Technical efficiency of multi-output farming: biodiversity, yield and profit

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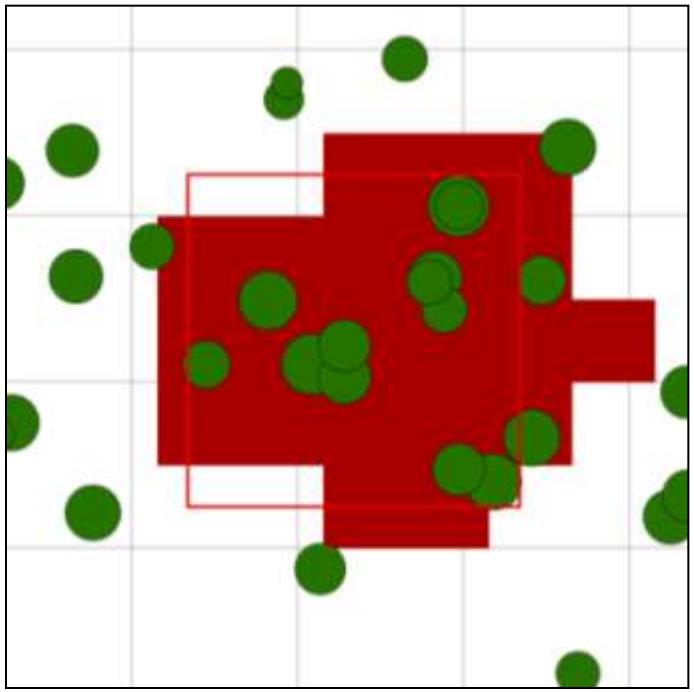
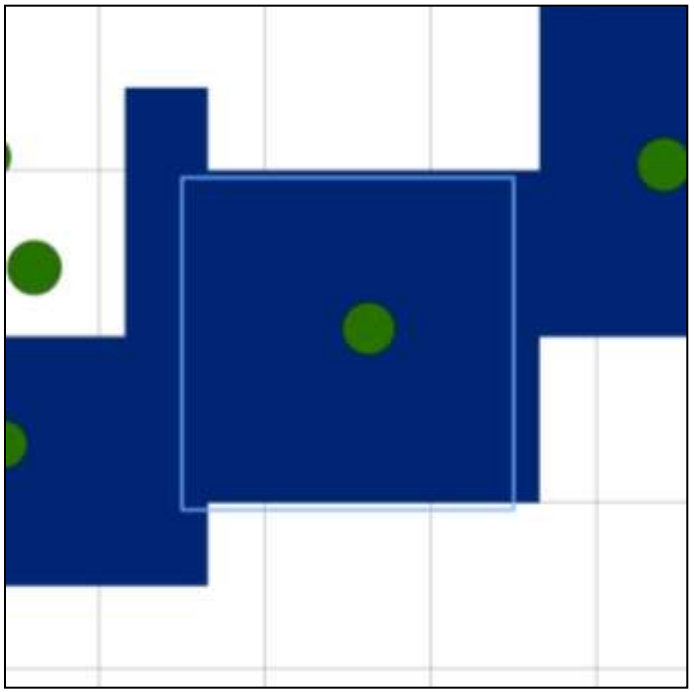
Quick project overview

- 4-year interdisciplinary project (£0.8m)
- RELU-Scale (Rural Economy and Land Use Programme funded)
- Scale effects of alternative agricultural systems
- Comparable set of 32 farms, as pairs
  organic & conventional in **hotspot** and **coldspot** landscapes
- 2006, 2007 and 2008 data

Hotspot versus Coldspot
(10 x 10 km or 10,000 ha)



Hotspot > 10 % organic farming
min 2 farms



Coldspot < 2 % organic farming
max 2 farms

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Farm selection

-> select hotspot organic farm (limiting factor)

-> then match with conventional farm

- similar in enterprise type, size, soil type…
- close neighbourhood
- for cropland proxy: **winter wheat**
  for grassland proxy : **permanent pasture**
  (*both by far most common land-use types in UK*)

- *Same in coldspot*

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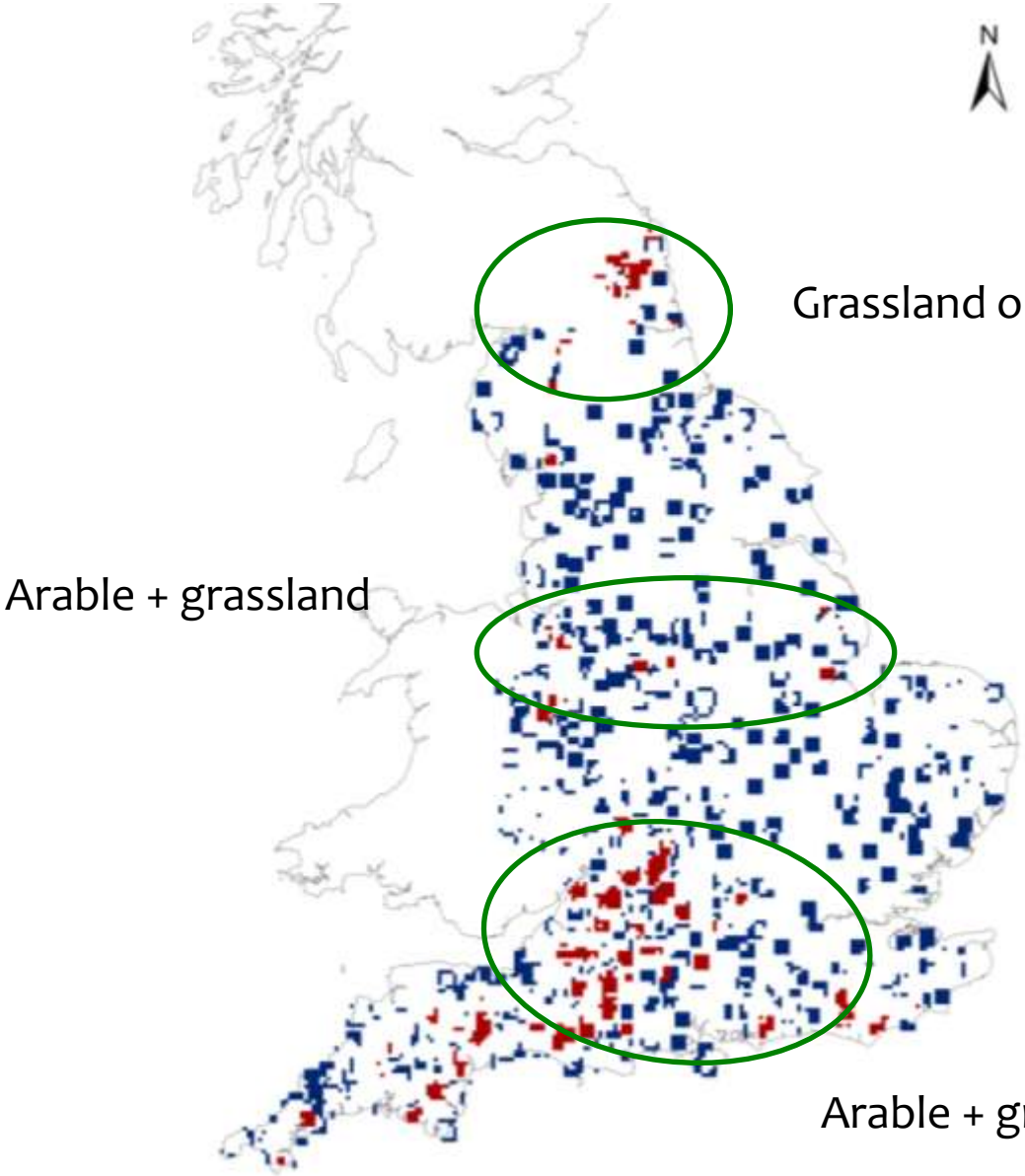
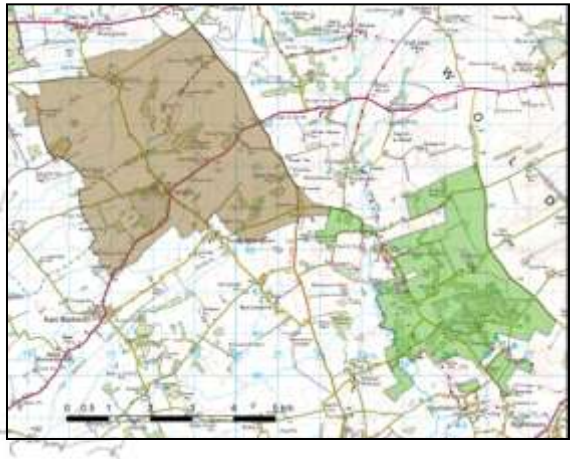
Three potential study regions

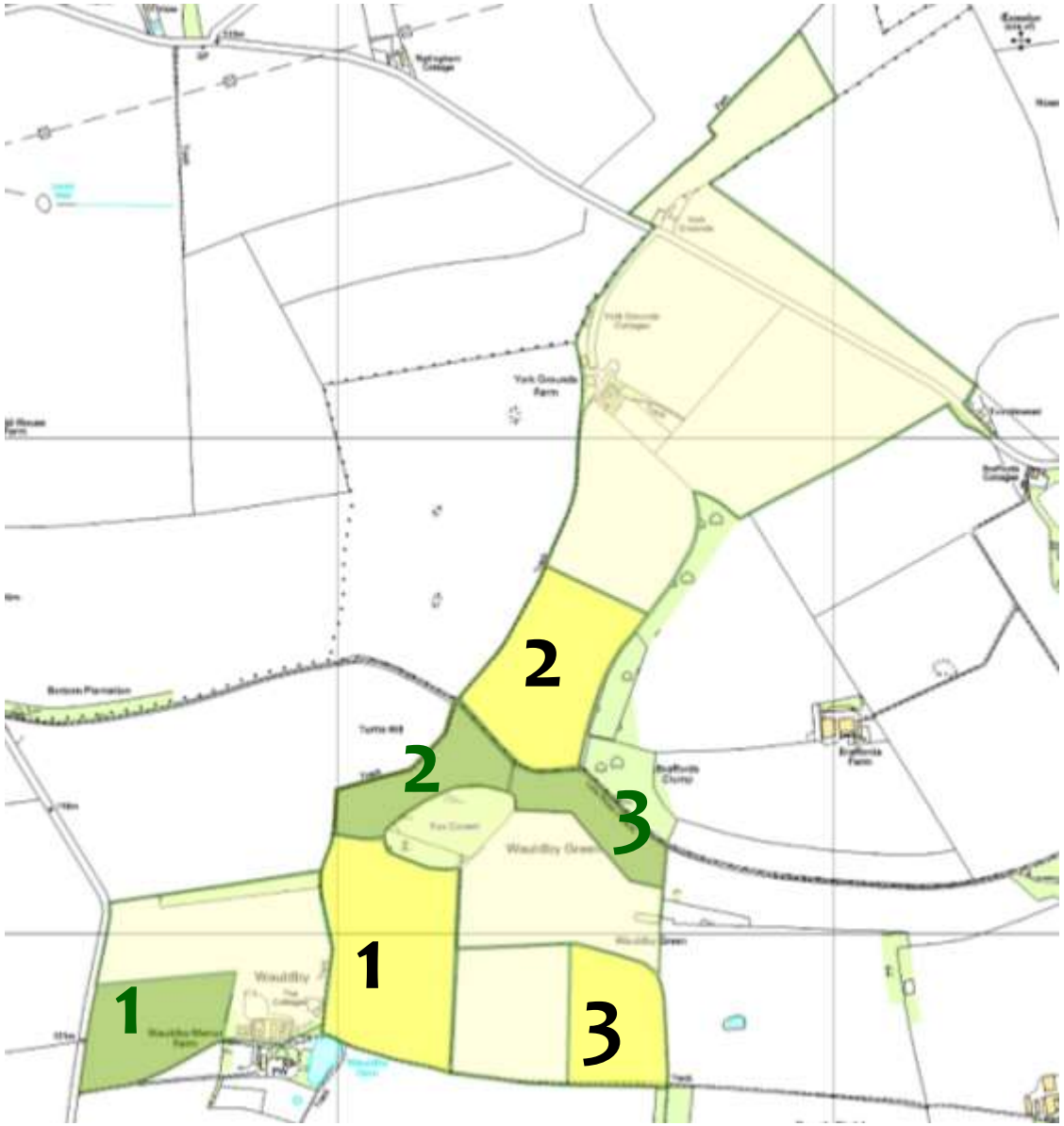


Final sample farms

- Two regions:
  South central and
  Midland central
- Four clusters
  in each region
- Two landscapes
  in each cluster
- Pair of organic and
  conventional
  farm



3 crop and 3 grass fields per farm



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Research design

- 32 farms with 3 wheat and 3 permanent grass fields
- **Hotspot** (8.9-36.8 % org. land use; av. 17%)
- **Coldspot** (0.5-3.3 % org. land use; av. 1.4%)
- Descriptive statistics of **178** wheat data sets and **216** grass data sets

=> *Novel research design, but still limited sample and crop choice*

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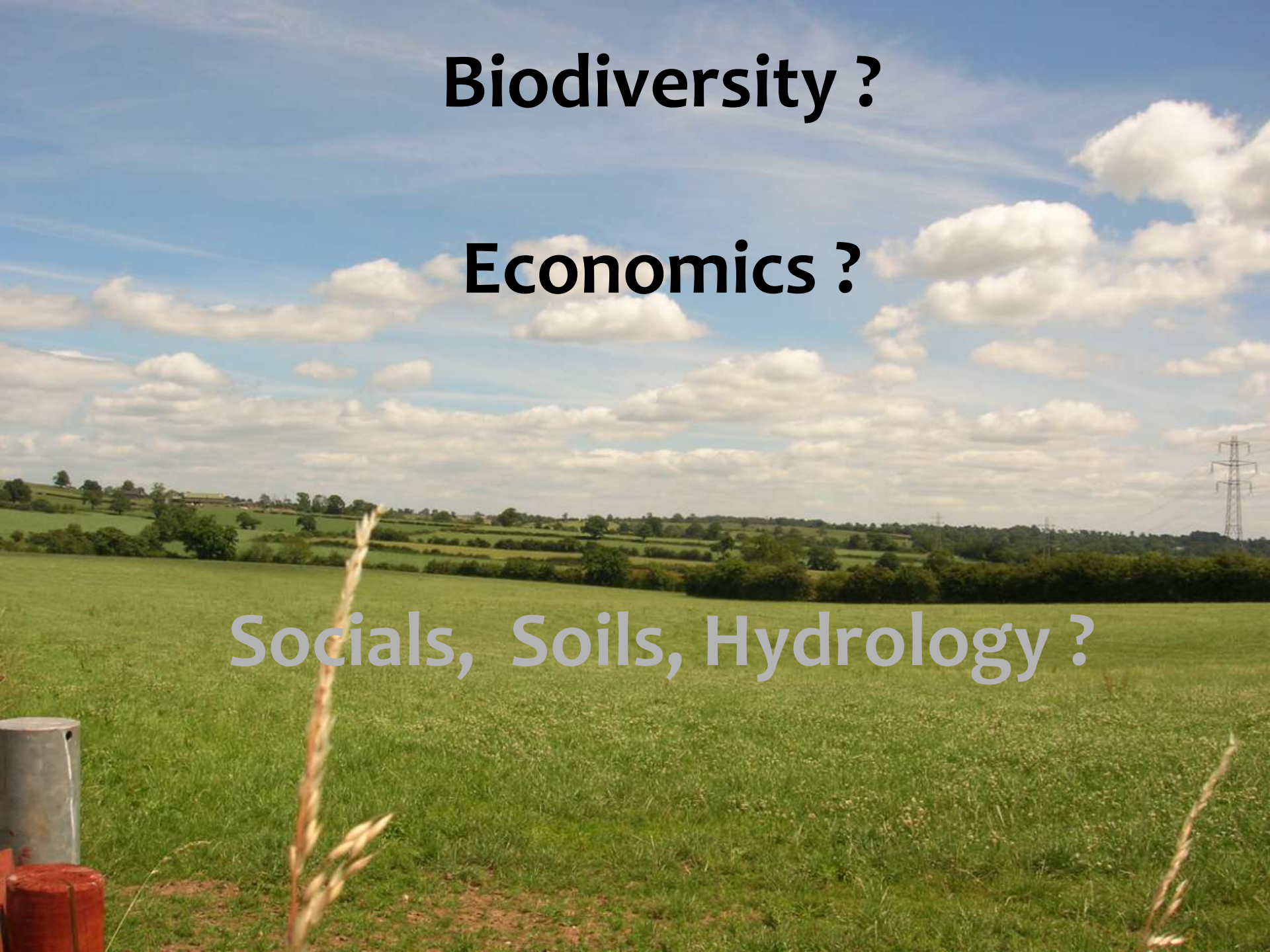
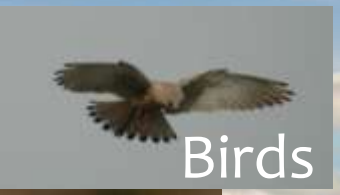

Biodiversity ?
Economics ?
Socials, Soils, Hydrology ?

Biodiversity



Birds

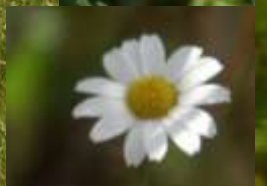
Butterflies

Bumblebee, Solitary bees

Hoverflies

Arthropods

Plants



Earthworms

Technical efficiency (TE)

- Technical efficiency (TE) definition:
  How efficient is a set of inputs used to produce an output?
- *"the ability of a farm to produce as much output as possible with a specified level of inputs, given the existing technology."*
- In ecological economics the yield and biodiversity are treated as equal outputs

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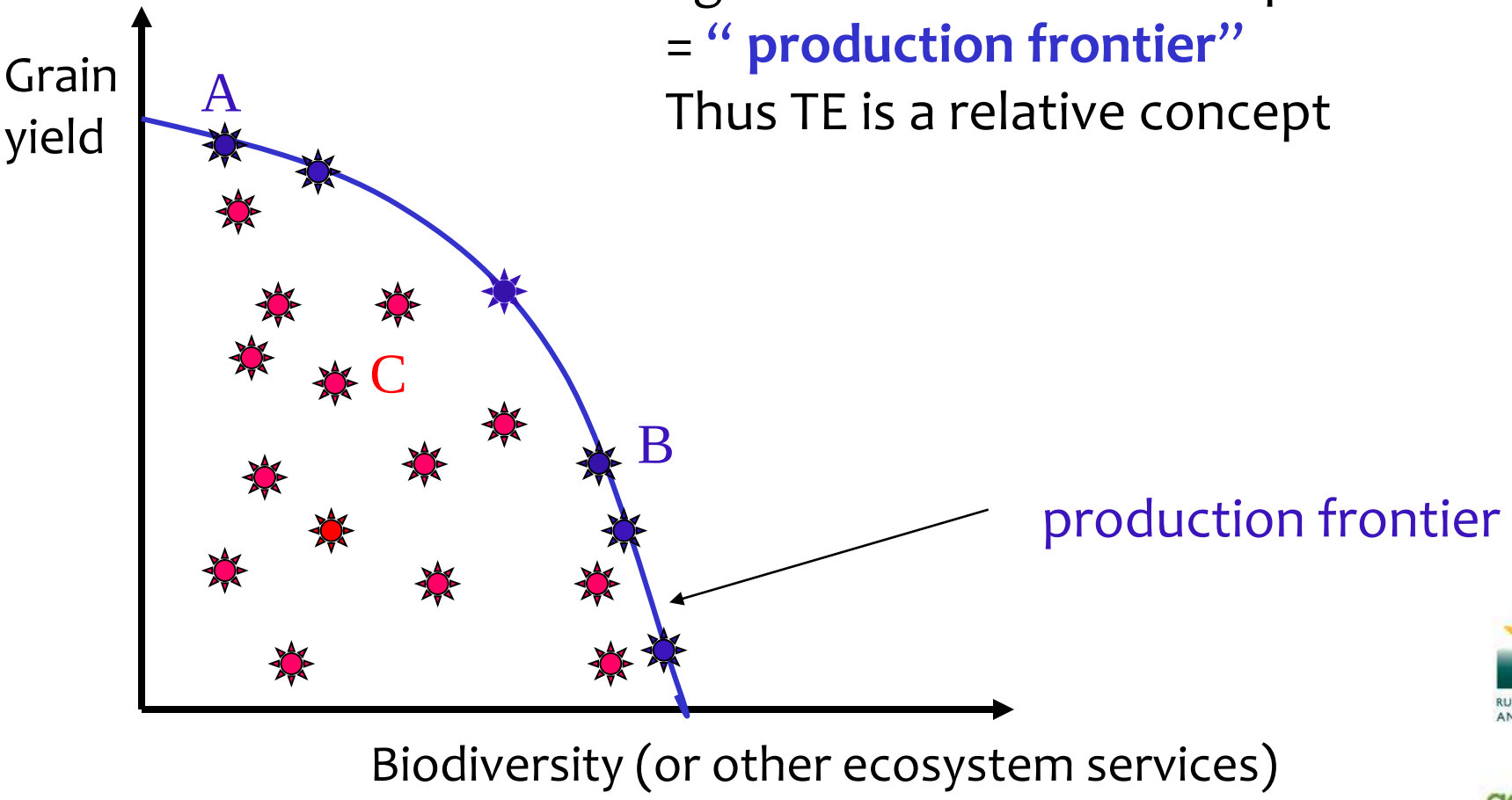
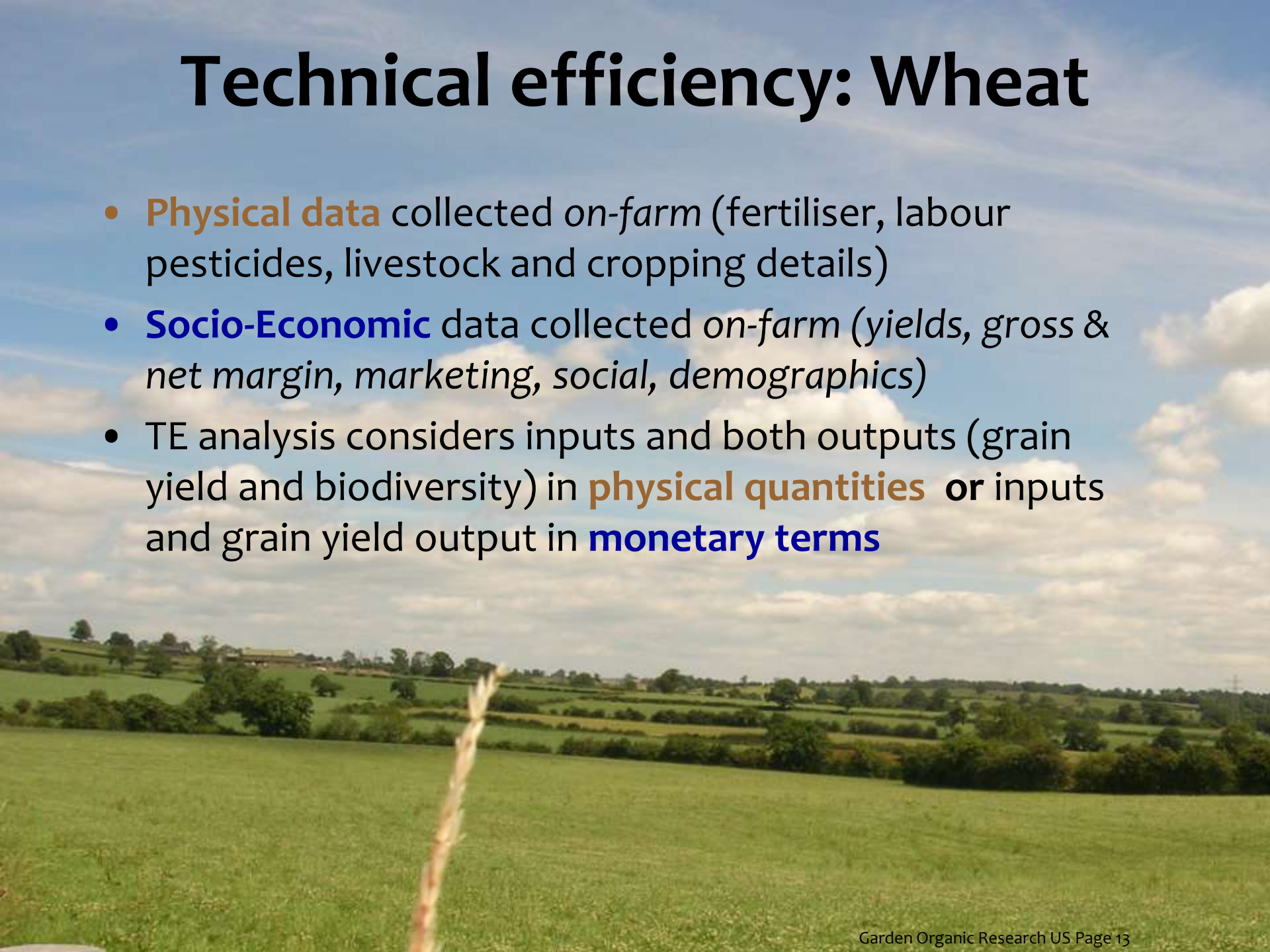
TE example

Farms (e.g., "C") are compared against a combination of peers = **" production frontier"**
Thus TE is a relative concept



Technical efficiency: Wheat

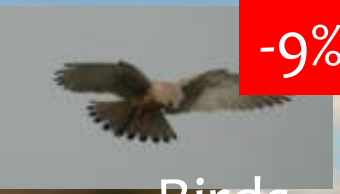
- **Physical data** collected *on-farm* (fertiliser, labour pesticides, livestock and cropping details)
- **Socio-Economic** data collected *on-farm (yields, gross & net margin, marketing, social, demographics)*
- TE analysis considers inputs and both outputs (grain yield and biodiversity) in **physical quantities** **or** inputs and grain yield output in **monetary terms**



RESULTS

Biodiversity

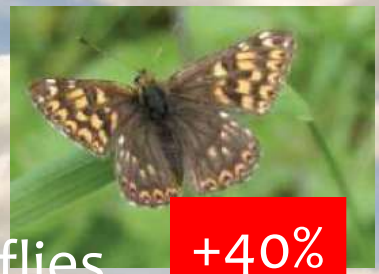
+12% (Diversity = different species present)



-9%

Birds

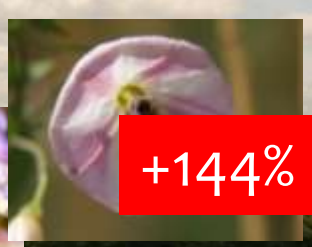
Abundance = more of same species



Butterflies

+40%

+34%



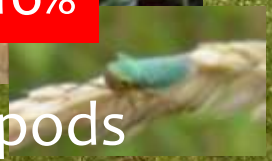
+144%

Bumblebee, Solitary bees

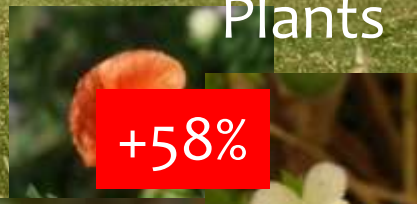
-33%

Hoverflies

+16%



Arthropods

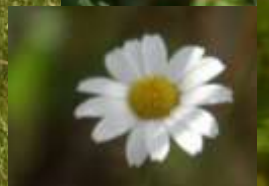


Plants

+58%

+23%

Earthworms



Biodiversity results

- Plant biodiversity higher in hotspots, but even isolated organic farms have high biodiversity relative to conventional

- Bumblebees are more abundant in organic hotspots. Conventional farms in hotspots have greater abundance than isolated organics

- High densities of organic landscapes create higher biodiversity levels, with some cross over with nested conventional farms

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Yield & profit

- Organic grain yields disappointing:
  3.5 versus **8.3** t/ha (42%)
  If straw yield and biomass yield (weeds) is included picture improves somewhat
- Organic higher prices **247** versus **132** £/t (187%)
- Lower total costs **336** versus **657** £/ha (51%)
- Higher net margin **660** versus **516** £/ha (128%)

- Organic on average lower percentage of subsidies in turnover

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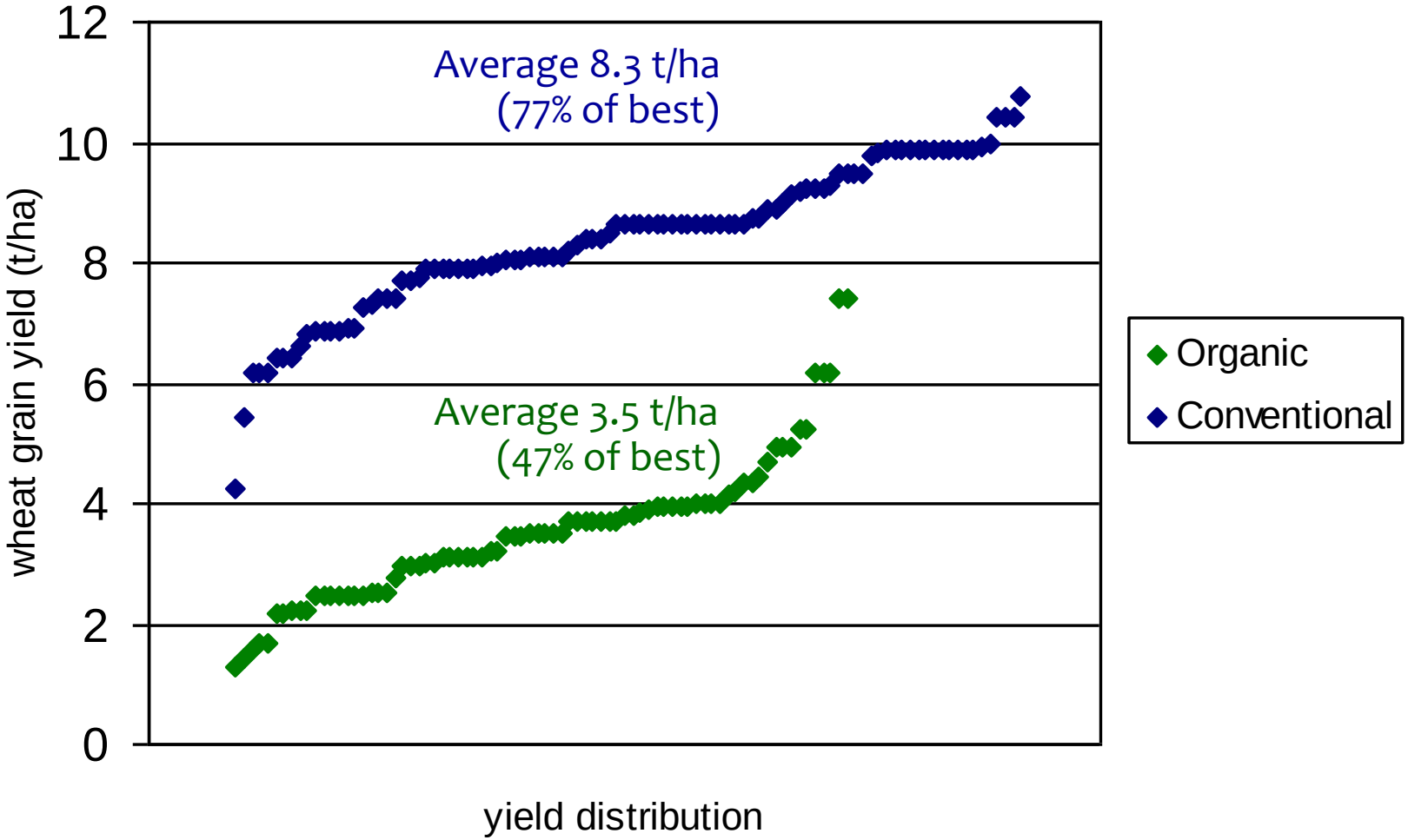
Yield distribution



Technical efficiency

- Physical TE analysis, considering multi-output yield and **biodiversity** showed higher technical efficiency on conventional, and on hotspot versus coldspot organic
- In monetary terms, no significant difference between organic and conventional; as before, higher efficiency in organic hotspot versus coldspots
- => concentration of organic farmland could provide relatively higher physical and monetary efficiencies when considering yield and biodiversity as dual output

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Socio-economics

organic hotspots versus coldspots

- higher membership in research associations
- more mixed farming (number of farm enterprises)
- less years farming experience and lower age (45 yr hot vs 53 cold)
- higher education (College University) 100% vs 56
- more triticale and rye, more legumes, more other crops
- less livestock units total (0.6 LSU/ha vs 1.0), and per grazing land

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Conclusions

1. Landscapes with higher concentration of organic have greater technical efficiency to produce yield & biodiversity
2. Organic wheat yields on average disappointingly low (42% of conventional). However, best organic 70% of best conventional. Unlike in conventional, average organic far below best organic
   => organic has much room to improve
3. Best organic farms with high yields and biodiversity are the 'win-win' for dual output yield & biodiversity
4. Organic winter wheat to be replaced by triticale and other low input crops or population mixes
5. Good education and *on-farm* research key 'soft' inputs of technical efficient farms
6. Organic farms less affected by subsidies then conventional
7. Conventional farms in hotspot organic landscapes also have higher levels of biodiversity (cross over or Public Good)

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Support material

Birds: '3 down 2 up'

Corn Bunting	n.s. (not significant different)
Grey Partridge	- *
Lapwing	- *
Linnet	n.s.
Skylark	n.s.
Starling	n.s.
Tree Sparrow	n.s.
Yellowhammer	n.s.
Common Whitethroat	- *
Kestrel	n.s.
Stock Dove	n.s.
Goldfinch	- *
Greenfinch	n.s.
Jackdaw	+ * (nest predator)
Rook	+ * (nest predator)
Wood Pigeon	n.s.

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Hoverflies

(Ecology Letters supplement)

- majority (62 %) of hoverflies found predatory = aphidophagous

- both, aphidophagous and non-aphidophagous species benefited from organic farming, but at different!
aphidophagous hoverflies at landscape scale
non-aphidophagous at farm scale

- 30% more hoverfly larvae on the organic farms, **however**, it is surprising to find higher numbers of aphidophagous adult hoverflies in conventional fields – why?

=> spill over of more mobile adults from organic fields?
=> aphidophagous hoverflies abundance correlated to crop density (yield)?

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Arable margins (1)

Wheat enterprise economics	Organic	Conventional	% org/ conv.
Output grain & straw net (£/ha)	**£961**	**£1,171**	82%
Seed and seed treatment costs (£/ha)	£79	£41	193%
N £/ha (£ per kg straight N)	£0	£165	0%
P £/ha (£ per kg straight P)	£0	£37	0%
K £/ha (£ per kg straight K)	£0	£33	0%
Organic fertiliser costs (£/ha)	£16	£13	119%
Pesticide costs (£/ha)	£0	£94	0%
Variable costs (£/ha)	£95	£383	25%
Gross margin (£/ha)	**£870**	**£794**	110%
Syn. fert. application costs & labour (£/ha)	£0	£28	0%
Org. fert. application costs & labour (£/ha)	£17	£14	124%
Pesticide spraying cost & labour (£/ha)	£0	£35	0%
Agronomist labour (£/ha)	£1	£4	18%
Mechanical weeding & labour (£/ha)	£15	£0	
Casual labour £6/h (£/ha)	£4	£1	393%
Cultivations & labour ((£/ha)	£121	£111	109%
Combine & labour (£/ha)	£84	£79	107%
Labour & allocated fixed costs (£/ha)	£242	£272	89%
Total costs (£/ha)	**£337**	**£655**	51%
Net margin (£/ha)	**£628**	**£522**	120%

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Other explaining variables			
Marketable yield (t/ha)	3.5	8.4	42%
Price wheat (£/tonne)	£247	£129	192%
Field size	9.1	10.5	86%
Total agricultural area (ha)	460	563	82%
Winter wheat (ha)	39	133	30%
Farm production income (% of total)	95%	86%	111%
Mixed farming (number of enterprises)	3.6	2.4	152%

(2)

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Market channels

- Seed
  10% organic versus 2% conv * (<0.05)

- Milling or other food
  46% organic versus 31% conv *

- Feed
  44% organic versus 67% conv *

Arable margins (3)

Wheat enterprise economics	Average	Hot organic	Cold organic	% H/C	Hot conv.	Cold conv.	% H/C	Year 07 org.	Year 08 org.	% 08/07	Year 07 conv.	Year 08 conv.	% 08/07
Output grain & straw net (£/ha)	**£1,079**	**£900**	**£1,059**	**85%**	**£1,100**	**£1,244**	**88%**	**£976**	**£944**	**97%**	**£1,284**	**£1,093**	**85%**
Seed and seed treatment costs (£/ha)	£57	£71	£92	77%	£45	£37	122%	£72	£85	118%	£36	£48	134%
N £/ha (£ per kg straight N)	£93	£0	£0		£182	£147	124%	£0	£0		£156	£178	114%
P £/ha (£ per kg straight P)	£21	£0	£0		£33	£41	81%	£0	£0		£30	£46	153%
K £/ha (£ per kg straight K)	£19	£0	£0		£25	£41	62%	£0	£0		£32	£38	117%
Organic fertiliser costs (£/ha)	£14	£21	£7	305%	£18	£9	204%	£16	£16	97%	£11	£10	95%
Pesticide costs (£/ha)	£53	£0	£0		£93	£95	98%	£0	£0		£81	£108	133%
Variable costs (£/ha)	£257	£92	£99	93%	£396	£370	107%	£89	£101	114%	£347	£428	124%
Gross margin (£/ha)	**£828**	**£814**	**£961**	85%	**£717**	**£875**	82%	**£888**	**£850**	96%	**£952**	**£665**	70%
Syn. fert. application costs & labour (£/ha)	£16	£0	£0		£29	£28	104%	£0	£0		£28	£28	98%
Org. fert. application costs & labour (£/ha)	£15	£23	£8	272%	£18	£9	199%	£18	£17	93%	£11	£11	99%
Pesticide spraying cost & labour (£/ha)	£20	£0	£0		£37	£32	115%	£0	£0		£32	£37	114%
Agronomist labour (£/ha)	£3	£1	£0		£5	£3	155%	£1	£1	103%	£4	£4	102%
Mechanical weeding & labour (£/ha)	£7	£12	£20	63%	£0	£0		£14	£16	113%	£0	£0	
Casual labour £6/h (£/ha)	£2	£3	£6	51%	£0	£2	0%	£5	£4	85%	£1	£1	62%
Cultivations & labour ((£/ha)	£115	£117	£126	93%	£112	£110	102%	£124	£117	94%	£111	£109	98%
Combine & labour (£/ha)	£81	£84	£85	99%	£77	£81	95%	£83	£85	101%	£79	£78	100%
Labour & allocated fixed costs (£/ha)	£259	£241	£245	98%	£279	£265	105%	£245	£239	98%	£267	£268	100%
Total costs (£/ha)	**£516**	**£333**	**£343**	**97%**	**£675**	**£635**	**106%**	**£333**	**£340**	**102%**	**£613**	**£696**	**113%**
Net margin (£/ha)	**£569**	**£573**	**£716**	**80%**	**£439**	**£609**	**72%**	**£643**	**£611**	**95%**	**£686**	**£397**	**58%**

Other explaining variables													
Marketable yield (t/ha)	6.3	3.3	3.9	87%	8.3	8.5	97%	3.3	3.7	111%	7.9	8.8	112%
Price wheat (£/tonne)	£180	£249	£243	102%	£120	£138	87%	£271	£223	82%	£151	£113	75%
Field size	9.9	10.1	7.3	139%	9.8	11.3	86%	8.3	9.9	119%	10.8	10.3	96%
Total agricultural area (ha)	513	712	180	396%	913	277	329%						
Winter wheat (ha)	88	53	25	214%	189	88	216%						
Farm production income (% of total)	90%	91%	100%	91%	84%	86%	98%						
Mixed farming (number of enterprises)	2.9	4.2	2.9	145%	1.8	2.8	63%						

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Grass: physical data

GRASS fields	Organic	Conventional	% org/ conv.	average	Hot organic	Cold organic	% H/C	Hot conv.	Cold conv.	% H/C
Field size (ha)	5.5	6.0	92%	5.8	6.9	4.2	164%	5.8	6.2	93%
PP=1, TP=0	82%	80%	103%	81%	76%	89%	85%	87%	72%	121%
Grass=0, G/C=0.5, Clover=1	43%	14%	309%	28%	37%	48%	77%	11%	16%	69%
Age of ley (years)	28.7	28.2	102%	28.4	38.1	19.2	198%	28.7	27.6	104%
Use: graze=1, graze & 1x conserve=0.5, graz	84%	76%	110%	80%	93%	75%	124%	70%	82%	85%
Use: graze only=1	75%	59%	126%	67%	85%	64%	133%	46%	72%	64%
Use: mixed cut & graze =1	20%	35%	58%	28%	15%	26%	57%	48%	22%	217%
Use: cut only=1	6%	6%	100%	6%	0%	11%	0%	6%	6%	100%
Silage=1, Hay and haylage=0	71%	41%	176%	53%	38%	85%	44%	23%	73%	32%
Number of cuts	1.4	1.1	121%	1.2	1.0	1.5	67%	1.2	1.0	118%
Cut yield (t/ha)	10.7	14.0	77%	13.3	6.0	14.2	43%	18.8	6.3	297%
Months grazing	5.0	4.1	121%	4.7	4.7	5.1	93%	1.7	6.3	27%
Mixed grazing=1, only one livestock type=0	29%	22%	136%	25%	25%	34%	74%	14%	29%	47%
Cattle	81%	73%	112%	77%	71%	92%	77%	71%	75%	95%
Sheep	48%	42%	114%	45%	54%	42%	128%	29%	55%	54%
Average weight of stock (kg)	499	481	104%	490	511	489	104%	434	517	84%
Re-seeding=1, no=0	6%	2%	341%	4%	6%	6%	96%	0%	3%	0%
Syn. fertiliser=1, no=0	1%	39%	2%	20%	0%	2%		44%	33%	133%
N amount (kg/ha)	0.6	64	1%	32	0.0	1.3		58	70	83%
P amount (kg/ha)	0	2	0%	1	0	0		0	3	
K amount (kg/ha)	0	1	0%	1	0	0		0	3	
Organic fert.=1, no=0	45%	9%	533%	27%	44%	46%	96%	0%	17%	
Amount (t/ha)	17.5	12.2	143%	17.2	15.8	19.8	80%		12.2	
N (kg/ha) conversion: Poultry-manure 16kg	41	14	291%	27	41	40	104%	0	28	
P2O5 (kg/ha) conversion: Poultry-manure 1	23	6	397%	14	22	25	88%	0	12	
K2O (kg/ha) conversion: Poultry-manure 9	51	16	320%	34	46	56	83%	0	32	
Total N applied	41	78	53%	60	41	41	100%	58	98	59%
Total P applied	23	8	307%	15	22	25	88%	0	15	
Total K applied	51	17	296%	34	46	56	83%	0	34	
Total spray passes	0	1.1	0%	1.1				1.3	1.0	130%
Products per pass	0	1.0	0%	1.0				1.1	1.0	110%
Number of products used	0	0.3	0%	0.1	0	0		0.3	0.3	88%
Mechanical weed control (including topping, r	67%	44%	151%	56%	70%	64%	110%	43%	46%	92%
Number of mechanical weeding passes	1.4	1.6	82%	1.5	1.4	1.3	101%	1.8	1.5	119%
Cultivation done (one or more) excluding har	1%	4%	25%	2%	2%	0%		0%	7%	
Casual labour (hours/ha)	0.23	0.11	206%	0.17	0.10	0.35	30%	0.22	0.00	
Fences for strip grazing	21%	6%	383%	13%	13%	30%	44%	4%	7%	50%
Any flooding events, crop failure history ?	6%	12%	52%	9%	5%	7%	70%	4%	20%	20%
Stewardship scheme yes=1, no=0	62%	30%	209%	46%	85%	39%	219%	22%	37%	60%

Grass: economic data (1)

GRASS fields	Organic	Conventional	% org/ conv.
Re-seeding cost £/ha	£6	£2	341%
N £/ha (£ per kg straight N)	£0.6	£60	1%
P £/ha (£ per kg straight P)	£0	£2	0%
K £/ha (£ per kg straight K)	£0	£1	0%
Syn. fertiliser application costs (£/ha)	£0.1	£3.9	2%
Org. fertiliser costs (£/ha)	£27	£1	2055%
Org. fert. application costs (£/ha)	£28	£1	2055%
Spray costs (£/ha)	£0	£7	0%
Spraying cost & labour (£/ha)	£0	£2	0%
Mechanical weeding & labour (£/ha)	£14	£11	130%
Cultivations & labour (£/ha)	£0.1	£0.6	25%
Casual labour £6/h (£/ha)	£1.4	£0.7	206%
Fence moving labour £6/h (£/ha)	£13	£3	383%
Costs (£/ha)	**£89**	**£96**	**93%**

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Grass: economic data (2)

GRASS fields	Hot organic	Cold organic	% H/C	Hot conv.	Cold conv.	% H/C	Year 07 org.	Year 08 org.	% 08/07	Year 07 conv.	Year 08 conv.	% 08/07
Re-seeding cost £/ha	£6	£6	96%	£0	£3		£4	£8	181%	£1	£1	100%
N £/ha (£ per kg straight N)	£0	£1		£55	£66	83%	£30	£0		£63	£59	94%
P £/ha (£ per kg straight P)	£0	£0		£0	£4		£1	£0		£4	£1	35%
K £/ha (£ per kg straight K)	£0	£0		£0	£2		£1	£0		£2	£1	54%
Syn. fertiliser application costs (£/ha)	£0	£0		£4	£3	133%	£2	£0		£4	£4	85%
Org. fertiliser costs (£/ha)	£27	£26	101%	£0	£3		£18	£25	139%	£2	£0	
Org. fert. application costs (£/ha)	£28	£28	101%	£0	£3		£19	£26	139%	£2	£0	
Spray costs (£/ha)	£0	£0		£5	£8	66%	£3	£0		£8	£5	66%
Spraying cost & labour (£/ha)	£0	£0		£2	£2	76%	£1	£0		£2	£2	108%
Mechanical weeding & labour (£/ha)	£14	£13	106%	£11	£10	114%	£13	£14	105%	£13	£10	83%
Cultivations & labour (£/ha)	£0	£0		£0	£1		£0	£0		£0	£1	200%
Casual labour £6/h (£/ha)	£0.6	£2.1	30%	£1.3	£0.0		£0.6	£1.8	292%	£0.8	£0.8	100%
Fence moving labour £6/h (£/ha)	£8	£18	44%	£2	£4	50%	£11	£13	119%	£3	£5	200%
Costs (£/ha)	**£83**	**£95**	**88%**	**£81**	**£110**	**74%**	**£104**	**£87**	**84%**	**£104**	**£90**	**87%**

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Three zones: centre, edge and margin

Soils Results: Key Findings (1)

- Organic management does not create many differences in soil properties relative to conventional management. Soil type is the main determinant of characteristics.

- There is a small increase in pesticide residues in conventional management soils, but all residues are below minimum threshold limits.

- There are significant differences in many characteristics between arable and permanent grassland.

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Soils Results: Key Findings (2)

- Infiltration rates are significantly lower in conventional grass fields (stocking rates higher: 1.3 v 1.1)
- For typical Midland catchments, replacing conventional with organics would cause peak run-off in storm events (20mm/hr) to fall from 1750 m^3/ha to 1250 m^3/ha.
- This would reduce a 1 in 10 year flooding event to a 1 in 2.
- Similar run-off reductions might also be caused due to increasing grass coverage as organic levels in catchments increase

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Social aspects: key results (1)

- Perceptions of 'good' farming critical to influences: tidiness, timeliness, doing the job right
- 'Almost organic anyway' attitudes to conversion (prior to conversion; and extensification)
- Longevity/viability since organic establishment influences levels of respect amongst conventional farmers (Southern cluster)

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Social aspects: key results (2)

"in the old days it was, we [organic farmers] were a joke you know, we were treated as a joke… [it] is increasingly becoming oh it doesn't look a mess, and he is still making money and he is still employing Andrew, whereas I made Fred redundant and all the rest of it."

Integrated research: "*Data Envelopment Analysis*" (DEA)

Various types of frontier efficiency analysis exist:
Deterministic Vs. Stochastic

DEA is a deterministic linear programming technique largely the result of multi-disciplinary research in economics, engineering and management

A basic DEA study results in an *efficiency measure* that reflects the *distance* from each unit to a technological frontier.

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DEA

DEA can handle multiple inputs & outputs

It possible to evaluate all:

- TE
- Scale efficiency (related to '*economies of scale*')
- Profit potential
- Technical progress (shifts of the frontier)

No requirement of any assumption about functional forms relating inputs to outputs.

Inputs & Outputs can have different units

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