Modelling European Agriculture with Climate Change for Food Security

Future climate change and impacts on yields and farm management: a case study at a pilot region in Finland

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Objectives – main research questions:

- What are the effects of crop productivity change on farm level land use, management and farm income?
- How much more value can a farmer expect from improved crop yields?
- How do the effects vary with different future price levels?
- Differences between spring and winter cereals in future climate conditions?
- Do higher crop yields lead to reduced GHG emissions per farm, or per kg produced?

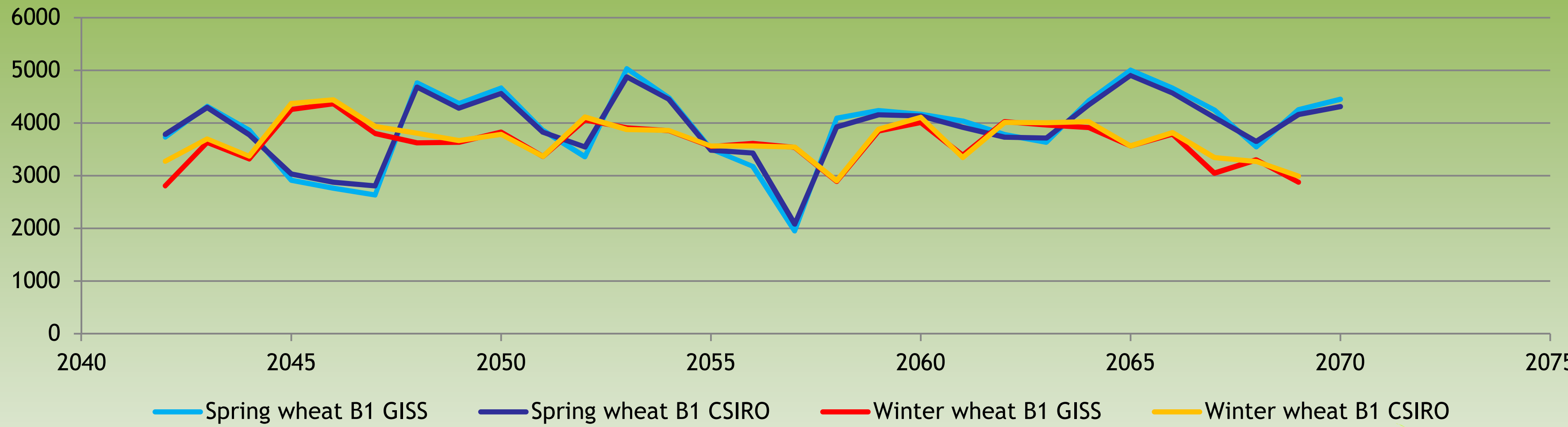
Crop modelling results utilised in this study

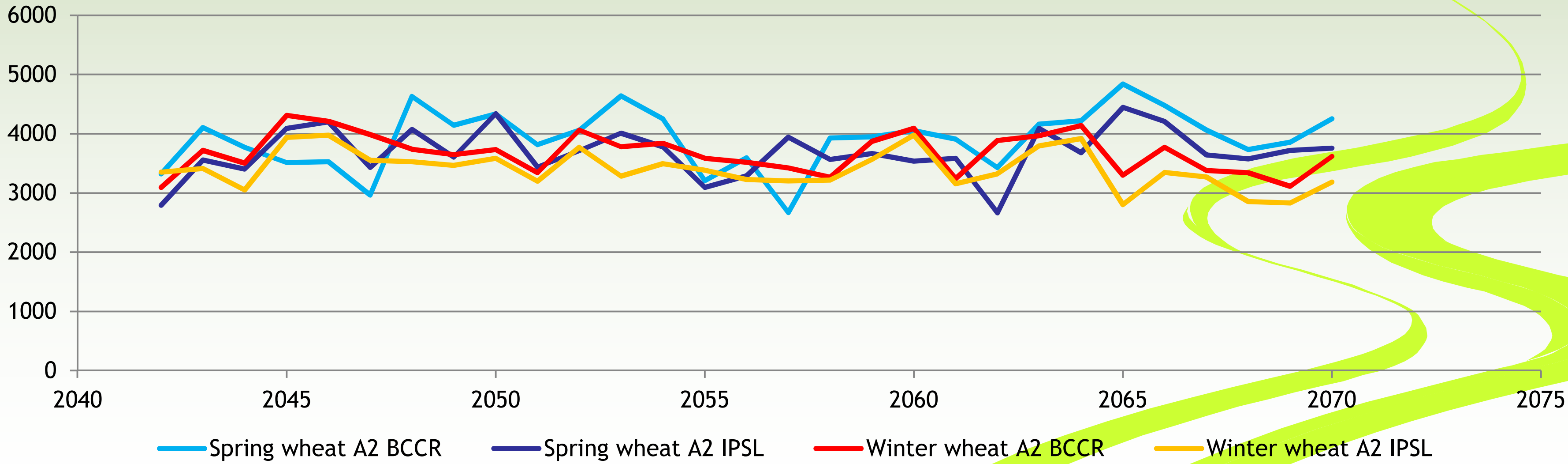
- Ensemble simulations using a process-based large area crop model (MCWLA) (Tao et al., 2015)

It explicitly parameterized the effects of extreme temperature and drought stress on wheat yields, and accounted for a wide range of wheat cultivars with contrasting phenological characteristics and thermal requirements.

- Climate scenarios B1, A2
- Other main assumptions
  - Yields of all spring crops will develop in the very similar way, but winter wheat yields differently

Estimated future yields 2042-2070 of spring and winter wheat in North Savo in B1 (upper) and A2 (lower) climate scenarios





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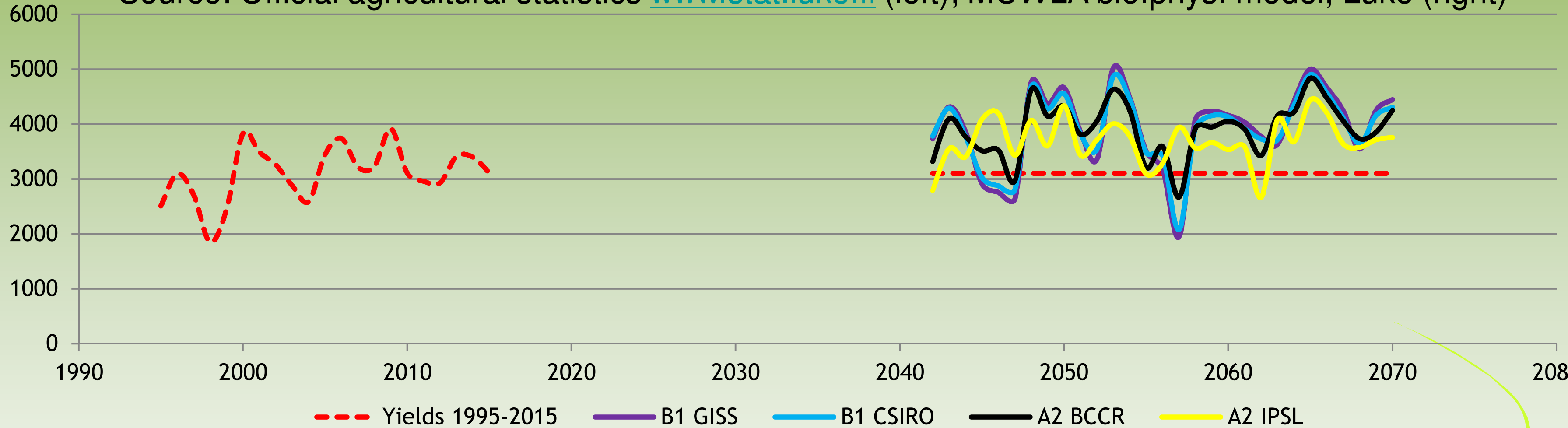
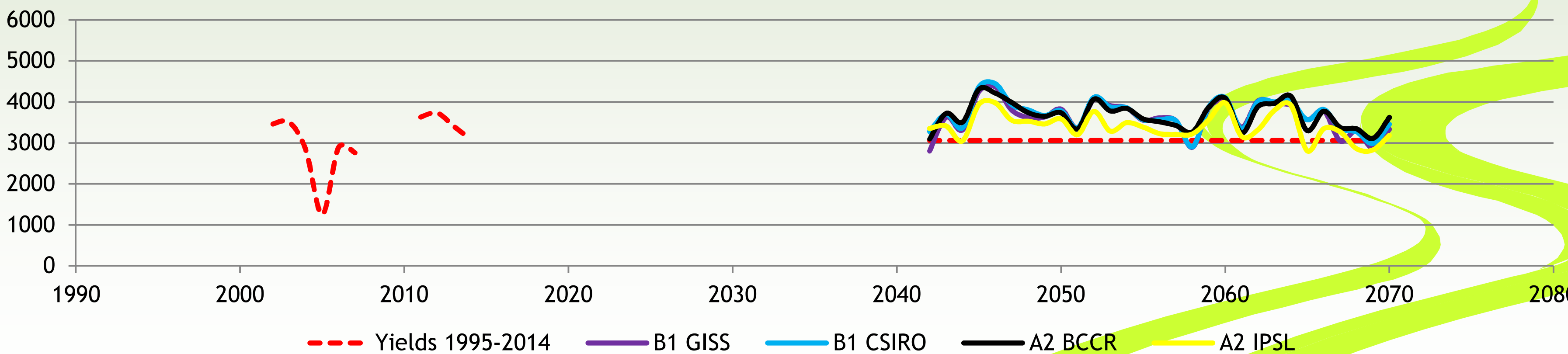
Historical yield vs. simulated future yield of spring (up) and winter (down) wheat in North Savo

Source: Official agricultural statistics www.stat.luke.fi (left); MCWLA bio.phys. model, Luke (right)





Economic model employed

- Rational farmers, mean-variance utility function:
- Maximize present income discounted expected profit
- Minimize the variance of expected profits
- Choosing the sequence of crops *i* planted on parcels *p* every year during next *H* years
- *A(p,t,i)*=Land allocation on parcel *p* of crop *i* on year *t*
- Y=Crop yield, depends on past land use, N fert., soil pH, fungicide use; X=past (expected) gross margin covariance; C=cost per ha; P=crop price; S=support payments per crop

$$Max \sum_{t=1}^{H} \sum_{p}^{10} \sum_{i=1}^{M} (1/(1+r))^{t} \Big(Y\big(A(p,t,i),\ p,t,i\big)A(p,t,i)P(i) + S(i) - C(p,t,i)\Big)$$

$$-\theta \sum_{t-1}^{H} \sum\nolimits_{c} \sum\nolimits_{c2} (1/(1+r))^{t} A' XA$$

$$\sum_{\forall c} A(p,t,c) = 1,$$

Special features of the economic model employed

➢Nitrogen response function (Lehtonen, 2001)

$$\begin{cases} Y_{mean}(N^i) = m(1 - ke^{bN^i}) & when \;\; i = wheat, barley, oats \\ Y_{mean}(N^i) = a_0 + b_0 N^i + c_0 N^{2i} & when \;\; i = oilseeds \end{cases}$$

➢Fungicide treatment (Purola, 2013)

$$F(p,t,c^i) = \delta(p,t,c^i) \sum_{j=1}^{\gamma} \beta_j K_j(c^i)$$

➢Liming treatment (Myyrä et al. 2006)

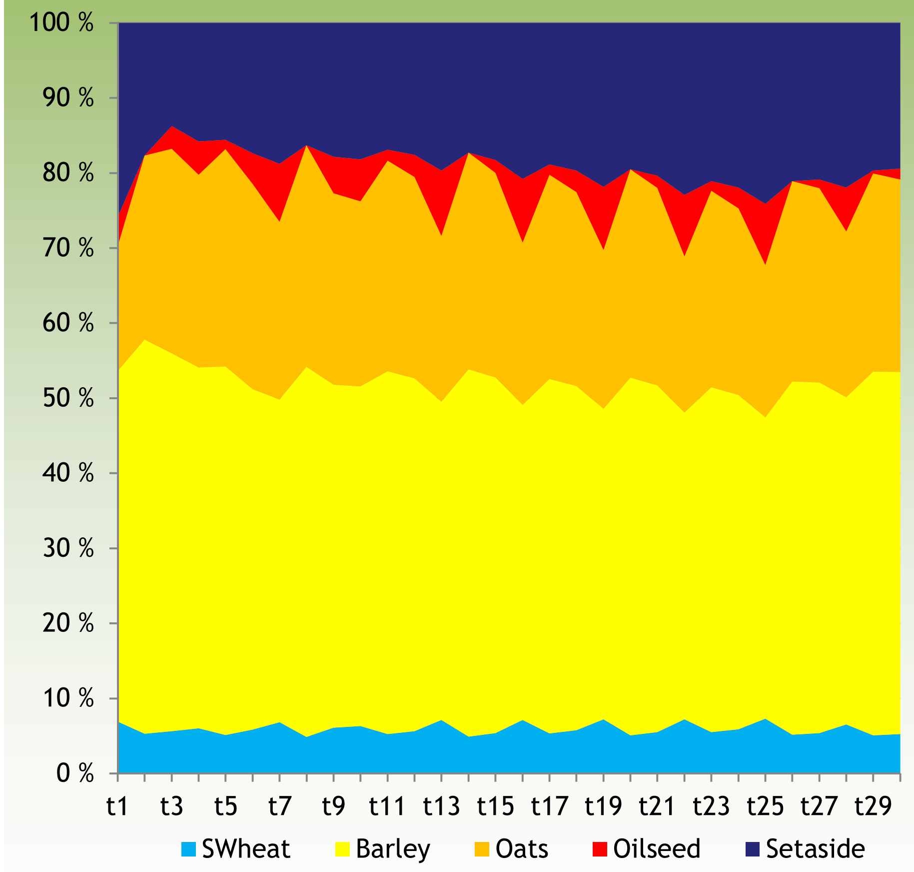
$$Y(A(p,t,i)) = \begin{cases} Y_{MEAN}(p,i) Y_{RED}(p,t,i)((1 + L(p,t) + F(p,t,i) - \rho D(i)) & if \quad i = wheat \quad or \quad barley \\ Y_{MEAN}(p,i) Y_{RED}(p,t,i)((1 + L(p,t)) & if \quad i = others \end{cases}$$

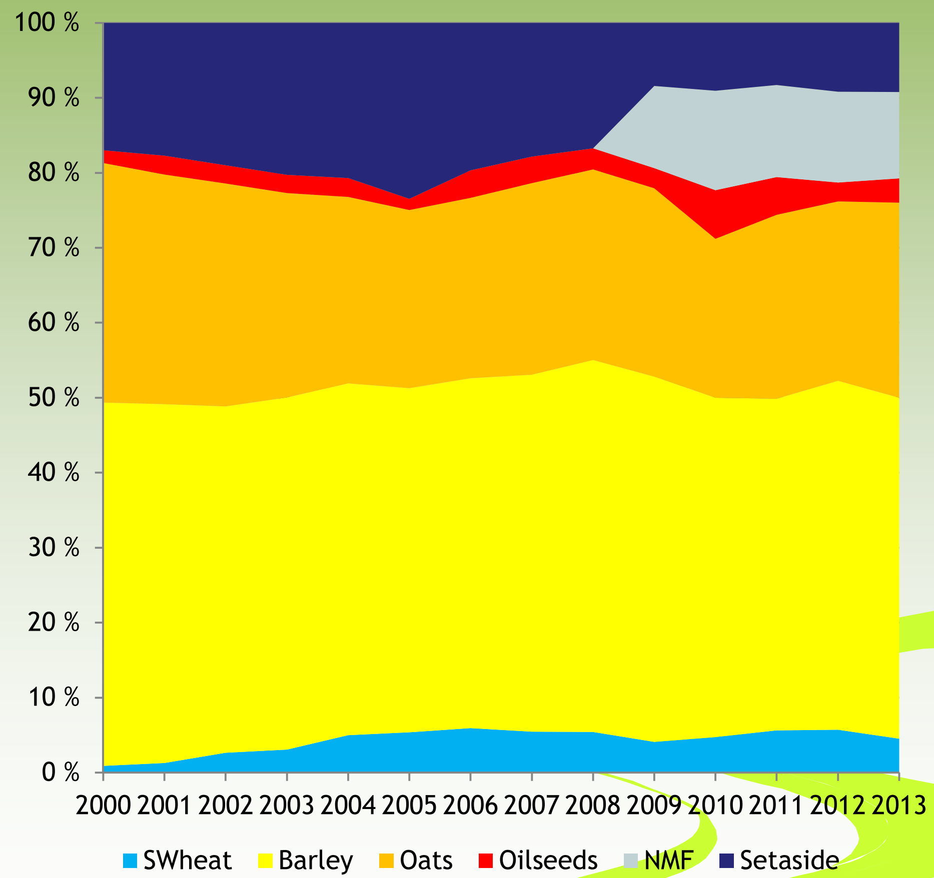
Cereals farms in North Savo region

- Farm size appr. 50 ha, average yields of the region, land and input use derived from statistical sources and verified calculations (Pro Agria (proagria.fi), Luke)
- 32% of farm family income from agriculture
- A generic assumption: 10 parcels and the distances of the parcels to the farm centre vary between 0 and 7 km, with an average distance of 2.9 km for the region
  - logistic costs dependent on the distance
- Decisions to cultivate a crop in each field parcel, with input use decisions (yields) set up a dynamic programming problem, over all field parcels

Simulated land allocation vs. historical land allocation

Source: Dynamic economic crop rotation and management model results, Luke 2017





Scenario settings

		Price scenario		
		-20% baseline price (LP)	Baseline price (BP)	+20% baseline price (HP)
Emission scenario - Climate model - combination	Baseline	Baseline LP	Baseline BP	Baseline HP
	A2 BCCR	A2 BCCR LP	A2 BCCR BP	A2 BCCR HP
	A2 IPSL	A2 IPSL LP	A2 IPSL BP	A2 IPSL HP
	B1 GISS	B1 GISS LP	B1 GISS BP	B1 GISS HP
	B1 CSIRO	B1 CSIRO LP	B1 CSIRO BP	B1 CSIRO HP

Simulated results in current climate under different price scenarios

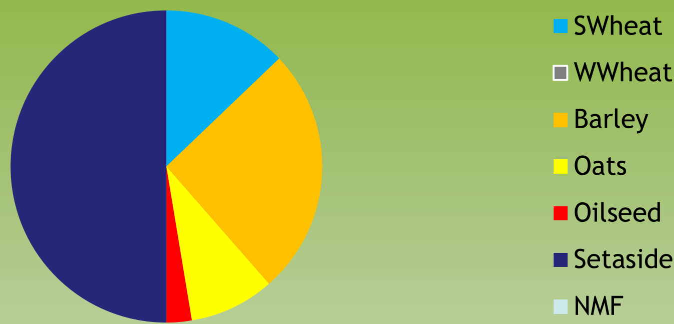
	Average yields 1995-2013	Simulated Yields from economic model		
		LP	BP	HP
Spring wheat	3086	2886(-6.5%)	3162(+2.4%)	3168(+2.6%)
Winter wheat	3051			
Barley	2948	2895(-1.8%)	3171(+7.6%)	3185(8.0%)
Oats	2785	2611(-6.2%)	2870(+3.1%)	2888(+3.7%)
Oilseed	1305	1228(-5.9%)	1376(+5.5%)	1388(+6.4%)
Frequency of fungicide treated barley and wheat/ farm		0	0	0
Average pH/ farm		5.71	6.56	6.65
Total profit €/farm/year		9290	10803	13030
GHG emissions tons CO2 eq. /year (normalized per 10 ha/year)		24.12	30.89	34.83

Simulated results under A2 and B1 climate scenarios

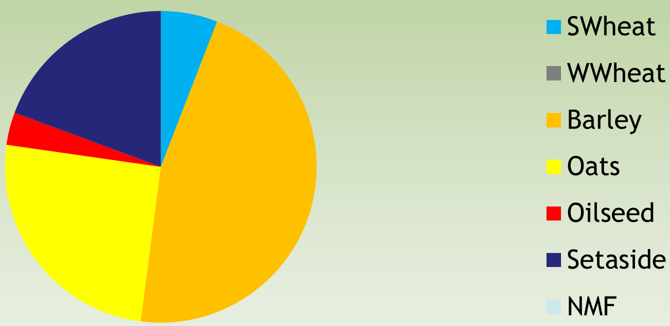
	B1 GISS				A2 IPSL			
Regional average yields kg/ha	Simulated Yield (MCWLA bio.phys. model)	Simulated Yield (Economic model)			Simulated Yield (MCWLA bio.phys. model)	Simulated Yield (Economic model)		
		LP	BP	HP		LP	BP	HP
Spring wheat [3086]	3927	4008 (+2.1%)	4020 (+2.4%)	4026 (+2.5%)	3685	3755 (+1.9%)	3766 (+2.2%)	3778 (+2.5%)
Winter wheat [3051]	3623				3402	-	-	-
Barley [2948]	3939	4231 (+7.4%)	4321 (+9.7%)	4396 (+11.6%)	3697	3962 (+7.2%)	4016 (+8.6%)	4101 (+10.9%)
Oats [2785]	3543	3680 (+3.9%)	3688 (+4.1%)	3711 (+4.7%)	3325	3458 (+4.0%)	3461 (+4.1%)	3472 (+4.4%)
Oilseed [1305]	1660	1761 (+6.1%)	1766 (+6.4%)	1773 (+6.8%)	1558	1647 (+5.7%)	1662 (+6.7%)	1660 (+6.5%)
Frequency of fungicide treated barley and wheat/ farm [0]		0	112	198		0	53	177
Average pH/ farm [6.56]		6.62	6.67	6.69		6.58	6.66	6.68
Total profit €/farm/year [10803]		16777	20644	24474		15050	19243	22849
GHG emissions overall tons CO2 eq. /year (normalized per 10 ha/year) [30.89]		31.68	33.59	34.79		29.79	33.67	34.79

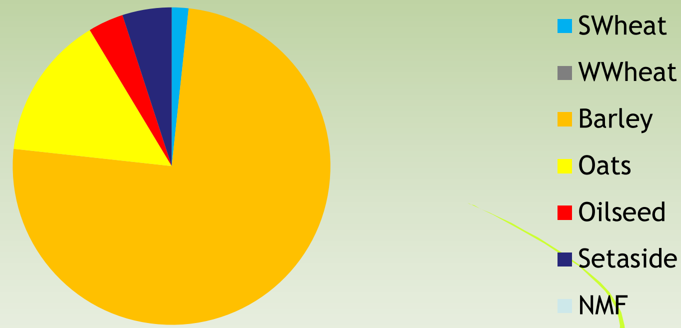
Land allocation: Baseline (left) vs. A2 IPSL (right)

LP

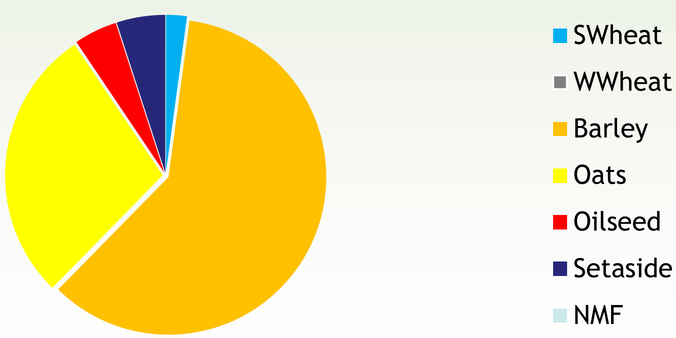


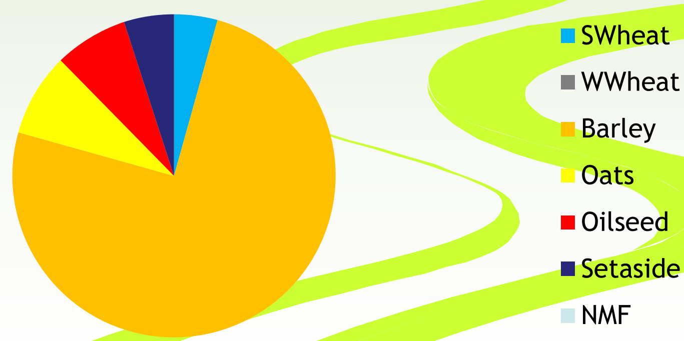
BP





HP





GHG emissions per kg produced decrease if higher yields - increase if higher prices

(due to concave production functions, decreasing marginal effect of inputs)

	Baseline	A2 IPSL	B1 GISS
Barley yield (kg/ha)	3171	4016	4321
Total crop production (tons per year per 10 ha)	24.225	36.529	39.135
Gross margin per farm per year (eur)(average over 30 years)	10.803	19.243	20.644
GHG emissions (tons CO2 eq. Per 10 ha)	30.89	33.67	33.59
GHG emissions per ton produced (tons CO2 eq./ton)	1.28	0.92	0.86

LP = -20% from baseline prices

BP = Baseline prices 2000-2013

HP = +20% from baseline prices

Emissions per unit produced (tons CO2 eq./ton)

	LP	BP	HP
BASE	1.75	1.28	1.22
A2 IPSL	0.95	0.92	0.95
B1 GISS	0.85	0.86	0.89

Emissions per unit (tons CO2 eq. /ton), set aside land excluded

	LP	BP	HP
BASE	0.87	1.03	1.10
A2 IPSL	0.76	0.85	0.87
B1 GISS	0.78	0.79	0.82

Conclusive remarks

- Crop modelling results suggest increase of spring cereals yields from current 3 t/ha up to 3.5-3.6 t/ha (winter wheat; +15-20%) and to 4 t/ha (barley, spring wheat; +30%) until 2040-2070 in A2, B1
- Higher yields incentivize higher soil pH (liming), fungicide use and thus a further increase yields by 2-12%
- Economic model results suggest that barley production becomes dominating if yields increase, due to lower (historical) gross margin variability and strong fungicide response of yields
- 26-36% higher yields would imply 50-60% higher production and 78-90% higher gross margins per farm in scenarios B1, A2 - from current low levels
- GHG emissions per kg produced decrease by 27-33%
- The results suggest that current unexploited production potential will be used if 20-30% higher yields, but 30% less GHG emissions per kg produced – There are possibilities for ”sustainable intensification”

Thank you for your attention!

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