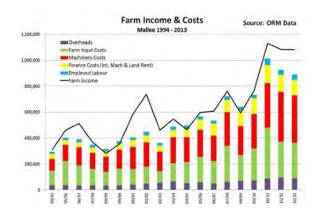
## Rigour - Relevance (Reality)





### **Revisiting long-fallows?**





Higher debt
Higher interest
High land value
Machinery costs
Climate variability

Income to costs ratios changed

In 2000, spend \$400K to make \$100K In 2013, spend \$800K to make \$100K

W-W; Chick-W; Fall-WW (set) or rule based (crop price, N price, N-water at sowing)

Whole-farm Economics (50% fallow)

- Fall-W more profitable than WW; and Chick-wheat if Chick < \$800/t
- Whole-farm costs reduced by 25%
- Inter-annual profit variability (risk) reduced by 51%
- Rule-based Fall-W increased cash-flow by 55-77%
- Smaller sowing program, more crop sown on time; more effective N management
- Lower whole-farm costs, less machinery replacement delayed and reduced depreciation
- Less risk in following crops



### **Dual-purpose crops**

DP Crops – grazing management/lock-up

Detailed physiology of regrowth after grazing

- physiological traits of cultivars
- radiation interception during grain growth





#### Rules of thumb based on:

- target yield  $\implies$  anthesis biomass  $\implies$  residual biomass











"The profitability of the dual-purpose canola is amazing, but I am exhausted and will probably need to hire more labour"

Peter Brookes, early adopter, Goulburn NSW



### **Obstacles? - ultimately its personal**

Conceptual - think more broadly - GxExM

Structural - reward "integrators" as specialists

Cultural - partner for impact

Statistical - consider the interactions

Institutional - impact, not "impact-factor"





# Numerous colleagues, collaborators farmers and friends









**CSIRO AGRICULTURE AND FOOD** 

www.csiro.au



### Department of Plant and Environmental Sciences logy



## What science? - What agriculture? - What research?

John R Porter

MUSE University of Montpellier
SCIENCE Copenhagen University DK
NRI Greenwich University UK
Lincoln University NZ

### The main question

What types, skills and disciplines of science are needed to address the current and future issues facing agriculture and food systems?



University of Montpellier
SupAgro – EMA –
ENSCM
Ensam – CEA – CNRS –
Inra
IRD – Cirad – Ifremer –
Inserm Inria – BRGM –
IAMM – Irstea Montpellier
U. Hosp. – Nîmes U.

19 establishments 6,000 scientists 50,000 students

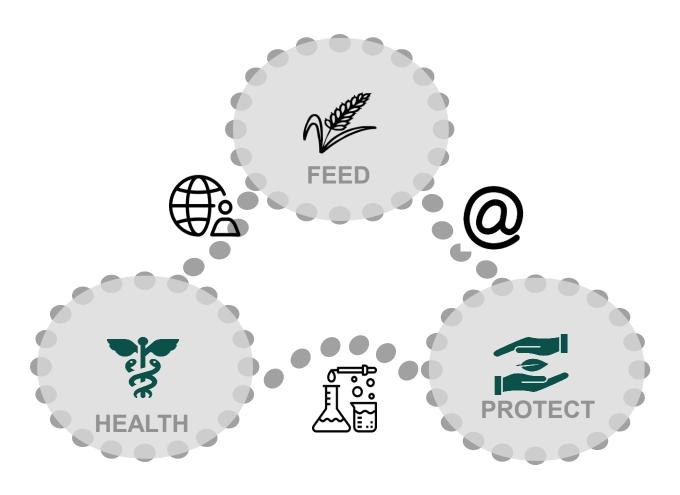


Endowment 550 M€ (670 M\$)





# Three societal challenges – for agricultural and food science







# 1976 - UK summer - but where is the obesity?





## Front cover of INRA history book





## The paradigms of INRA - 1947 to 2018

1946-1968: The imperative of production

1969-1989: Industrial agriculture - technology

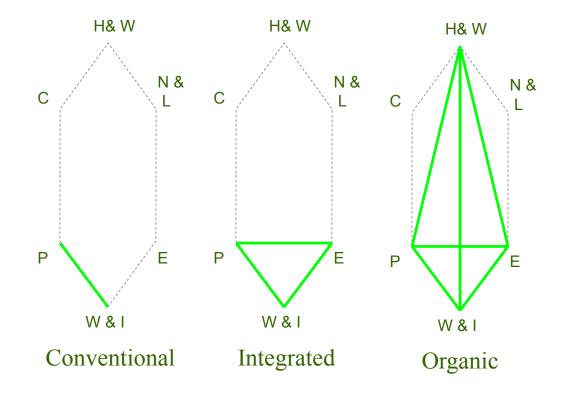
1990-2012: Agronomical research in a globalised time – quality and environment

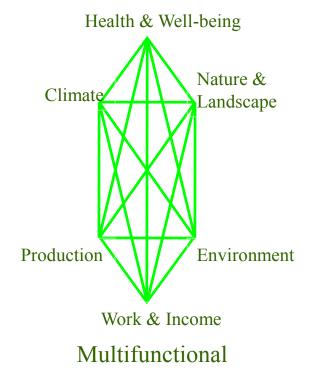
2012-2018: Produce less, conserve more, save more

What science is needed for these evolved paradigms?



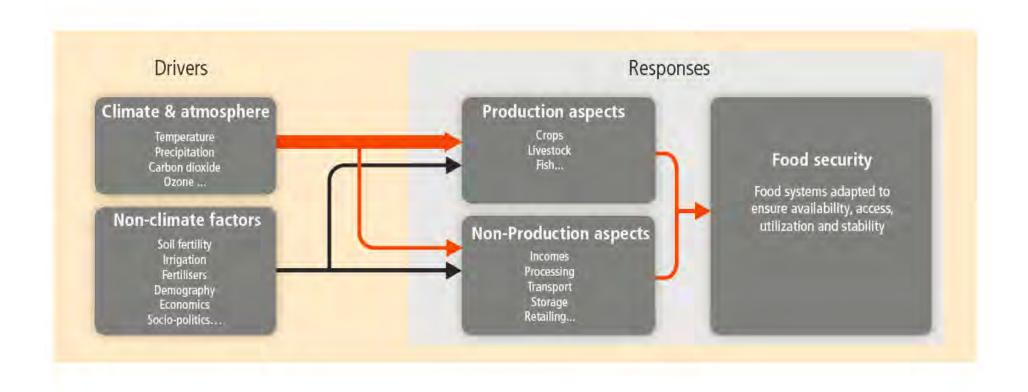
# From farming as production to farming as a service







# Food Security: IPCC AR5





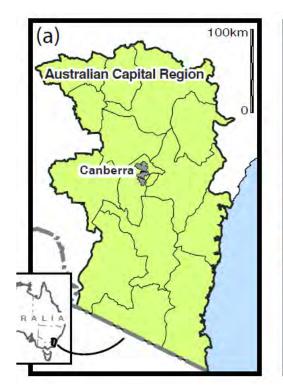
Food security is an outcome of food systems and not just food production

Come out of our 'comfort zones'

Come out of our 'expensive distractions'



## Three capital cities...

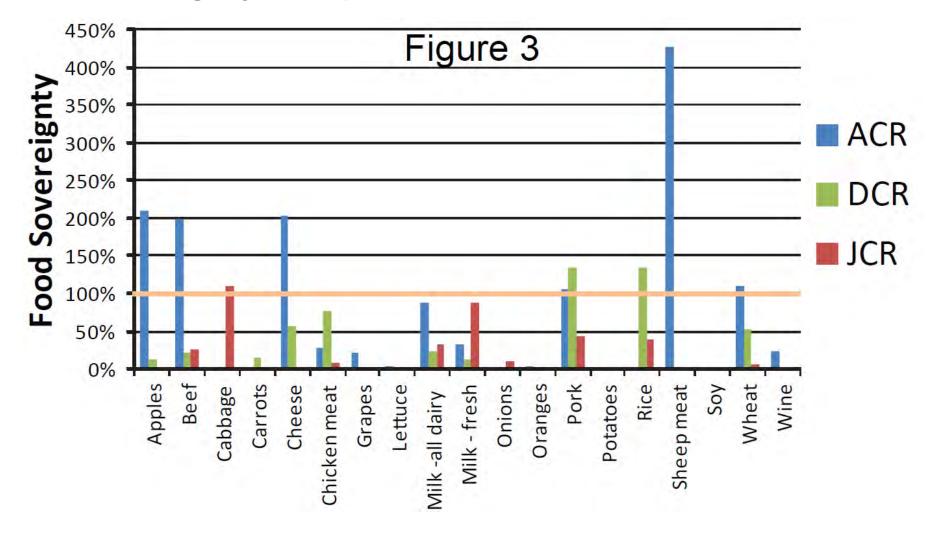






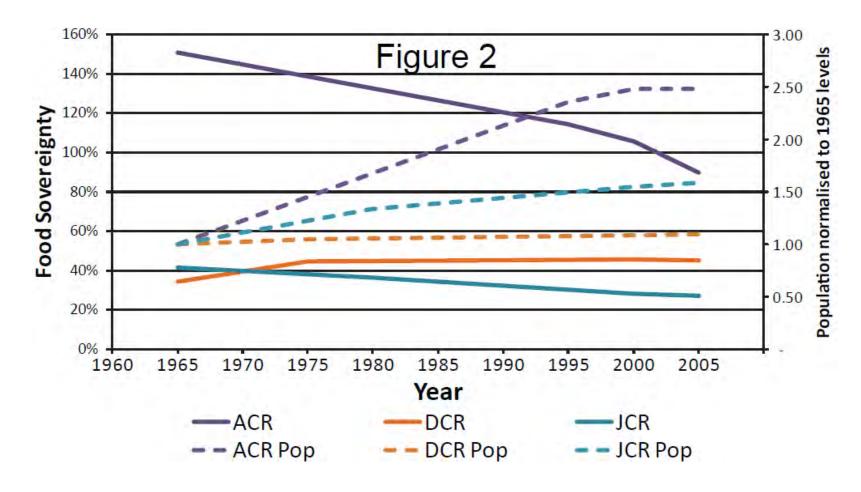


## Food sovereignty...snapshot



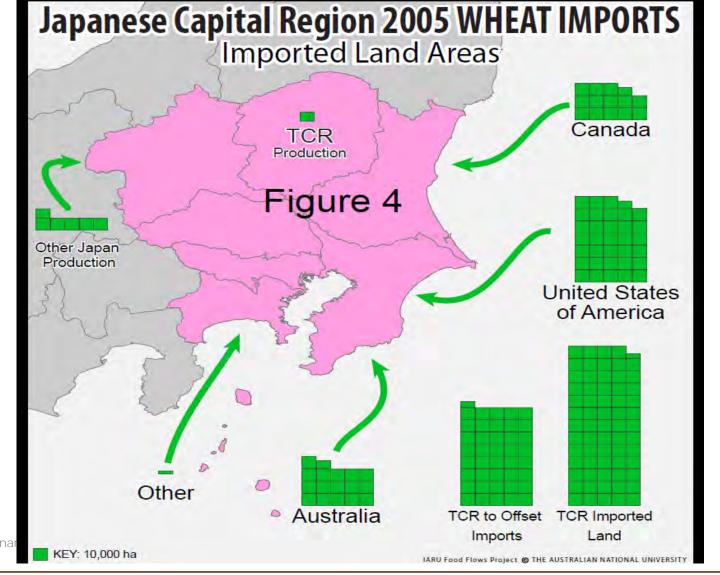


### .... and over time



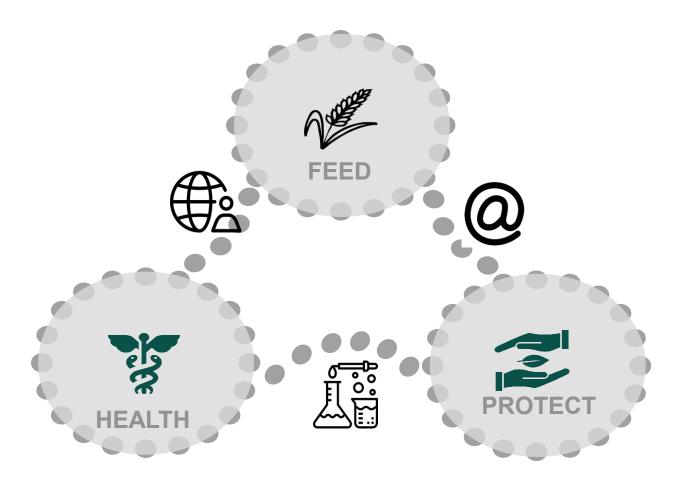


## What science to study food systems?





# Three societal challenges - for agricultural science







The ARI/MUSE team

The medical geneticist

The agronomist

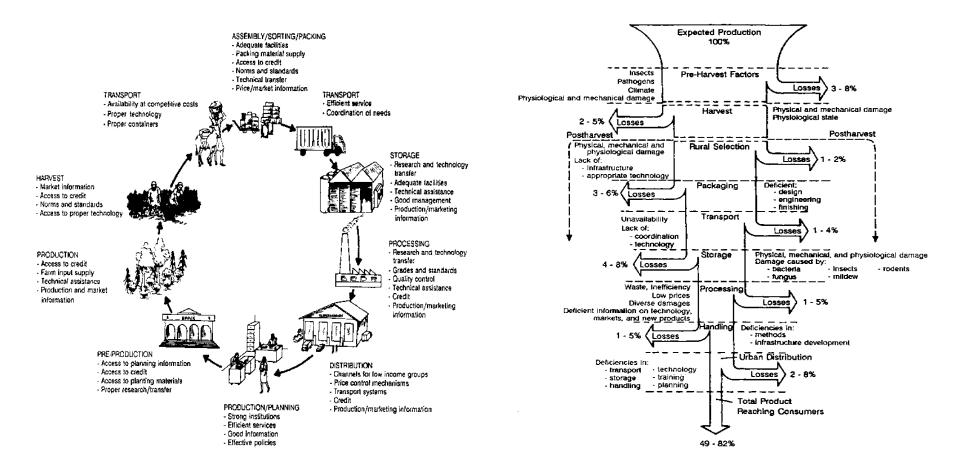
The climate scientist

The AIDS epidemiologist

The geographer



### Circular and linear food systems



What science? What metrics?



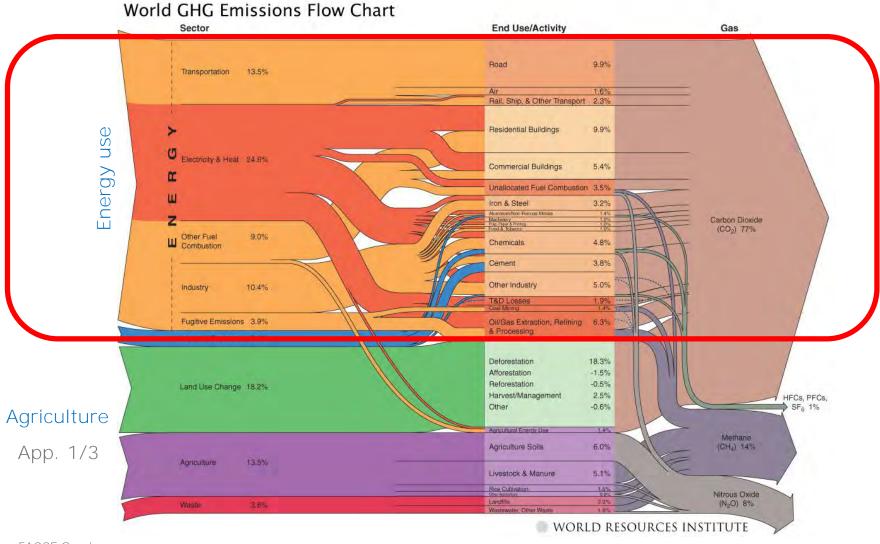
Linking policies..... energy and food

Identities - metrics for land-based GHG emissions

Relative efficiencies and absolute emissions



# Energy-based emissions





# The Kaya Identity - UNFCC/IPCC

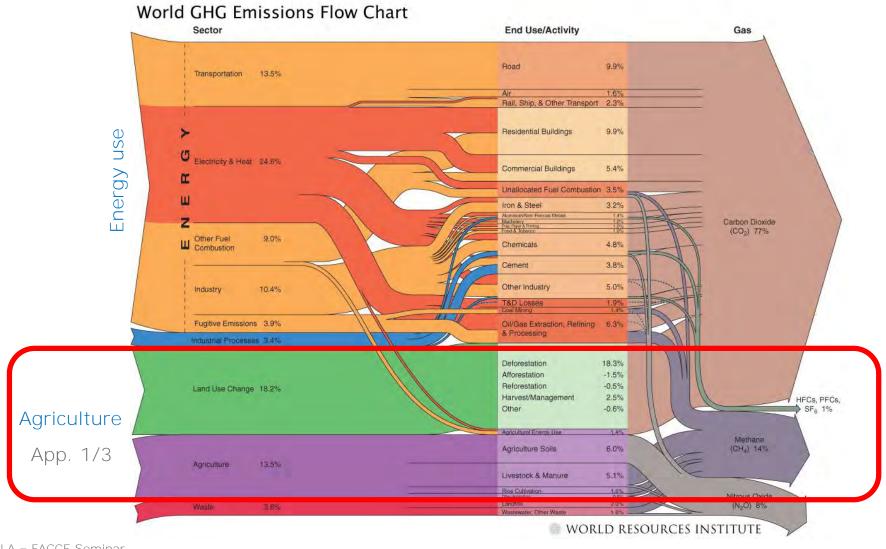
$$\frac{\mathsf{GHG}}{\mathsf{ENERGY}} \times \frac{\mathsf{ENERGY}}{\mathsf{GDP}} \times \frac{\mathsf{GDP}}{\mathsf{POPUL}} \times \frac{\mathsf{POPUL}}{\mathsf{ATION}} = \mathsf{GHG}$$

$$\mathsf{Fuels} \qquad \mathsf{Sectors} \qquad \mathsf{Services}$$

Scale independent - deconstruction



# Non-energy emissions





## JRP's Simple Land-Use Identity (KPI)

Production Technology Fuels



### The KPI



**Energy use efficiency** 



$$GHG_{crop} \equiv \left(\frac{GHG_{LUC}}{F} + \frac{GHG_{soil}}{F} + \left(\frac{GHG_{energy}}{F} \times \frac{E_{in}}{F}\right)\right) \times \frac{E_{out}}{DM} \times \frac{DM_{out}}{A} \times Are^{in}$$

**Total emissions** 

**Emissions from soils** 

**Cultivated area** 

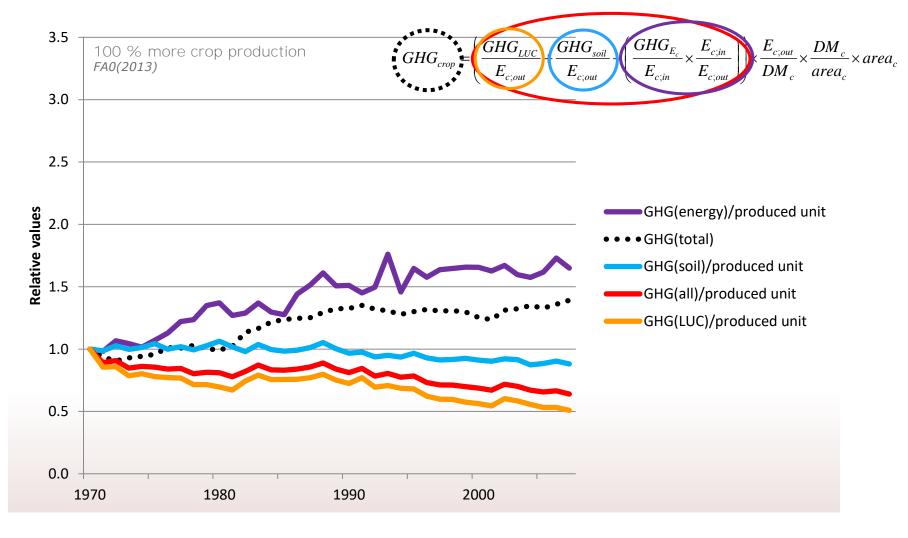
Deconstruction

Management 'handles'

Bennetzen *et al*. in prep.



# Reduced emissions per crop: but absolute emissions increase





# Connecting wealth, population, consumption and GHG emissions

$$GHG_{kaya} = \frac{GHG}{energy} \times \frac{energy}{GDP} \times \frac{GDP}{capita} \times population$$

$$GHG_{KPI} = \frac{GHG}{energy} \times \frac{energy}{drymatter} \times \frac{drymatter}{area} \times area$$

$$Demand = \frac{animalprot.}{totalprot.} \times \frac{totalprot.}{calorie} \times \frac{calorie}{capita} \times population$$

$$GHG = \frac{GHG_{bio}}{energy_{bio}} \times \frac{energy_{bio}}{animalpop} \times animalpop.$$



### To reduce both absolute and relative emissions

not More from Less

but Enough from Less

'Profit and Planet'



### From

Euphytica 17 (1968): 385-403

### THE BREEDING OF CROP IDEOTYPES

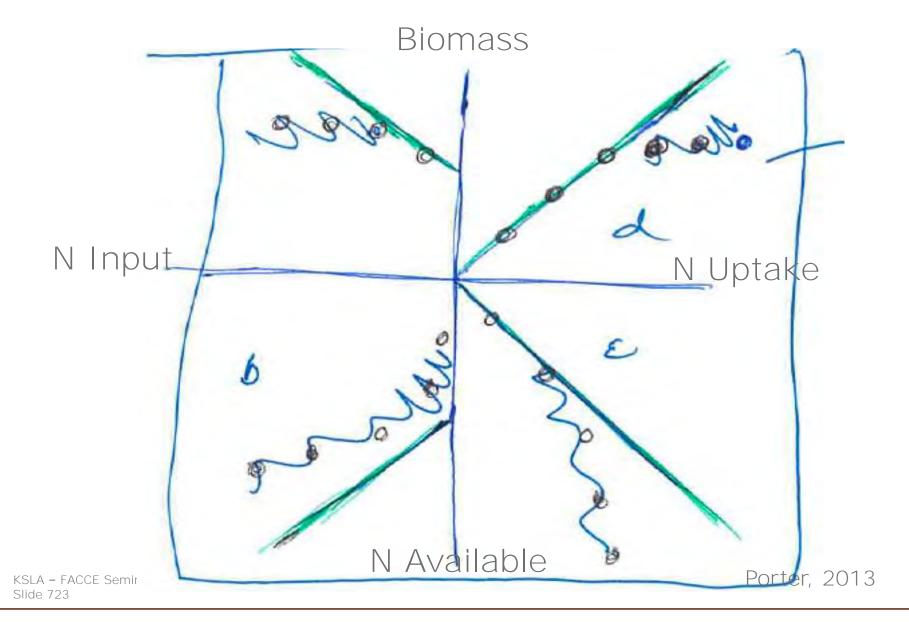
C. M. DONALD

To

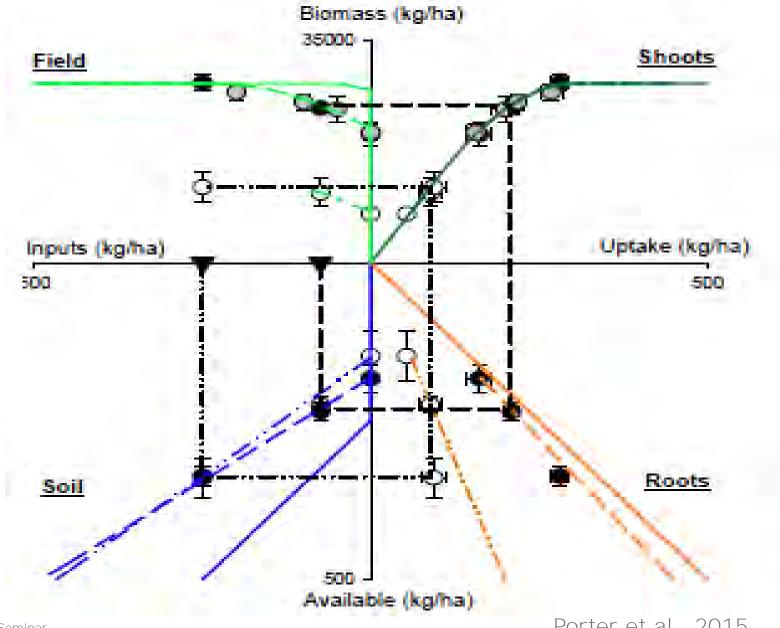
### THE DEVELOPMENT OF CROP IDEO-SYSTEMS



# A back of the envelope idea.....









### Identities in resource efficiences

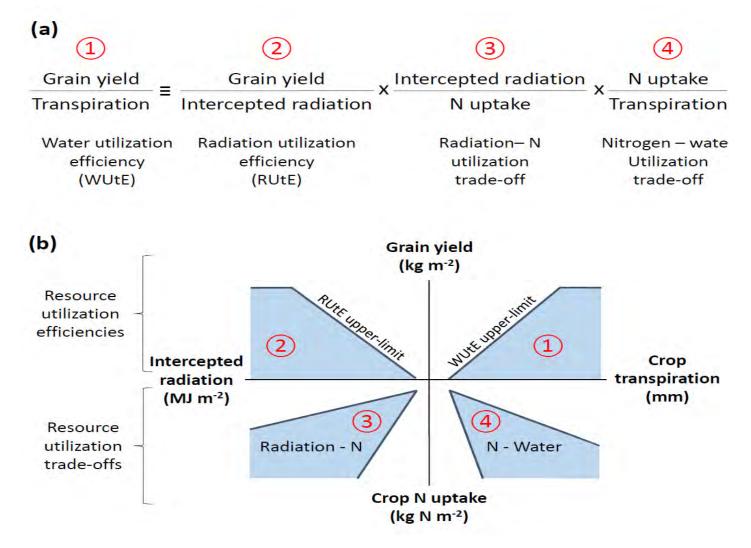
$$NUE = \frac{Biomass}{FertNinputs} \equiv \frac{SoilAvailableN}{FertNinputs} \times \frac{Nuptake}{SoilAvailableN} \times \frac{Biomass}{Nuptake}$$

$$WUE = \frac{Biomass}{IrrigationInputs} \equiv \frac{SoilAvailableWater}{IrrigationInputs} \times \frac{WaterUptake}{SoilAvailableWater} \times \frac{Biomass}{WaterUptake}$$

Interactions?

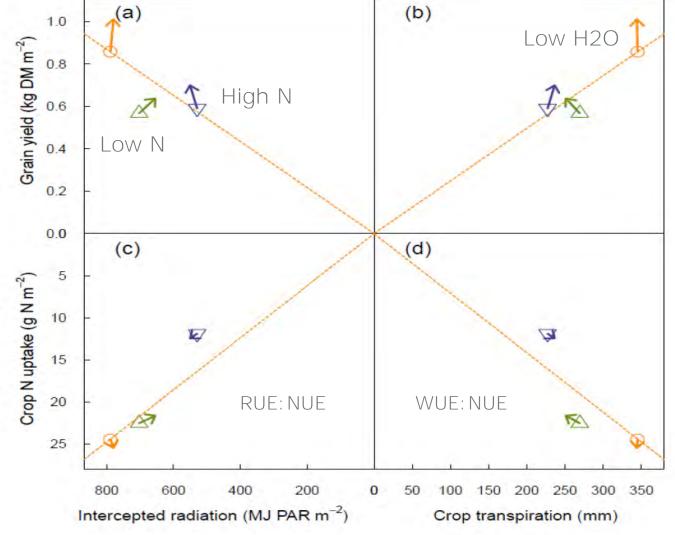
2012

### What CT de Wit thought about 50 years ago...



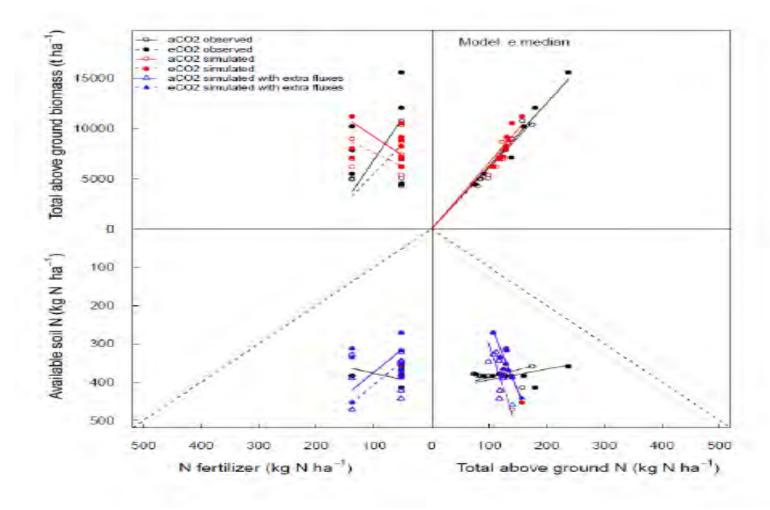


## Efficiency interactions: RUE, WUE, NUE





## Testing the models....





# Thinking the unthinkable....

What are the properties of circular food systems for health, the environment and food?

How should research organisations concerned with food and agriculture move their agendas from produce, consume and use to an agenda to produce less, consume less and save more?



## The 'Mertonian' norms for science (CUDOS)

The Normative Structure of Science (1942) 2017 = 75th anniversary



### **Communality**

A scientist ought to make knowledge accessible to other scientists, as knowledge is common ownership

### **Universalism**

Scientists ought to assess knowledge claims based on pre-established impersonal criteria i.e. **not** depending on race, nationality or religion

#### **Disinterestedness**

A scientist may not hold conflicts of interest that can corrupt research results

### **Organized Skepticism**

Scientists ought to conduct organised quality control of research results



## The norms of science have changed

### Communality -> **Solitariness**

Keeping research a secret in order to publish first or file a patent.

Contracts with companies frequently demand that research activities must be kept secret (<u>disclosure</u> agreements).

### Universalism -> Particularism

Researchers are reminded that their work is sponsored and that the application of research results therefore must be <u>profitable</u> = have demonstrable economic <u>impact</u>.



## The norms of science have changed

Disinterestedness -> Interestedness

Scientists pragmatically align their research interests with <u>funding</u> <u>opportunities</u>

Science is increasingly becoming <u>performative</u>
Emphasis on evaluating efficiency of scientific output 'scientometrics'

Organized Skepticism -> **Organized dogmatism**Funding bodies request that proposals have to fit into <u>politically</u> <u>defined programs</u>



## A way ahead for science in an age of (un)reason

#### **Confidence**

The power of scientific reasoning lies in its ability to make accurate and precise projections based on systematically acquired evidence.

#### Communication

A better dialogue between science and society, which has to accept that science provides reasonable, evidence-based facts and not 'fake news'.

### **Credibility and controversy**

Threats to the objectivity of science have to be acknowledged and dealt with.

#### Conviction

Science has to identify evident denialism and pseudo-scientific claims (climate denial, Lysenkoism, Intelligent Design..).



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### Summary

What kinds of science do we need so as to cover the developing issues relevant to agriculture and food systems?

GEM

Identity methods and metrics to link energy, food, health, diet, emissions in policy relevant ways

From More for Less to Enough for Less

Heresies and norms



### Thanks

MUSE - ARI Montpellier University/Agropolis International

Eskild Bennetzen (DK), Pete Smith (UK)

Bernd Wollenweber (DK)

IPCC colleagues

INRA

