Global Food Security

Sustainable, healthy food for all

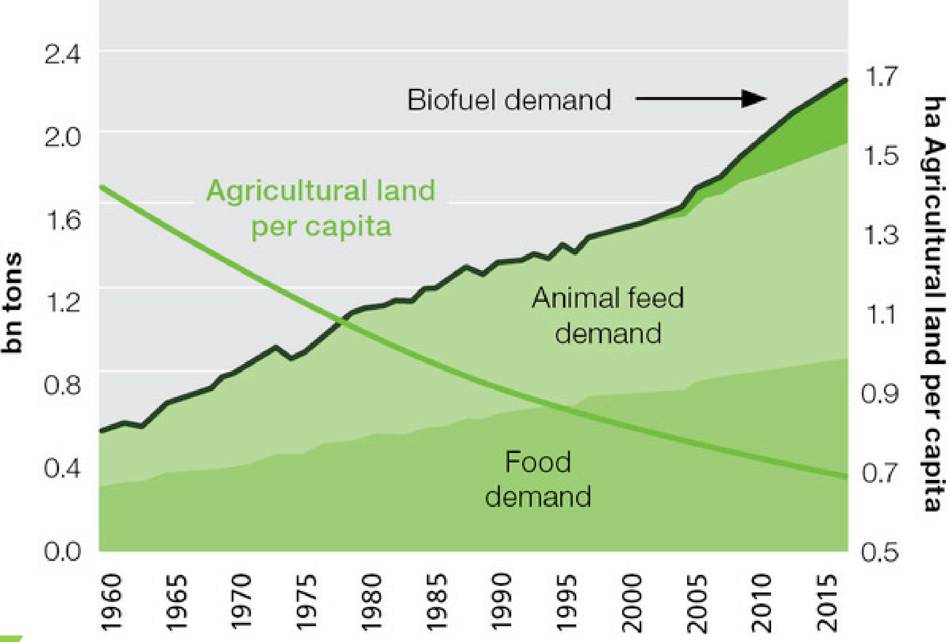
Tim Benton

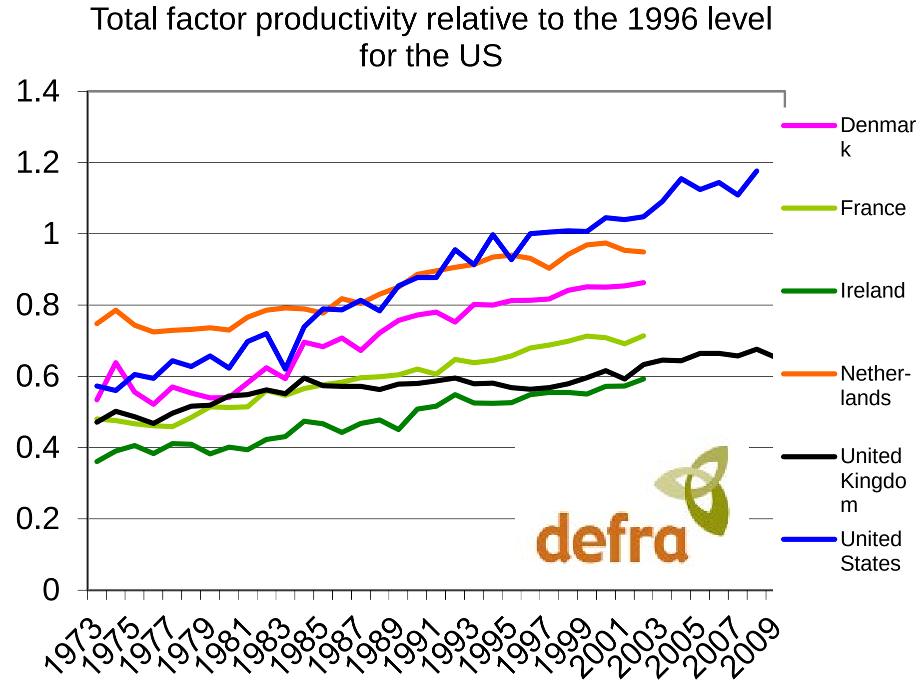
UK Champion for Global Food Security & Professor of Ecology, University of Leeds

tim.benton@foodsecurity.ac.uk

@timgbenton

Intensification is necessary: but how far is possible?





Total factor productivity relative to the 1996 level for the US

SHELF RELIANCE THRIVE™ 1-YEAR SUPPLY DEHYDRATED AND FREEZE-DRIED FOOD

1-Year Food Supply for 1 Person
5,011 Total Servings

$799.99
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15 gallons

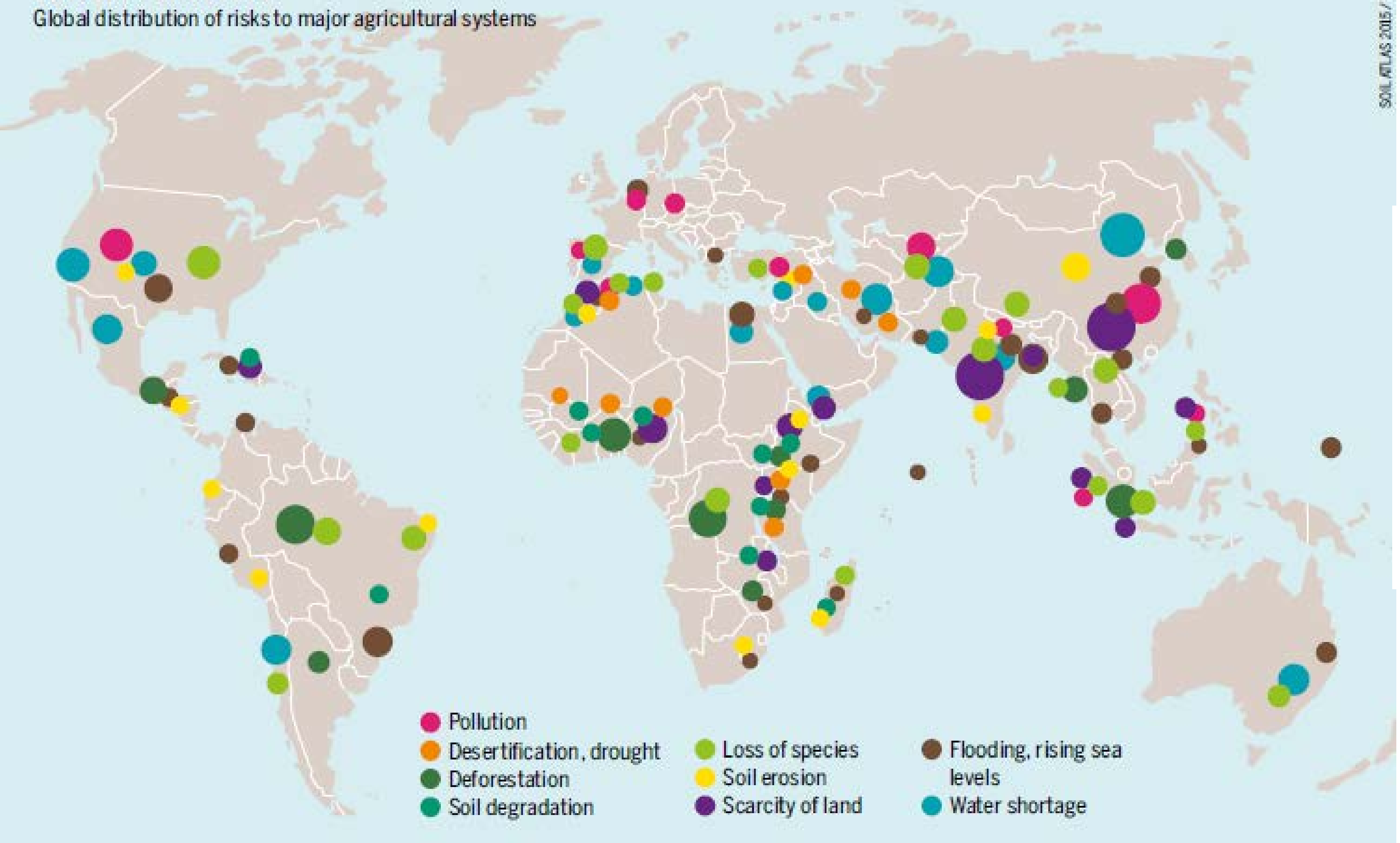
Sustainability is important

Global Food Security

The **SOIL ATLAS 2015** is jointly published by the Heinrich Böll Foundation, Berlin, Germany, and the Institute for Advanced Sustainability Studies, Potsdam, Germany

ON A SLIPPERY SLOPE

Global distribution of risks to major agricultural systems



- ● Pollution
- ● Desertification, drought
- ● Deforestation
- ● Soil degradation
- ● Loss of species
- ● Soil erosion
- ● Scarcity of land
- ● Flooding, rising sea levels
- ● Water shortage

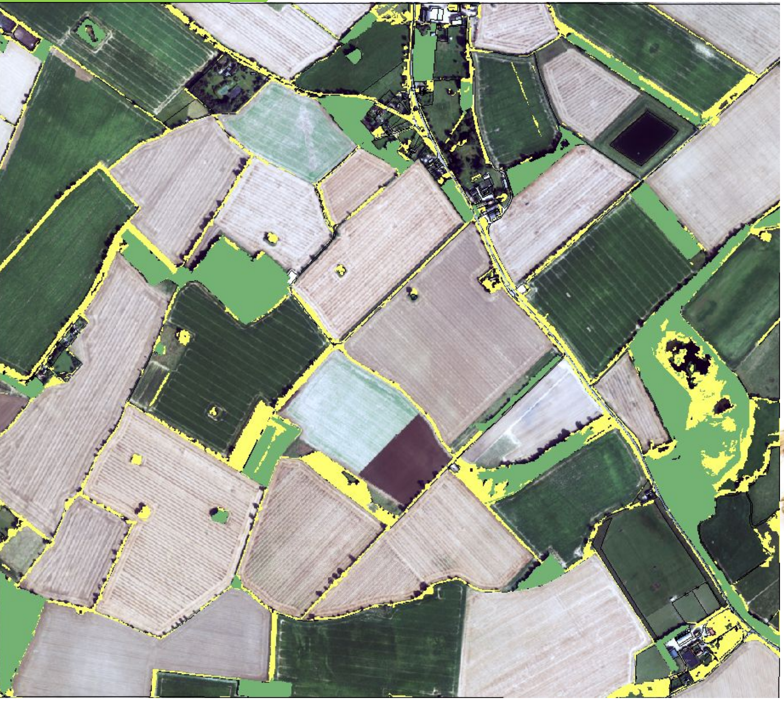
SOIL ATLAS 2015 / FAO

Land does much, for many



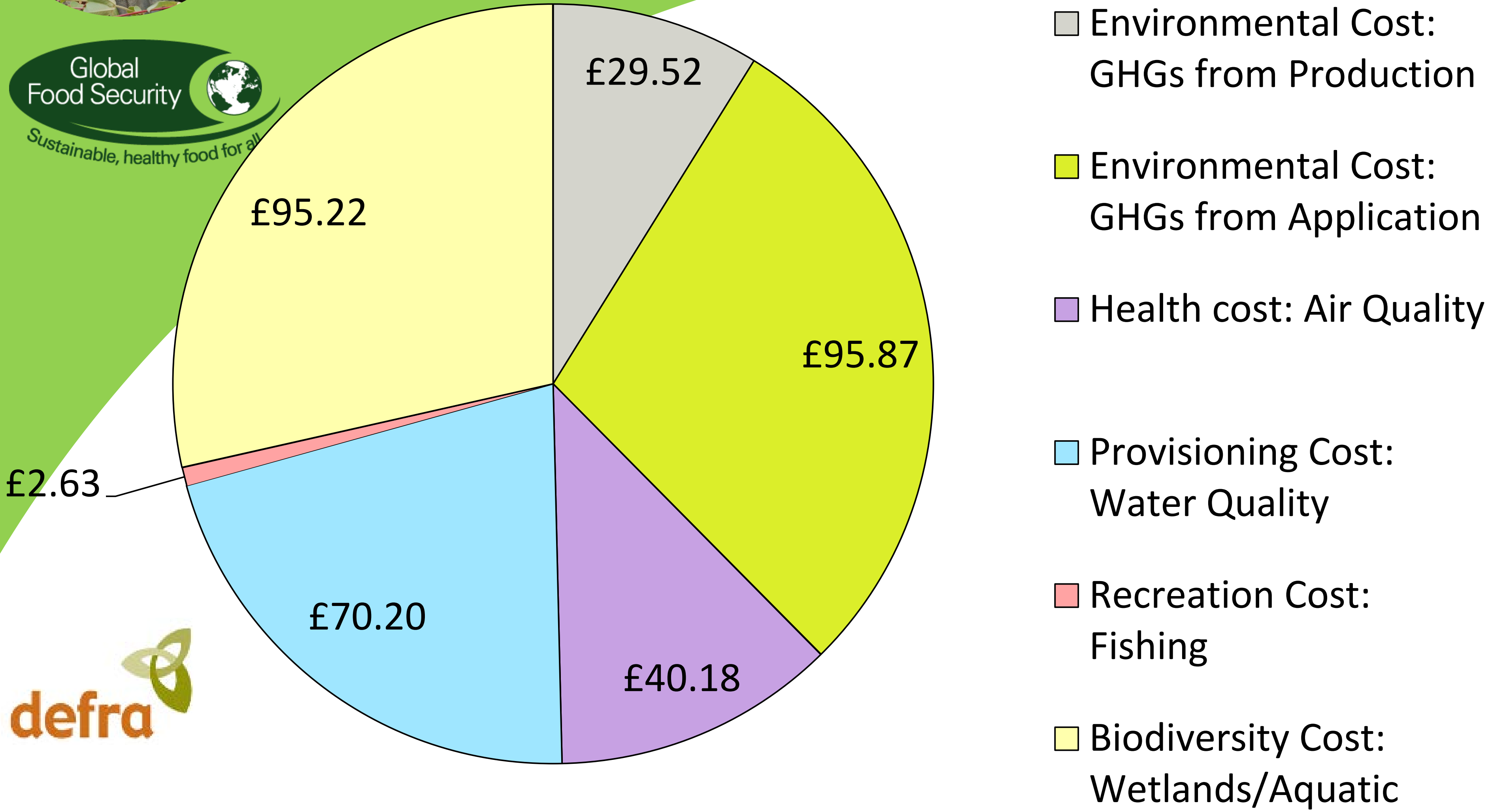




Environmental cost estimates per hectare

based on application of fertiliser at 190 kg N per hectare

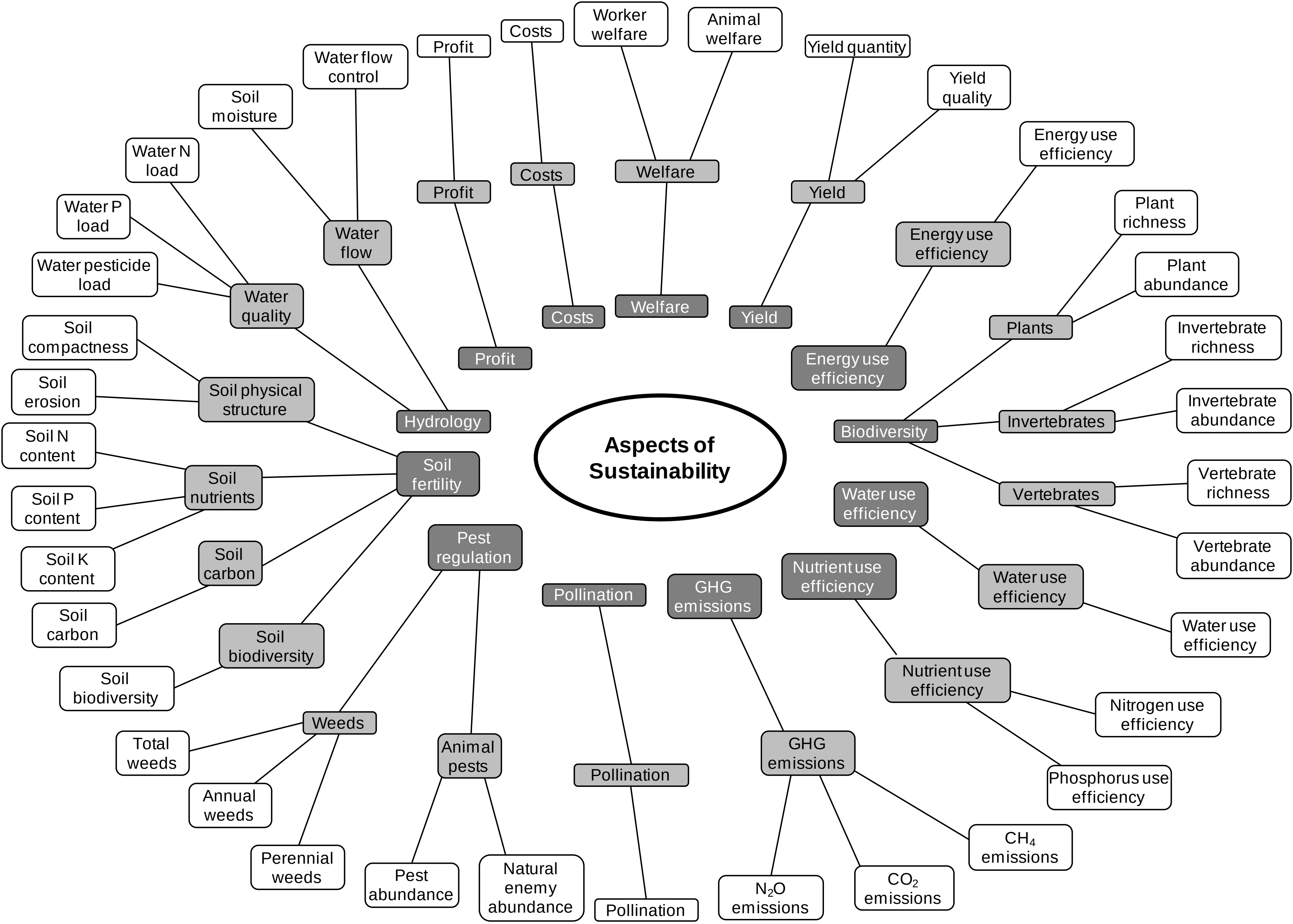


Total Environmental Cost ~ £333.61

For comparison p ha costs for wheat are ~£700 and gross income ~£1400 = £900 (less rent etc)

THE CHALLENGES OF SUSTAINABLE AGRICULTURE

1. Multiple axes

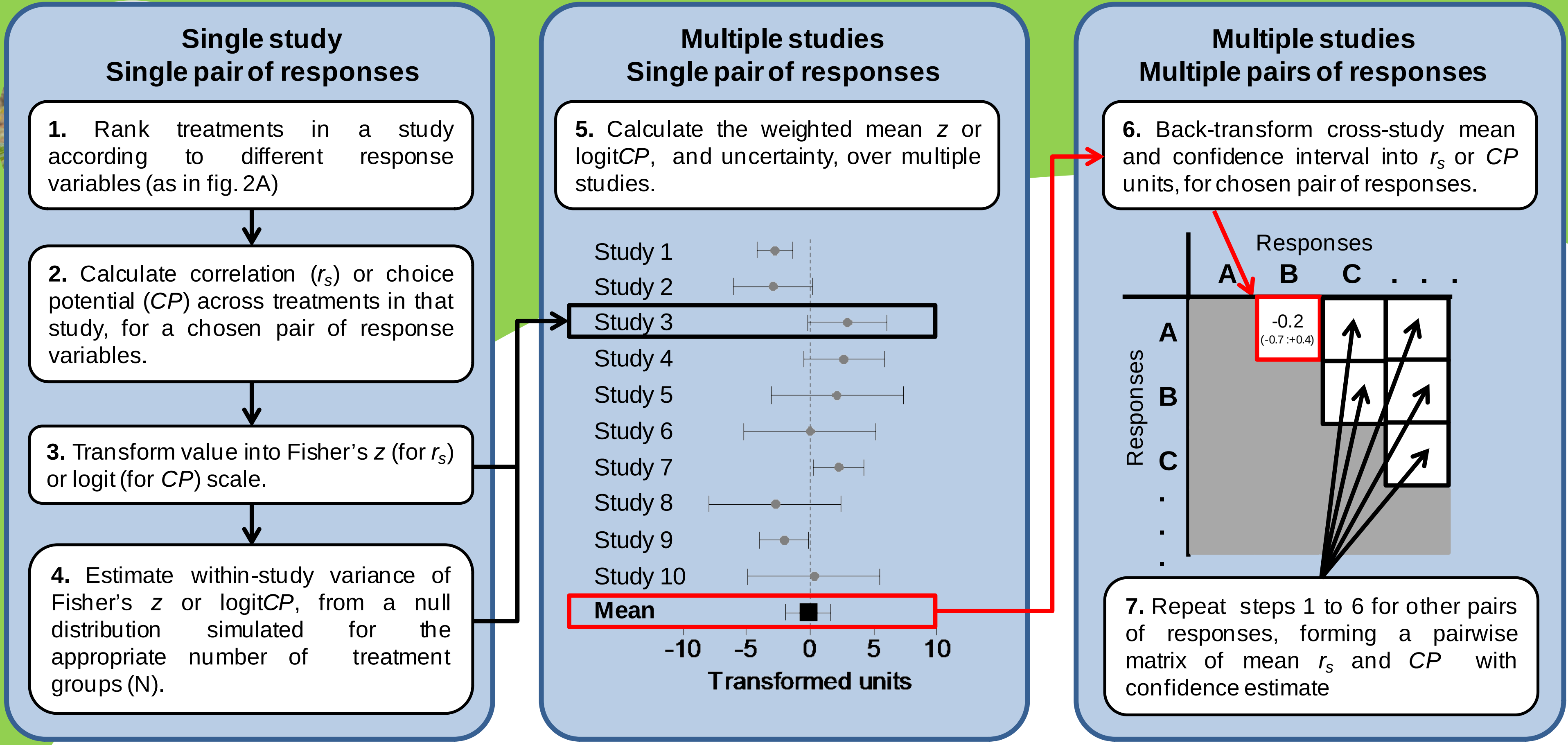


Aspects of Sustainability

- Hydrology
  - Water flow
    - Soil moisture
    - Water flow control
  - Water quality
    - Water N load
    - Water P load
    - Water pesticide load
- Profit
  - Profit
    - Profit
- Costs
  - Costs
    - Costs
- Welfare
  - Welfare
    - Worker welfare
    - Animal welfare
- Yield
  - Yield
    - Yield quantity
    - Yield quality
- Energy use efficiency
  - Energy use efficiency
    - Energy use efficiency
- Biodiversity
  - Plants
    - Plant richness
    - Plant abundance
  - Invertebrates
    - Invertebrate richness
    - Invertebrate abundance
  - Vertebrates
    - Vertebrate richness
    - Vertebrate abundance
- Water use efficiency
  - Water use efficiency
    - Water use efficiency
- Nutrient use efficiency
  - Nutrient use efficiency
    - Nitrogen use efficiency
    - Phosphorus use efficiency
- GHG emissions
  - GHG emissions
    - N_2O emissions
    - CO_2 emissions
    - CH_4 emissions
- Pollination
  - Pollination
    - Pollination
- Pest regulation
  - Weeds
    - Total weeds
    - Annual weeds
    - Perennial weeds
  - Animal pests
    - Pest abundance
    - Natural enemy abundance
- Soil fertility
  - Soil physical structure
    - Soil compactness
    - Soil erosion
  - Soil nutrients
    - Soil N content
    - Soil P content
    - Soil K content
  - Soil carbon
    - Soil carbon
  - Soil biodiversity
    - Soil biodiversity

Quantitative review of studies assessing “sustainable agriculture” (German, Thompson & Benton, in review)

Meta-analysis



Single study
Single pair of responses

1. Rank treatments in a study according to different response variables (as in fig. 2A)

2. Calculate correlation (r_s) or choice potential (*CP*) across treatments in that study, for a chosen pair of response variables.

3. Transform value into Fisher's z (for r_s) or logit (for *CP*) scale.

4. Estimate within-study variance of Fisher's z or logit*CP*, from a null distribution simulated for the appropriate number of treatment groups (N).

Multiple studies
Single pair of responses

5. Calculate the weighted mean z or logit*CP*, and uncertainty, over multiple studies.

Multiple studies
Multiple pairs of responses

6. Back-transform cross-study mean and confidence interval into r_s or *CP* units, for chosen pair of responses.

7. Repeat steps 1 to 6 for other pairs of responses, forming a pairwise matrix of mean r_s and *CP* with confidence estimate

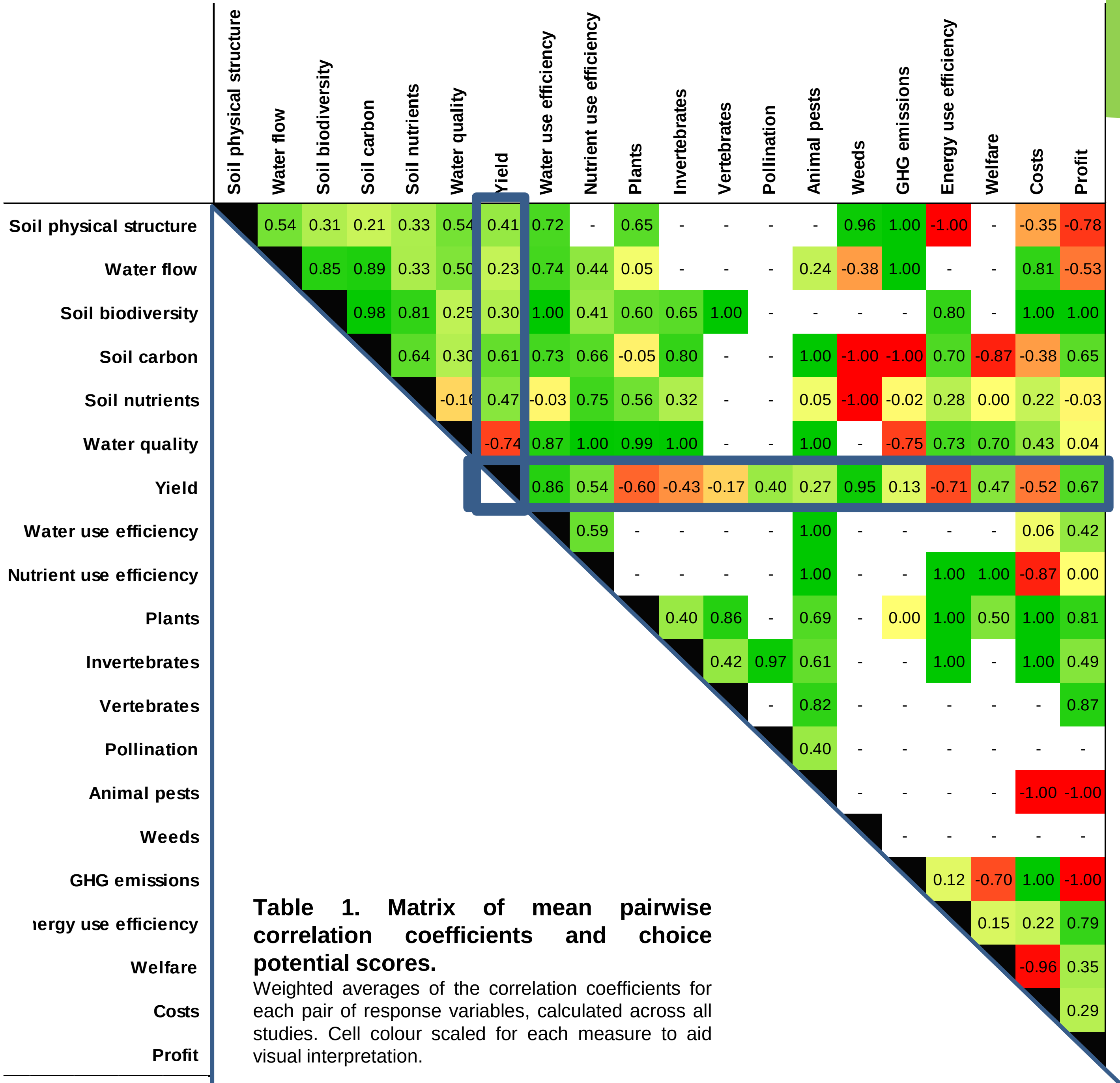
A

e.g. yield water

Treatment ID	Response A (rank)	Response B (rank)
S	1	2
T	2	1
U	3	7
V	4	8
W	5	5
X	6	3
Y	7	6
Z	8	4

Variable 2

Variable 1



	Soil physical structure	Water flow	Soil biodiversity	Soil carbon	Soil nutrients	Water quality	Yield	Water use efficiency	Nutrient use efficiency	Plants	Invertebrates	Vertebrates	Pollination	Animal pests	Weeds	GHG emissions	Energy use efficiency	Welfare	Costs	Profit
Soil physical structure		0.54	0.31	0.21	0.33	0.54	0.41	0.72	-	0.65	-	-	-	-	0.96	1.00	-1.00	-	-0.35	-0.78
Water flow			0.85	0.89	0.33	0.50	0.23	0.74	0.44	0.05	-	-	-	0.24	-0.38	1.00	-	-	0.81	-0.53
Soil biodiversity				0.98	0.81	0.25	0.30	1.00	0.41	0.60	0.65	1.00	-	-	-	-	0.80	-	1.00	1.00
Soil carbon					0.64	0.30	0.61	0.73	0.66	-0.05	0.80	-	-	1.00	-1.00	-1.00	0.70	-0.87	-0.38	0.65
Soil nutrients						-0.16	0.47	-0.03	0.75	0.56	0.32	-	-	0.05	-1.00	-0.02	0.28	0.00	0.22	-0.03
Water quality							-0.74	0.87	1.00	0.99	1.00	-	-	1.00	-	-0.75	0.73	0.70	0.43	0.04
Yield								0.86	0.54	-0.60	-0.43	-0.17	0.40	0.27	0.95	0.13	-0.71	0.47	-0.52	0.67
Water use efficiency									0.59	-	-	-	-	1.00	-	-	-	-	0.06	0.42
Nutrient use efficiency										-	-	-	-	1.00	-	-	1.00	1.00	-0.87	0.00
Plants											0.40	0.86	-	0.69	-	0.00	1.00	0.50	1.00	0.81
Invertebrates												0.42	0.97	0.61	-	-	1.00	-	1.00	0.49
Vertebrates													-	0.82	-	-	-	-	-	0.87
Pollination														0.40	-	-	-	-	-	-
Animal pests															-	-	-	-	-1.00	-1.00
Weeds																-	-	-	-	-
GHG emissions																	0.12	-0.70	1.00	-1.00
ıergy use efficiency																		0.15	0.22	0.79
Welfare																			-0.96	0.35
Costs																				0.29
Profit																				

Table 1. Matrix of mean pairwise correlation coefficients and choice potential scores.

Weighted averages of the correlation coefficients for each pair of response variables, calculated across all studies. Cell colour scaled for each measure to aid visual interpretation.

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THE CHALLENGES OF SUSTAINABLE AGRICULTURE

2. Context dependencies

There is no recipe for "sustainable agriculture"

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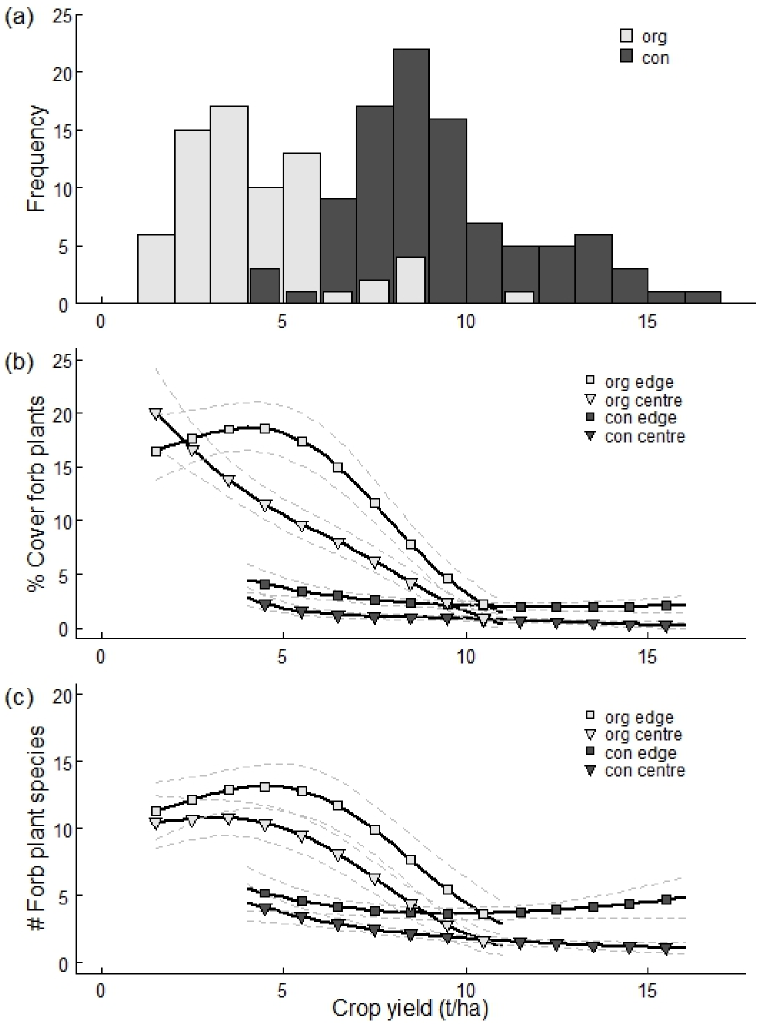
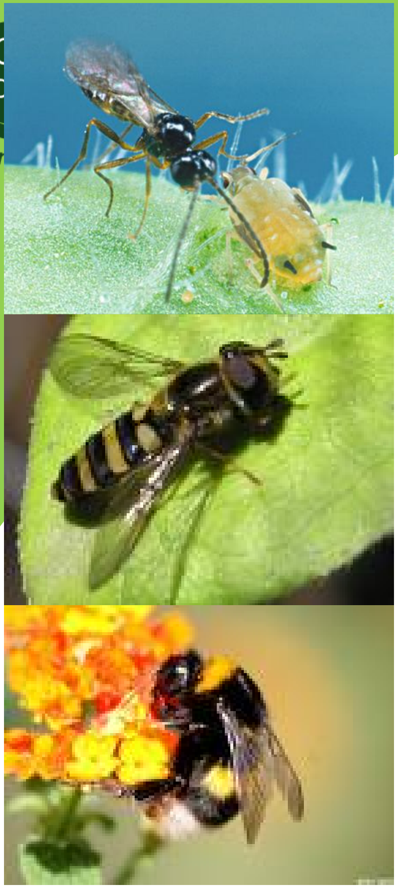
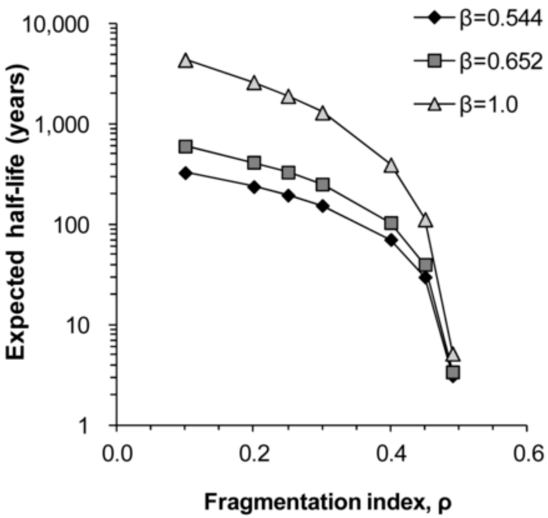
High yielding organic agriculture can impact on ecology in similar ways to conventional farming

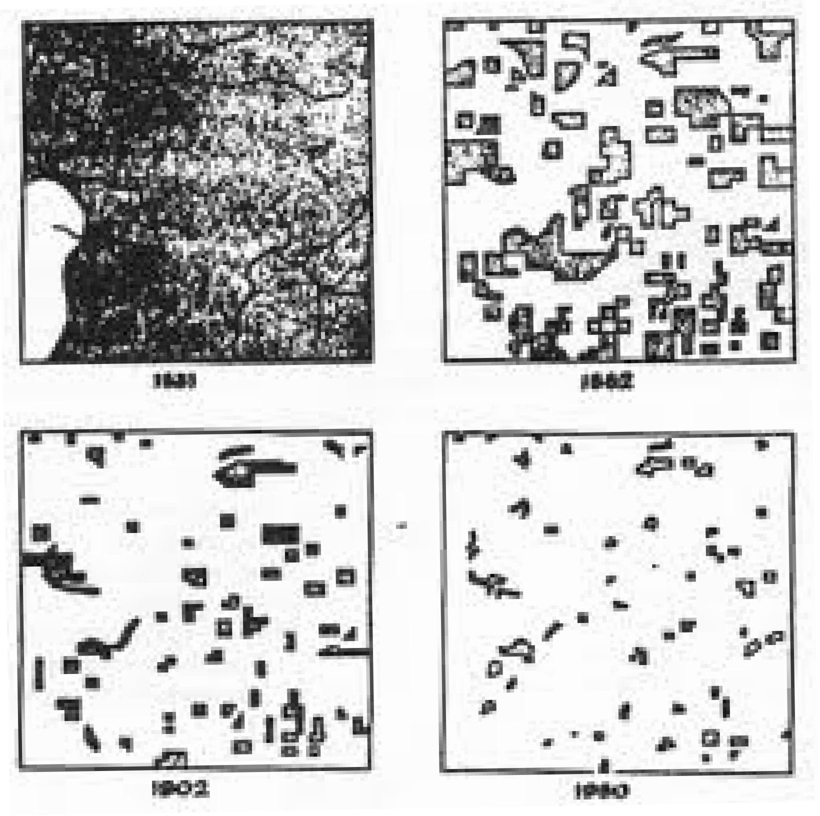


Gabriel et al 2013 J appl ecology

Frequency dependence







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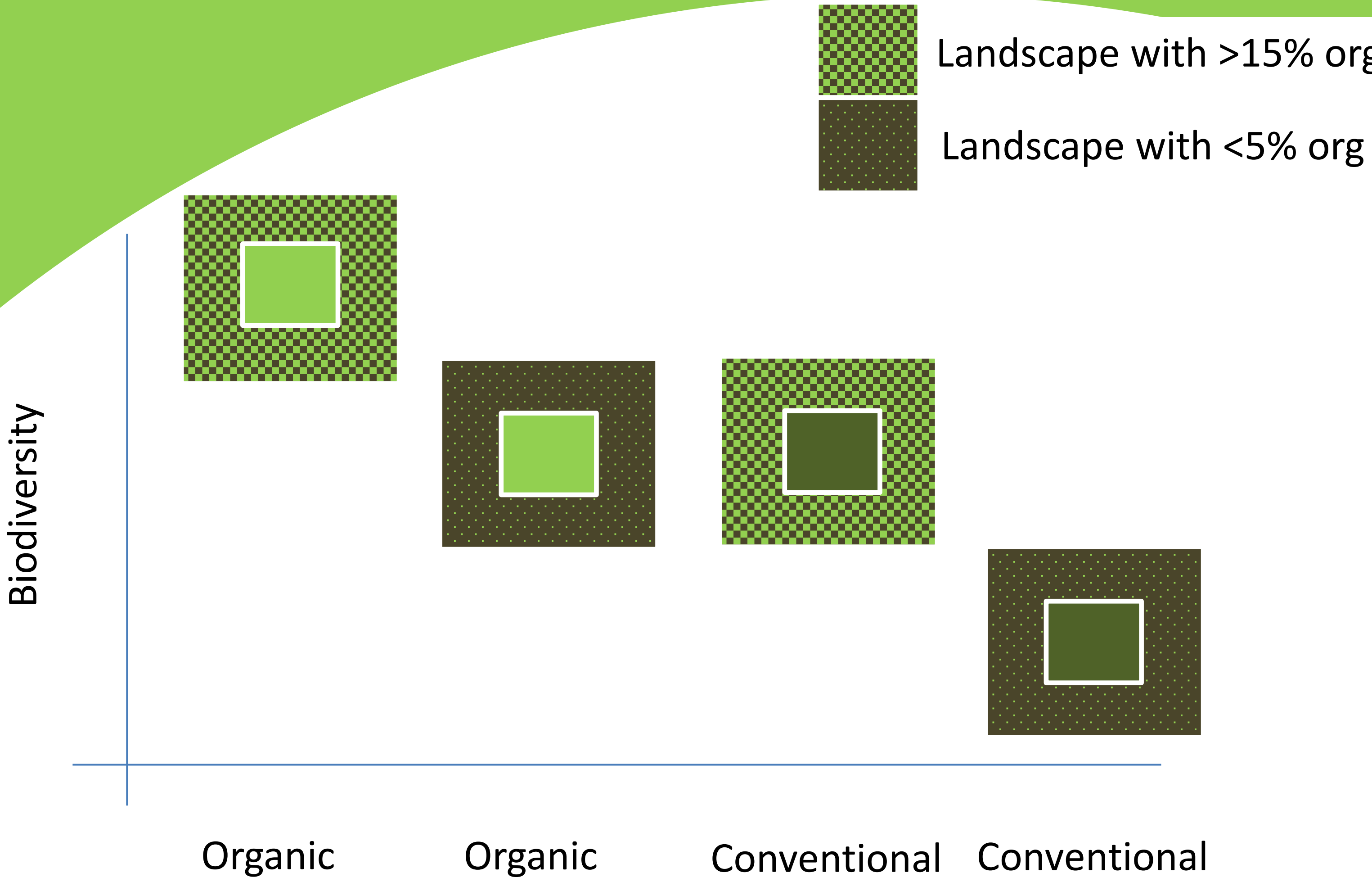
Context matters



Gabriel et al 2010 Ecol Letts

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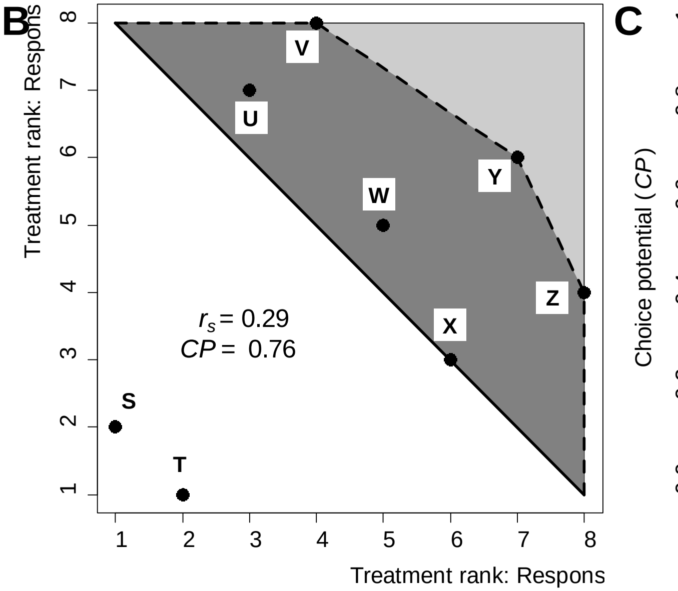
"choice potential"

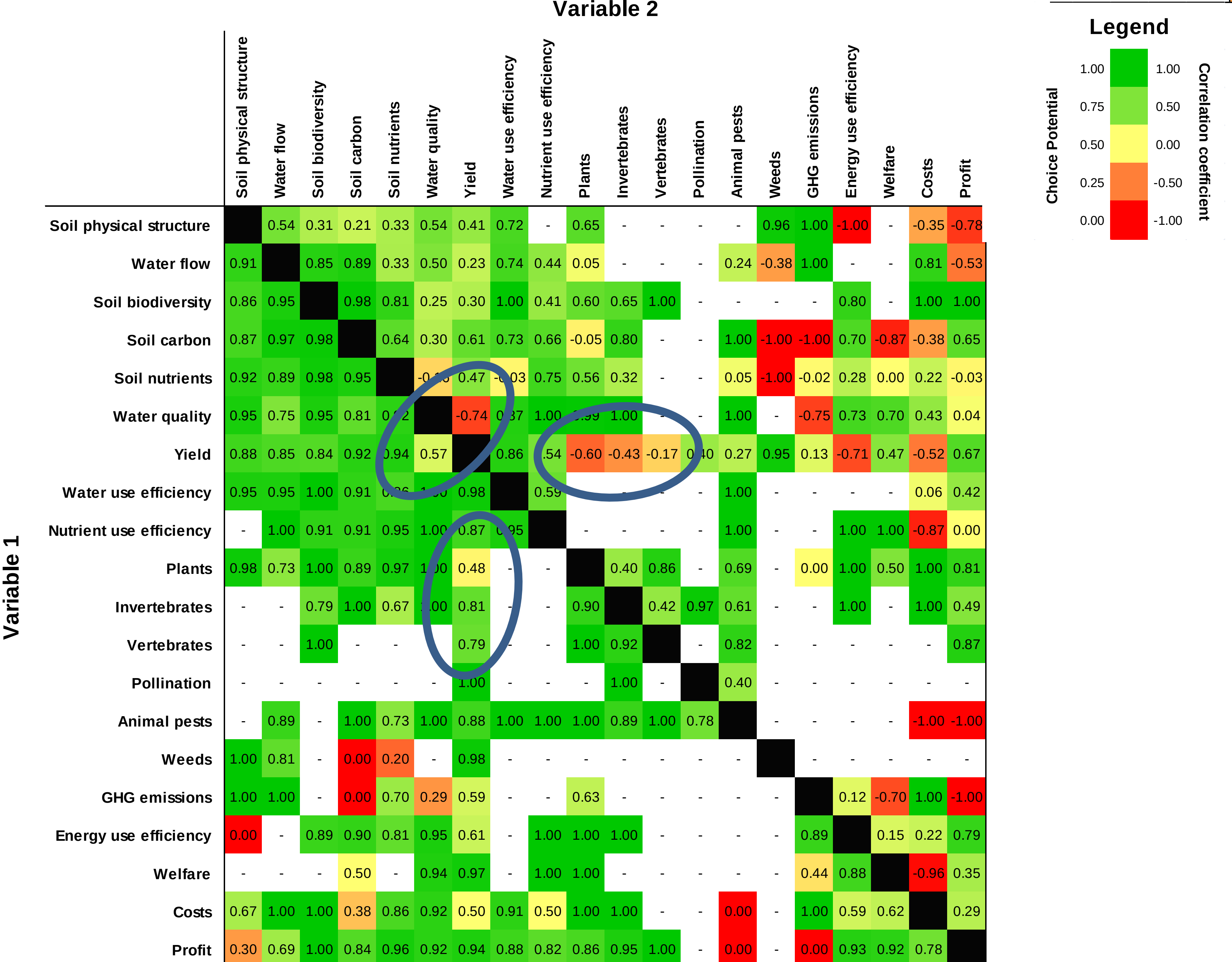
- To capture the degree to which context may influence performance ("the efficiency frontier")

e.g. yield NUE

A

Treatment ID	Response A (rank)	Response B (rank)
S	1	2
T	2	1
U	3	7
V	4	8
W	5	5
X	6	3
Y	7	6
Z	8	4





Variable 2

Variable 1

	Soil physical structure	Water flow	Soil biodiversity	Soil carbon	Soil nutrients	Water quality	Yield	Water use efficiency	Nutrient use efficiency	Plants	Invertebrates	Vertebrates	Pollination	Animal pests	Weeds	GHG emissions	Energy use efficiency	Welfare	Costs	Profit
Soil physical structure	■	0.54	0.31	0.21	0.33	0.54	0.41	0.72	-	0.65	-	-	-	-	0.96	1.00	-1.00	-	-0.35	-0.78
Water flow	0.91	■	0.85	0.89	0.33	0.50	0.23	0.74	0.44	0.05	-	-	-	0.24	-0.38	1.00	-	-	0.81	-0.53
Soil biodiversity	0.86	0.95	■	0.98	0.81	0.25	0.30	1.00	0.41	0.60	0.65	1.00	-	-	-	-	0.80	-	1.00	1.00
Soil carbon	0.87	0.97	0.98	■	0.64	0.30	0.61	0.73	0.66	-0.05	0.80	-	-	1.00	-1.00	-1.00	0.70	-0.87	-0.38	0.65
Soil nutrients	0.92	0.89	0.98	0.95	■	-0.16	0.47	-0.03	0.75	0.56	0.32	-	-	0.05	-1.00	-0.02	0.28	0.00	0.22	-0.03
Water quality	0.95	0.75	0.95	0.81	[illegible]	■	-0.74	0.87	1.00	0.99	1.00	-	-	1.00	-	-0.75	0.73	0.70	0.43	0.04
Yield	0.88	0.85	0.84	0.92	0.94	0.57	■	0.86	0.54	-0.60	-0.43	-0.17	0.40	0.27	0.95	0.13	-0.71	0.47	-0.52	0.67
Water use efficiency	0.95	0.95	1.00	0.91	0.86	1.00	0.98	■	0.59	-	-	-	-	1.00	-	-	-	-	0.06	0.42
Nutrient use efficiency	-	1.00	0.91	0.91	0.95	1.00	0.87	0.95	■	-	-	-	-	1.00	-	-	1.00	1.00	-0.87	0.00
Plants	0.98	0.73	1.00	0.89	0.97	1.00	0.48	-	-	■	0.40	0.86	-	0.69	-	0.00	1.00	0.50	1.00	0.81
Invertebrates	-	-	0.79	1.00	0.67	1.00	0.81	-	-	0.90	■	0.42	0.97	0.61	-	-	1.00	-	1.00	0.49
Vertebrates	-	-	1.00	-	-	[illegible]	0.79	-	-	1.00	0.92	■	-	0.82	-	-	-	-	-	0.87
Pollination	-	-	-	-	-	-	1.00	-	-	-	1.00	-	■	0.40	-	-	-	-	-	-
Animal pests	-	0.89	-	1.00	0.73	1.00	0.88	1.00	1.00	1.00	0.89	1.00	0.78	■	-	-	-	-	-1.00	-1.00
Weeds	1.00	0.81	-	0.00	0.20	-	0.98	-	-	-	-	-	-	-	■	-	-	-	-	-
GHG emissions	1.00	1.00	-	0.00	0.70	0.29	0.59	-	-	0.63	-	-	-	-	-	■	0.12	-0.70	1.00	-1.00
Energy use efficiency	0.00	-	0.89	0.90	0.81	0.95	0.61	-	1.00	1.00	1.00	-	-	-	-	0.89	■	0.15	0.22	0.79
Welfare	-	-	-	0.50	-	0.94	0.97	-	1.00	1.00	-	-	-	-	-	0.44	0.88	■	-0.96	0.35
Costs	0.67	1.00	1.00	0.38	0.86	0.92	0.50	0.91	0.50	1.00	1.00	-	-	0.00	-	1.00	0.59	0.62	■	0.29
Profit	0.30	0.69	1.00	0.84	0.96	0.92	0.94	0.88	0.82	0.86	0.95	1.00	-	0.00	-	0.00	0.93	0.92	0.78	■

Legend

Choice Potential		Correlation coefficient
1.00	🟩	1.00
0.75	🟩	0.50
0.50	🟨	0.00
0.25	🟧	-0.50
0.00	🟥	-1.00

THE CHALLENGES OF SUSTAINABLE AGRICULTURE

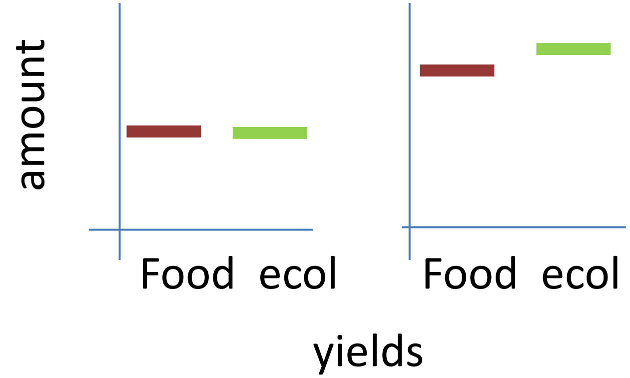
3. Systemic impacts

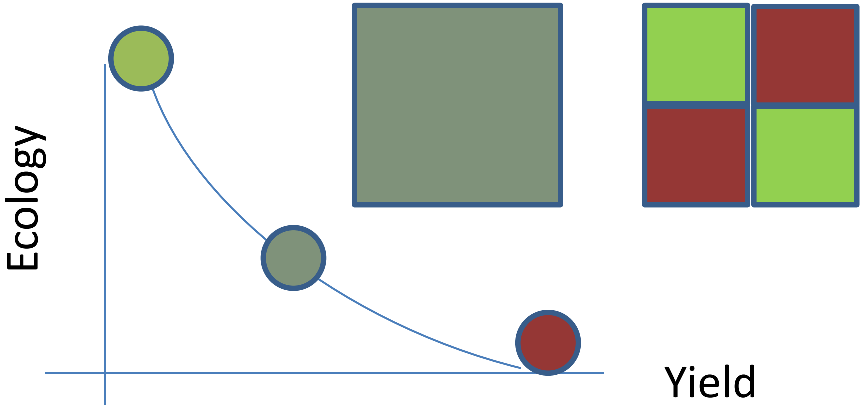
Specialisation of "function" can be more efficient: land sparing

Parcel producing food+ biodiversity

Parcel producing food

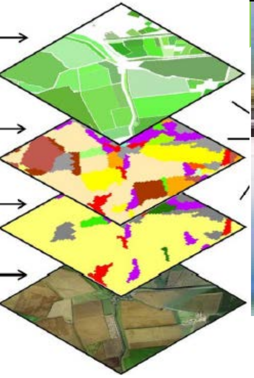
Parcel producing biodiversity

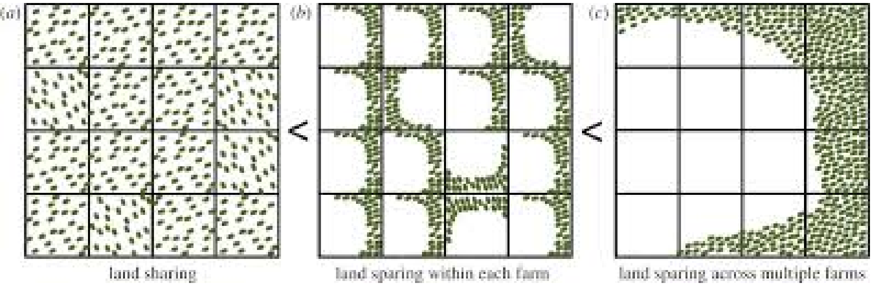




Gabriel et al. 2009 J app Ecol; 2010 Ecol Letts; Hodgson et al 2010 Ecol. Letts

Smarter landscapes are possible





- It is possible to “design” landscapes better to deliver a range of goods
- Governance issues abound

Sustainable landuse is further complicated by market forces connecting distant land

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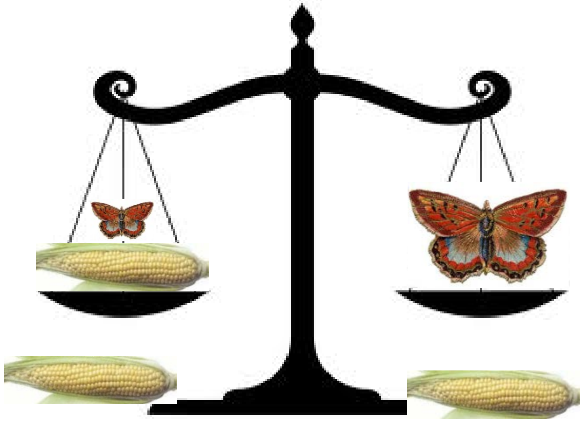


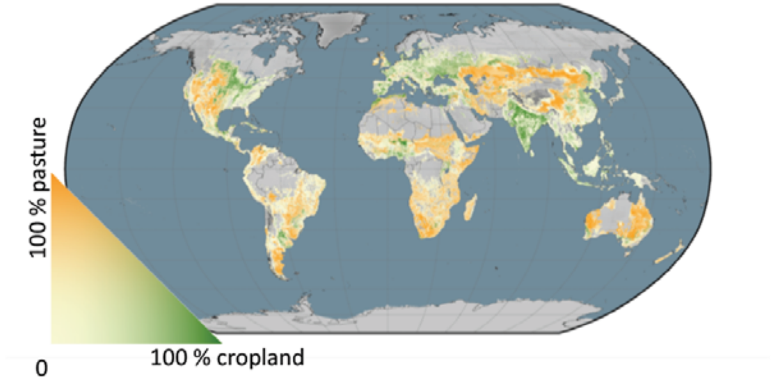
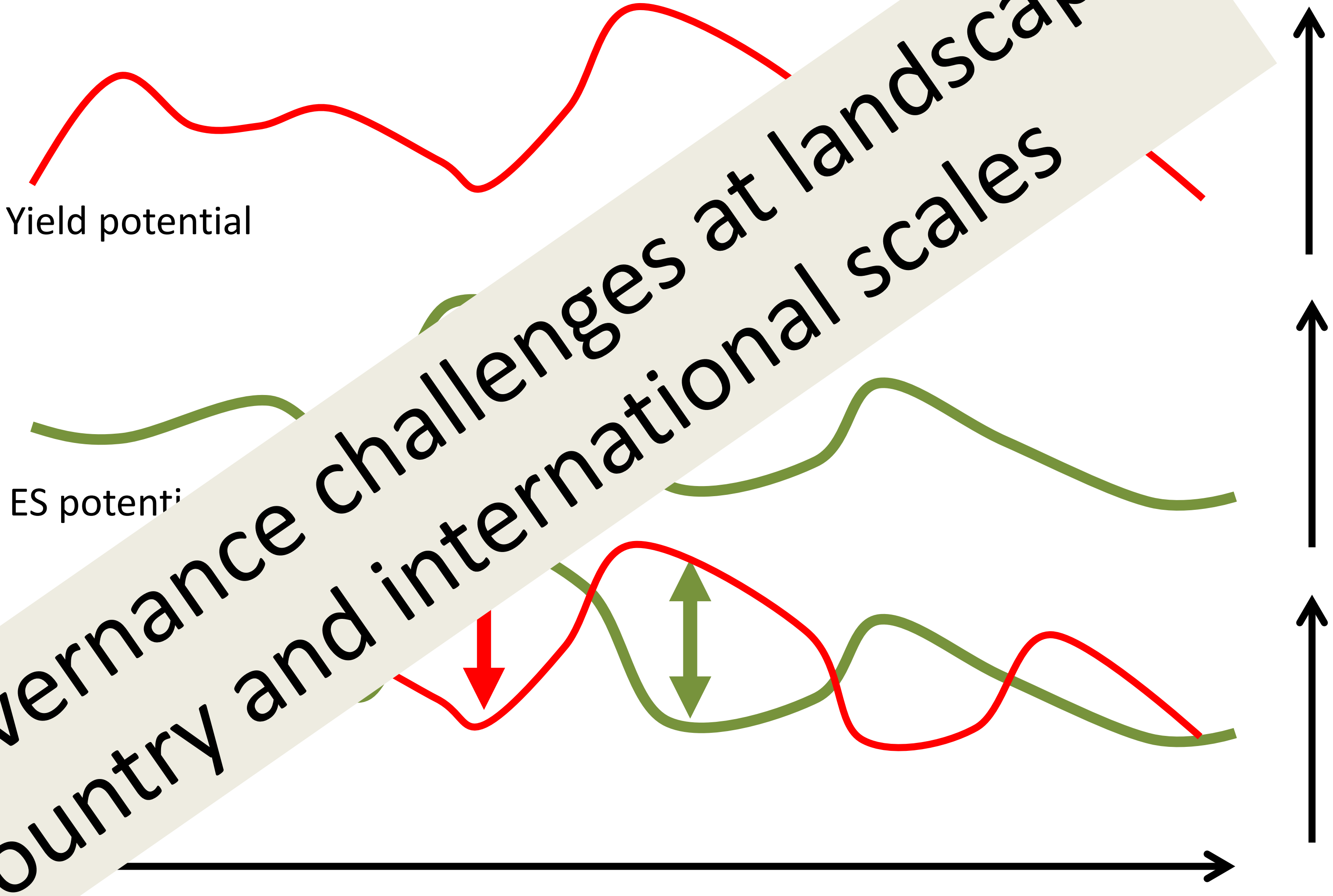


Figure S1. Extent of Global Agricultural Lands. This map illustrates the global extent of croplands (green) and pastures (brown), as estimated from satellite- and census-based data by Ramankutty *et al.*[1]. According to U.N. FAO statistics, croplands currently extend over 1.53 billion

Spatial planning needed for a "sustainable system"



Governance challenges at landscape, country and international scales

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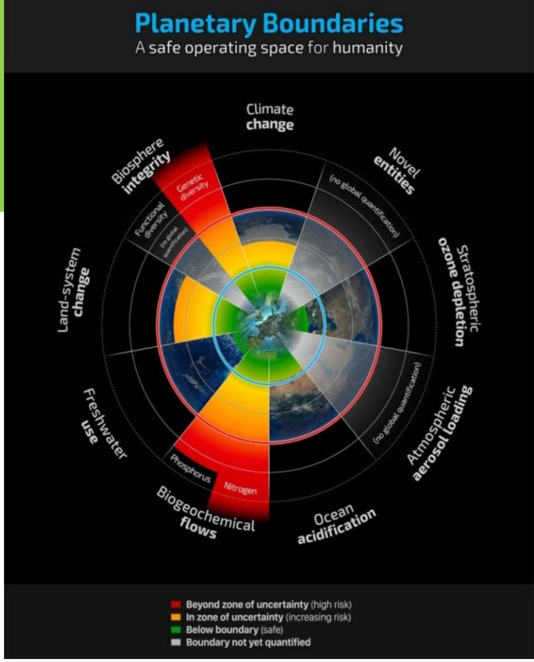

THE CHALLENGES OF SUSTAINABLE AGRICULTURE

4. Limits

Limits, tipping points, transitions

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Science of the Total Environment 506–507 (2015) 164–181

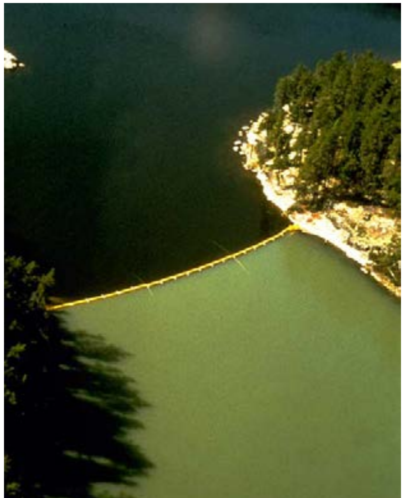
Contents lists available at ScienceDirect

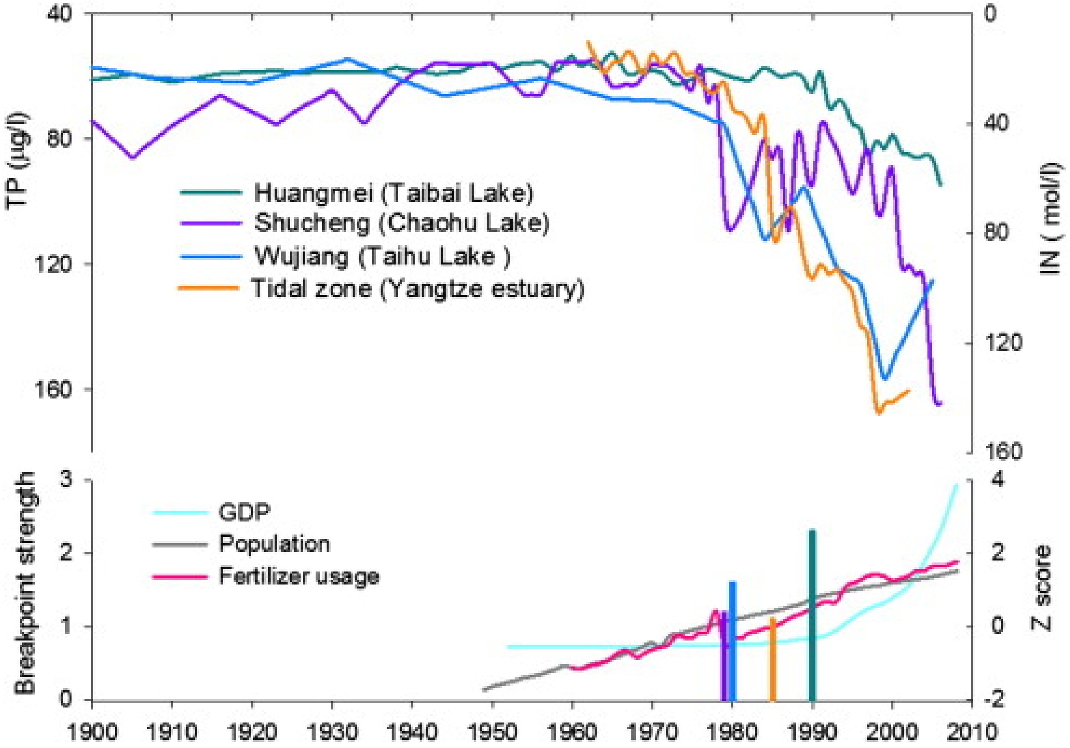
Science of the Total Environment

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

Poverty alleviation strategies in eastern China lead to critical ecological dynamics

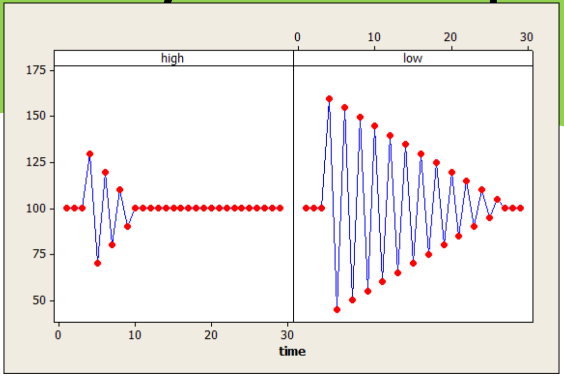
Ke Zhang [a,1], John A. Dearing [a,*], Terence P. Dawson [b], Xuhui Dong [c], Xiangdong Yang [c], Weiguo Zhang [d]



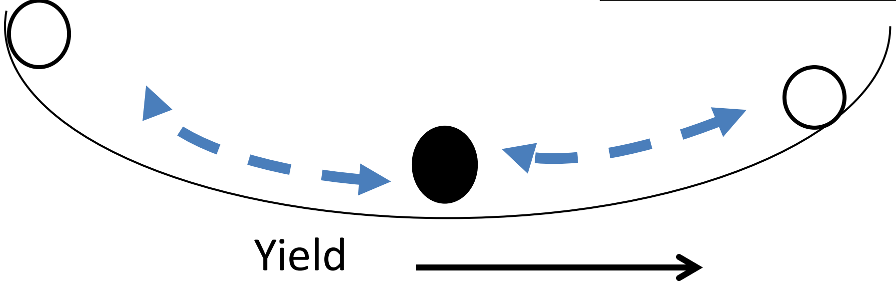


Breakpoints and regime shifts in water quality records across the LYB 1900–2006. Reconstructed time series (upper panel) for total dissolved phosphorus (TP µg/l) in Huangmei, Shucheng and Wujiang and dissolved inorganic nitrogen (in mol/l) in the tidal Yangtze zone show rapid nutrient enrichment (note reversed left and right axes) after the 1970s. Normalized (z score) records of potential drivers of agricultural intensification (lower panel)

Resilience: how does a system respond to a perturbation?

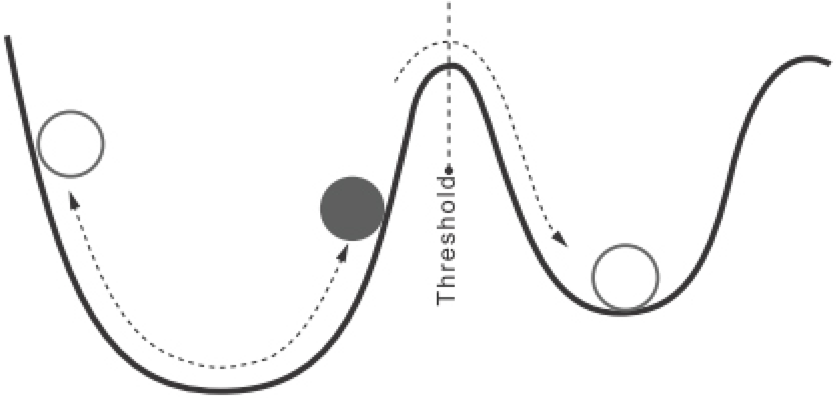


Engineering resilience concept



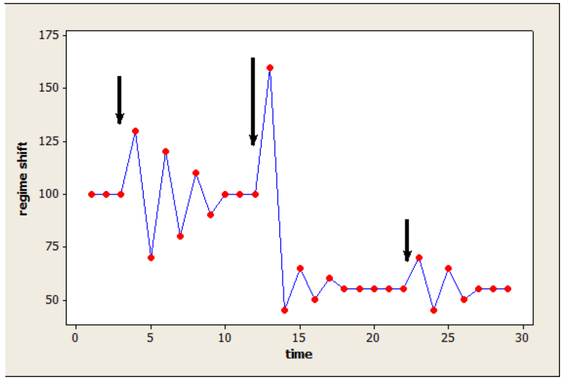
Yield

Soil, water, nutrients, genetics

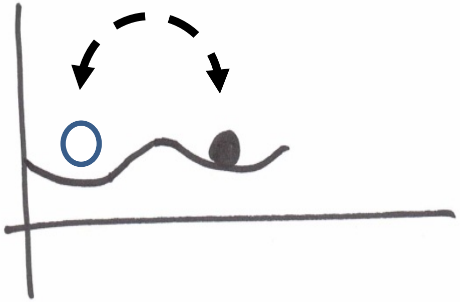


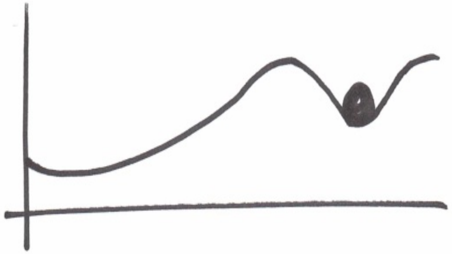
Ecological resilience concept

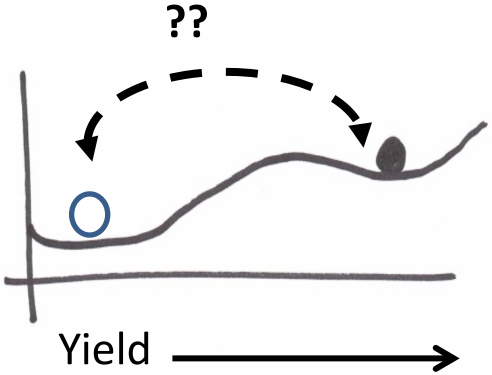
Yield



time →






??
Yield

If we carry on as we are…

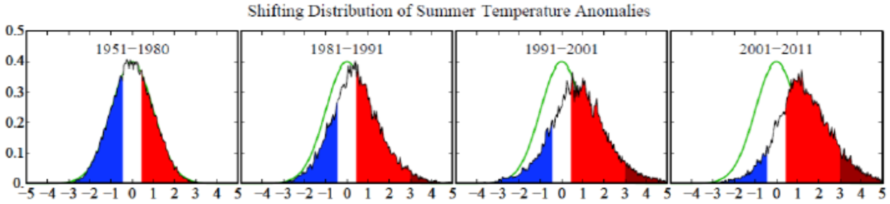
- We need to produce more food by 2050 than we have done in human history
- This will require 120% more water; 42% more cropland and loss of 14% more forest
- This will emit enough carbon dioxide to create 2 degrees of global warming
- We'll lose much of the world's biodiversity
- Food will increasingly be associated with early deaths

Importance of food-demand management for climate mitigation

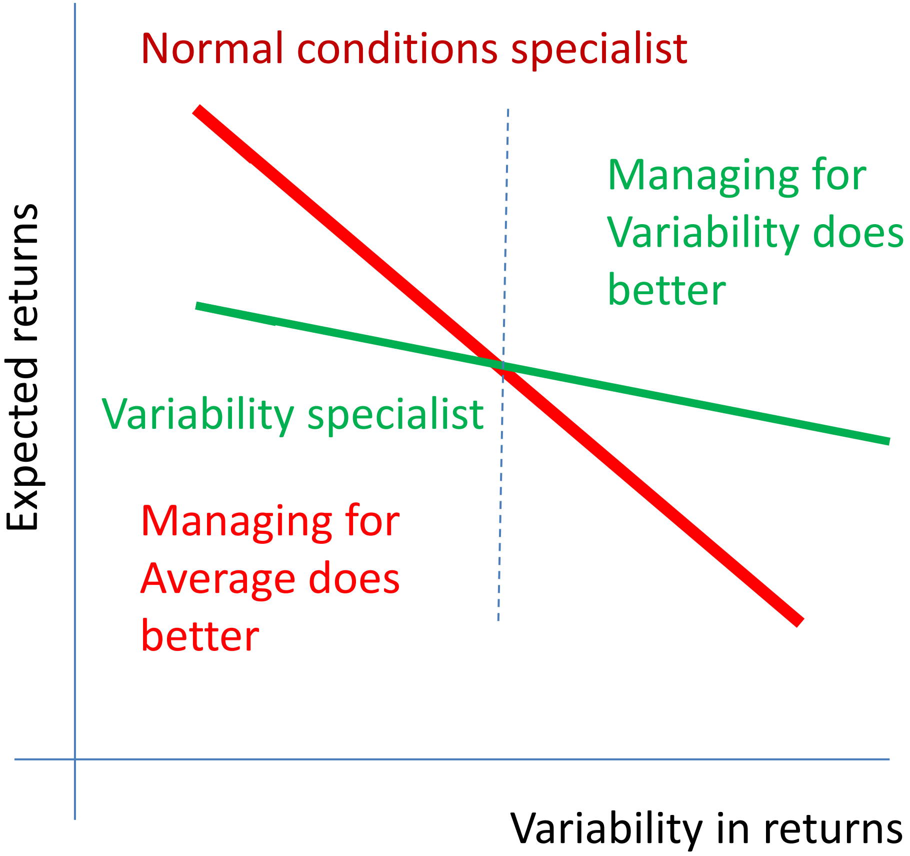
Bojana Bajželj[1]*, Keith S. Richards[2], Julian M. Allwood[1], Pete Smith[3], John S. Dennis[4], Elizabeth Curmi[1] and Christopher A. Gilligan[5]

NCC
2014

Conclusions



Shifting Distribution of Summer Temperature Anomalies



Normal conditions specialist

Managing for Variability does better

Variability specialist

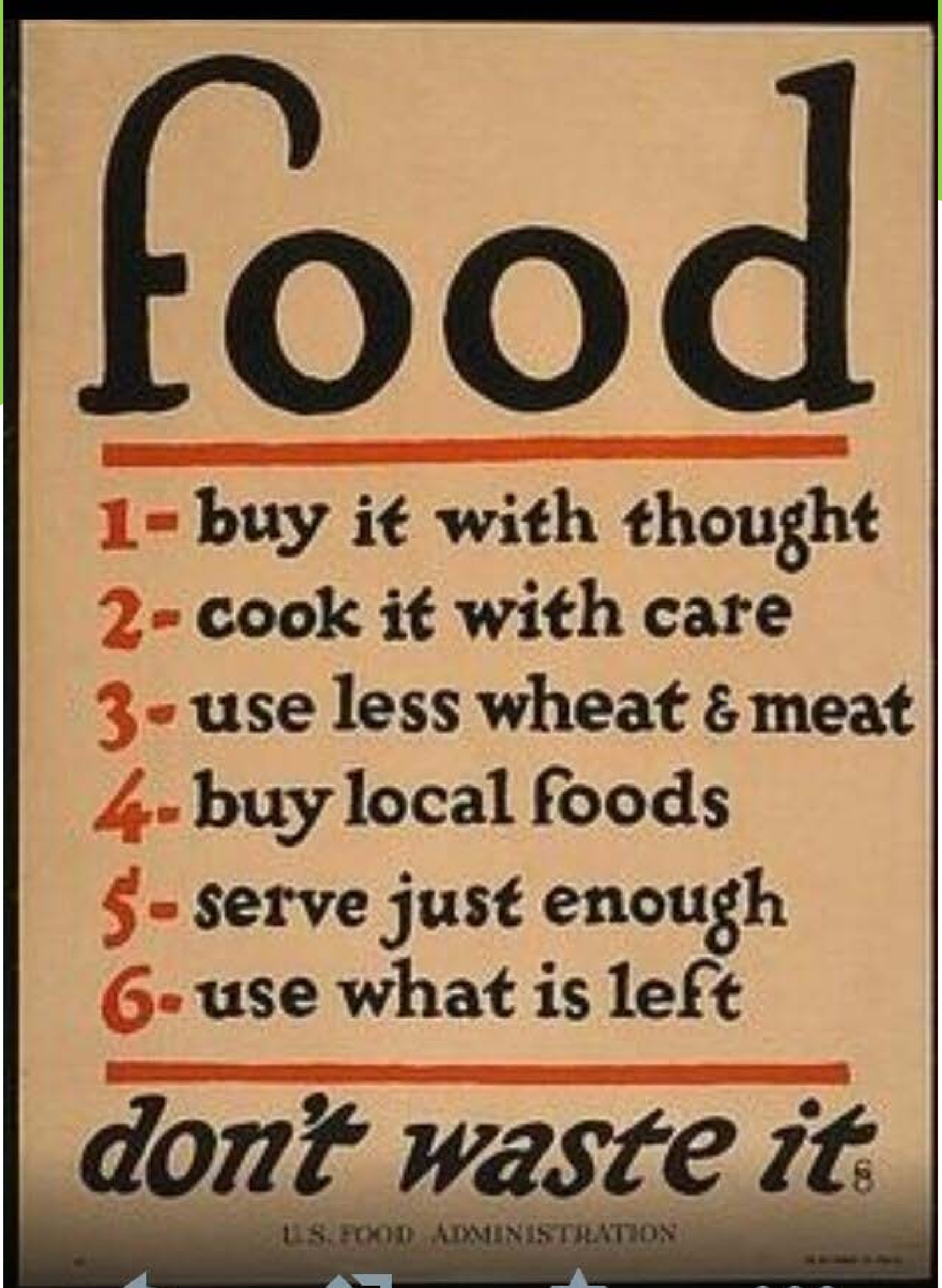
Managing for Average does better

Expected returns

Variability in returns

Abson et al 2013

- In each place there are likely to be limits to “sustainable agriculture” (soils, water, other services)
- Efficiency metrics (“do more with less”) do not capture limits or non-linearities in functions
- Not clear spatial or temporal scale to monitor sustainable agric
  - Field/farm /landscape/region/country/world
  - Annual or multiple years
- Navigating trade-offs: many ecosystem services valued but not marketed
- Resilience and climate change variability may lead to structural changes



food

1- buy it with thought
2- cook it with care
3- use less wheat & meat
4- buy local foods
5- serve just enough
6- use what is left

don't waste it

U.S. FOOD ADMINISTRATION

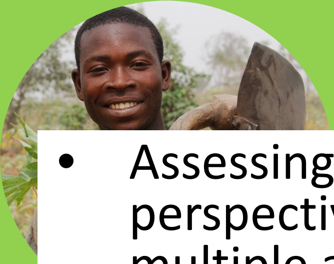
Global Food Security

Sustainable, healthy food for all

Thank you!

tim.benton@foodsecurity.ac.uk

www.foodsecurity.ac.uk



- Assessing the sustainability of agriculture – from an environmental perspective – is dogged by three specific issues. The first is that there are multiple axes of environmental impacts associated with farming (impacts on water use and quality, soil, GHG, biodiversity etc), as well as outputs being measured in the amount of yield, the quality of yield (e.g. people fed per hectare) or farm profit. As many of these variables are negatively correlated, it is not clear how best to navigate trade-offs. The second is that management's impacts are place dependent, giving rise to the potential for the same action to have positive or negative outcomes. The third is that as different bio-physical processes work at different spatial (and temporal) scales, some impacts need to be assessed at scales larger than the farm: for example, for pollination and natural pest control the aggregate habitat availability at the landscape scale determines the population size which can be found on farm, so a farm's biodiversity depends in part on the actions of farmers in the neighbourhood. These factors suggest that "maximally efficient farming" and sustainable agriculture are not necessarily the same thing. To ensure sustainable agriculture requires some degree of "spatial planning" to match management to location and impacts.
- 25 MINS

Cows, cars and carbon emissions

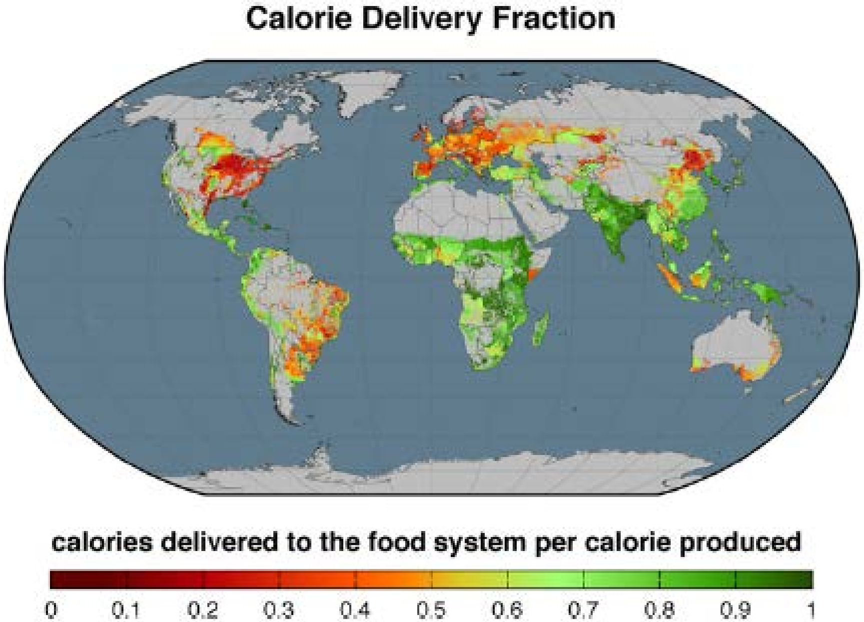


Figure 1. Calorie delivery fraction per hectare. The proportions of produced calories that are delivered as food are shown.

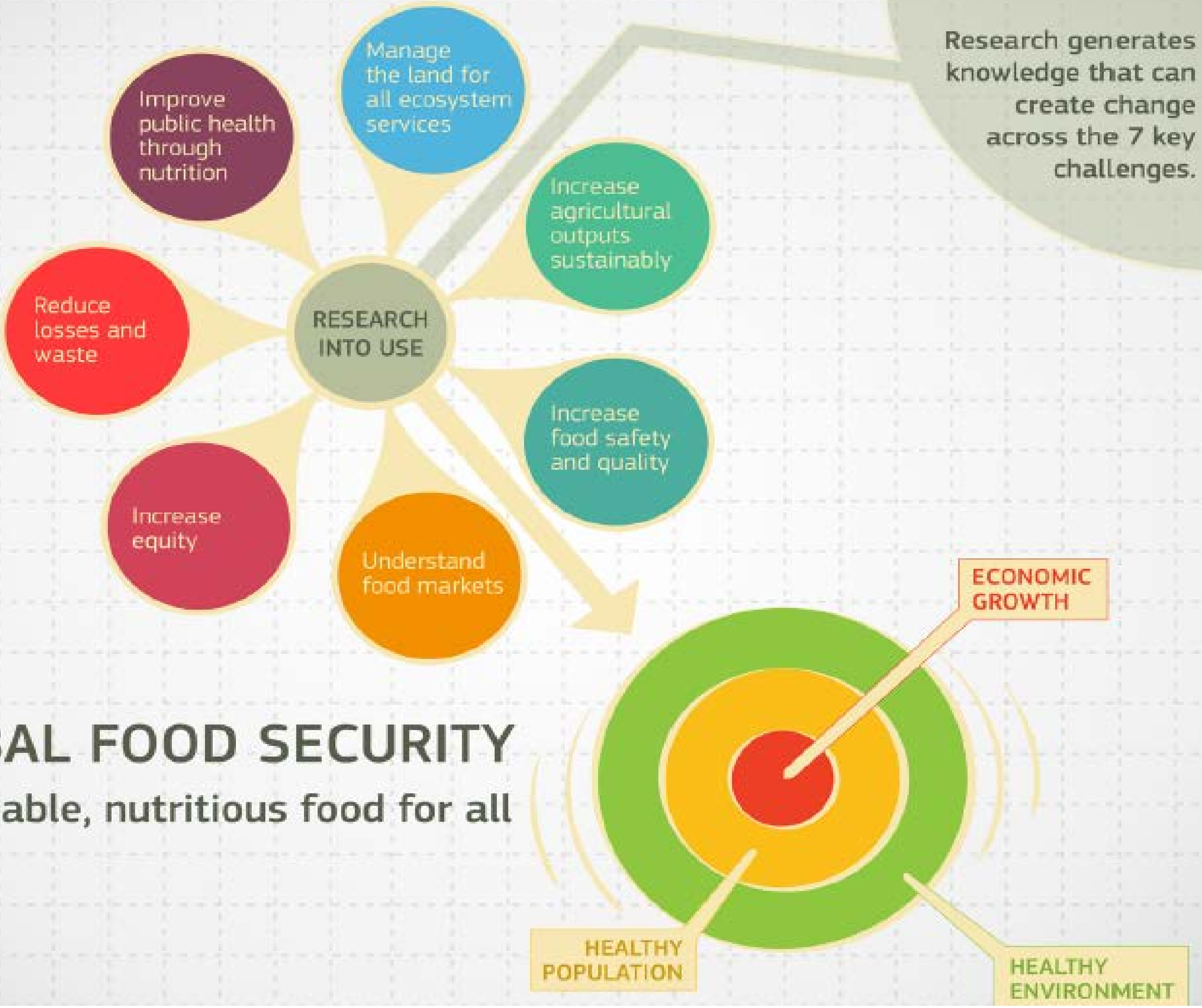
E S Cassidy *et al* Environ. Res. Lett. **8** (2013) 034015

vs

GLOBAL FOOD SECURITY

Sustainable, nutritious food for all

Research generates knowledge that can create change across the 7 key challenges.



RESEARCH INTO USE

Improve public health through nutrition

Manage the land for all ecosystem services

Increase agricultural outputs sustainably

Increase food safety and quality

Understand food markets

Increase equity

Reduce losses and waste

ECONOMIC GROWTH

HEALTHY POPULATION

HEALTHY ENVIRONMENT