The impact and value of climate change adaptations in agriculture at the sector level

Presentation prepared for MACSUR TradeM Workshop ”Scaling in global, regional and farm models”, Vienna, September 24, 2014

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Agenda

- Introduction
- Farm level impacts and adaptations
  - Key issues indentified
  - Results from dynamic economic model of crop rotation and farm management
- Incorporating the farm level input use adjustments in a sector model
  - Nitrogen response
  - Plant disease pressure
  - Liming and fungicide use
- Empirical implementation of the model
- Examples of simulation results
- Discussion

Median changes in selected agro-climatic indicators relative to 1971-2000

GISS-ER/B1

	2011-2040	2041-2070	2071-2100
Sowing date change (nr of days)	-3	-3	-4
Proportion of suitable sowing days	12	12	16
Date of the last spring frost (days)	-6	-5	-7
Effective radiation change (%)	13	9	14
Effective growing days (change in days)	20	26	41
Rain 3-7 weeks after sowing, change, mm	1,8	1,4	10,8
Proportion of dry days in AMJ, change (%)	0	1	-4
Proportion of dry days in JJA, change (%)	-6	-4	-14
Extreme high temp stress, change (days)	1	1	1
Temperature sum accumulation during grain filling, change, C	1,4	1,5	1

IPSL-CM4/A2

	2011-2040	2041-2070	2071-2100
Sowing date change (nr of days)	-9	-15	-17
Proportion of suitable sowing days	20	28	32
Date of the last spring frost (days)	-18	-24	-24
Effective radiation change (%)	5	-3	-13
Effective growing days (change in days)	7	31	52
Rain 3-7 weeks after sowing, change, mm	-6,4	-9,5	-12,3
Proportion of dry days in AMJ, change (%)	2	19	21
Proportion of dry days in JJA, change (%)	2	13	17
Extreme high temp stress, change (days)	1	4	6
Temperature sum accumulation during grain filling, change, C	2,3	3,7	5,4

Source: R. P. Rötter , J. G. Höhn & S. Fronzek (2012) Projections of climate change impacts on crop production: A global and a Nordic perspective, Acta Agriculturae Scandinavica, Section A – Animal Science, 62:4, 166-180, DOI: 10.1080/09064702.2013.793735

Indicators selected by Rötter et. al. (2010), Trnka (2011),

Median dates of start of growing and hardening periods, days with simulated snow cover depth > 10 cm
Climate scenario A1B

	Growing period, start	Growing period, start	Hardening period, start	Hardening period, start	Snow days, > 10 cm	Snow days, > 10cm
	baseline	Ensemble	baseline	Ensemble	Baseline	Ensemble
Kuopio, North-Savo	May 6	April 27	Oct 13	Oct 27	159	78
Jokioinen, South-West Finland	May 8	April 28	Oct 15	Oct 31	142	46
St. Petersburg region, Russia	May 1	April 16	Oct 24	Nov 9	131	45

Source: Höglund, M., Thorsen S. M., and Semenov M. A. 2013. Assessing uncertainties in impact of climate change on grass production in Northern Europe using ensembles of global climate models. *Agricultural and Forest Meteorology* 170: 103–113.

Adaptation solutions, grass

- Three cuts per year
  - Earlier cuts
- New grassland species and cultivars
  - More resistant to heat stress and drought
  - Better nutritive value
  - Sufficient winter hardiness
- Adjusted fertilisation levels
  - Proper timing, according to developmental phases
  - According to yield potential of different crops and cultivars
- Prevention of soil compaction
  - Drainage
  - Development of machinery/use of machinery

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Adaptation solutions, cereals

- Cereals cultivars requiring longer growing season
  - Decrease vulnerability to early summer drought
  - More resistant to heat stress
- Improved crop protection needed
  - Currently no/little fungicide use => can be increased
  - More diverse crop rotations may relieve disease pressure
    - higher yielding oilseed crops and cultivars => more protein production?
- Adjusted fertilisation levels / shared fertilisation
  - Timely, according to development phases
  - According to yield potential of different crops and cultivars
- Improved soil structure, soil pH, drainage => resilience, extra costs…

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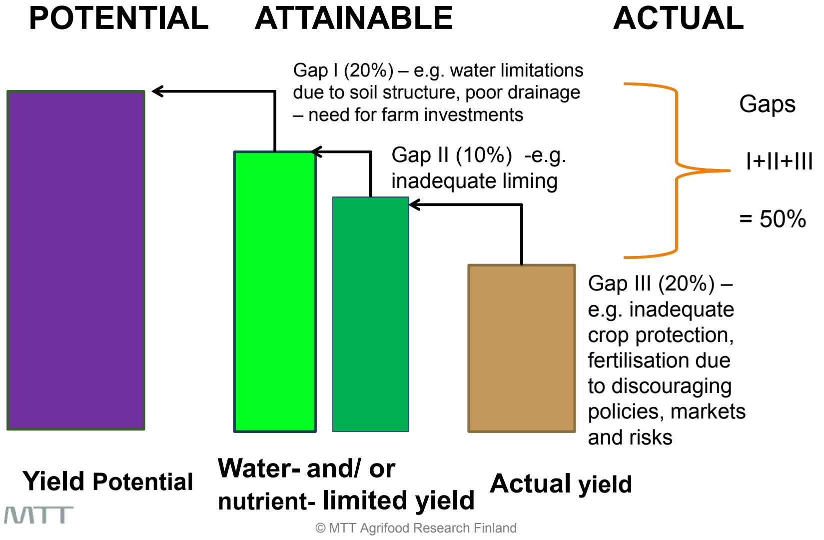
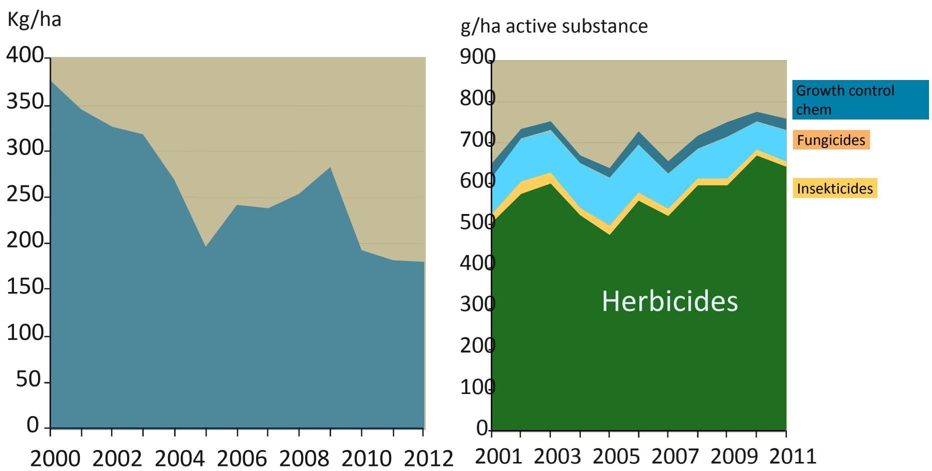
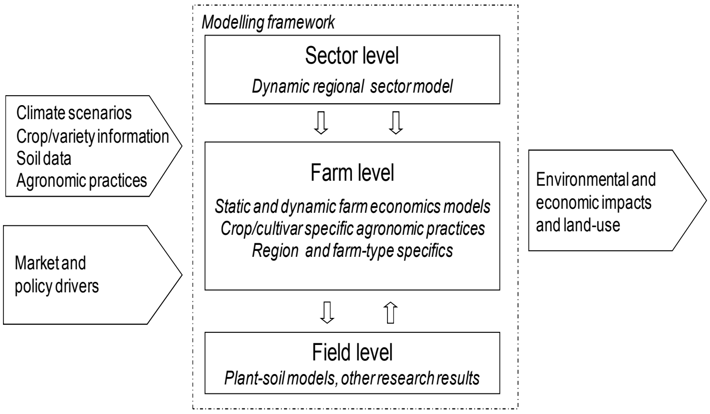
Production situations and yield gaps – explaining current yield gaps and their evolution



Use of lime (left) and crop protection chemicals (right)



Multi-scale integrated modelling framework AGRISIMU



Lehtonen, H.S., Rötter, R.P., Palosuo, T.I., Salo, T.J., Helin, J.A., Pavlova, Y., Kahiluoto, H.M. (2010). A Modelling Framework for Assessing Adaptive Management Options of Finnish Agrifood Systems to Climate Change. Journal of Agricultural Science, Vol 2, No 2 (2010), p. 3-16. ISSN: 1916-9752. E-ISSN: 1916-9760.
http://ccsenet.org/journal/index.php/jas/article/viewFile/4599/4888

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Crucial farm level management issues in climate change

- Crop rotation has various benefits in comparison to monocropping:
  - improve or maintain crop yield
  - promote a more diverse ecosystem
  - reduce reliance on a chemical approach to pest management
  - reduce the risk and extend of flooding
- Crop rotational effects also impact other management decisions
  - Land maintenance (liming, drainage)
  - Crop protection
  - Nitrogen fertilisation
- Farmer's behavior, especially attitude toward risks, also affect decisions on the use inputs and the rotation plan
- A farm level dynamic model used for studying economically rational land use and crop rotation with selected current and future cultivars in Finland for the next 30 years
  - under different market and policy conditions and climate change scenarios
  - with key adaptation mechanism at the farm level
  - with farmer's behavior of risk aversion considered
  - with different parcel locations in a farm, implying logistic costs
  - different farm types (e.g. specialised, smaller scale)

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Nitrogen response and other management options

- Nitrogen response function

$$Y_m(N) = m(1 - ke^{-bN}) \quad (2)$$

$$Y_q(N) = a + bN + cN^2 \quad (3)$$

- Adaptation practices
  - Fungicide treatment for barley
  - Liming for all selected parcels

$$Y(A(p,t,c^i) = \begin{cases} Y_{MEAN}(p,c^i)Y_{RED}(p,t,c^i)(1+LF(p,t)+F(p,t,c^i)-D(p,t,c^i)) & if \quad i = barley \\ Y_{MEAN}(p,c^i)Y_{RED}(p,t,c^i)(1+LF(p,t)) & if \quad i = otherthan \quad barley \end{cases} \quad (4)$$

$$LF(p,t) = \alpha_{lc}(SPH(p,t) + L(pH\_incr)) \quad (5)$$

$$F(p,t,c^i) = \sum_{j=1}^{\gamma} \beta_j K_j(p,t,c^i) \quad (6)$$

$$D(p,t,c^i) = \sum_{j}^{\gamma} K_j(p,t,c^i) \quad (7)$$

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Disease pressure scenario settings

High and low yield penalty matrix figures due to monoculture are obtained from expert judgement (MTT crop experts views based on long-term field trial experiments, consulted in various projects)

Crops	S.Wheat	W. Wheat	Barley	Oats	Oilseed	Set-aside	NMF
Spring wheat	0.99 (0.97)	0.99 (0.97)	0.99 (0.97)	0.995 (0.975)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)
Winter wheat	0.99 (0.97)	0.99 (0.97)	0.99 (0.97)	0.995 (0.975)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)
Barley	0.99 (0.97)	0.99 (0.97)	0.99 (0.97)	0.995 (0.975)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)
Oats	0.995 (0.975)	0.995 (0.975)	0.995 (0.975)	0.99 (0.97)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)
Oilseed	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	0.75 (0.65)	1.00 (1.00)	1.00 (1.00)
Set-aside	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)
NMF	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)	1.00 (1.00)

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Farm level results, cereals farm south-west Finland

Simulated average yields, profit , pH value and times of fungicide usage over the next 30 years under chosen scenario settings for crop prices and disease pressure

		S1	S2	S3	S4	S5	S6
Average Yields	Spring wheat [3557]	3842 (+8.0 %)	3740 (+5.1%)	3750 (+5.4%)	3604 (+1.3%)	3557 (+0.0%)	3545 (-0.3%)
	Winter wheat [3794]	-	-	-	-	-	-
	Barley [3550]	3513 (-1.0%)	3610 (+1.7%)	3927 (+10.6%)	3217 (-9.4%)	3300 (-7.0%)	3624 (+2.1%)
	Oats [3574]	-	3811 (+6.6%)	3812 (+6.6%)	3557 (-0.5%)	3529 (-1.3%)	3501 (-2.0%)
	Oilseed [1400]	1503 (+7.4%)	1510 (+7.9%)	1516 (+8.0%)	1397 (-0.2%)	1505 (+7.5%)	1513 (+8.1%)
Annual average gross margin per ha, eur		201	263	342	183	242	306
Share of fungicide treated barley		0%	14%	100%	0	0	100%
Average pH		6.44	6.57	6.69	6.07	6.62	6.66

S1: Low- disease-pressure with Low-price exp.
S2: Low-disease-pressure with Current-price exp.
S3: Low-disease-pressure with high-price exp.
S4: High-disease-pressure with Low-price exp.
S5: High-disease-pressure withCurrent-price exp.
S6: High-disease-pressure with High-price exp.

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Farm level crop yield development highly responsive on expected prices in North Savo region (only the case of low disease pressure simulated)

(LP=Low Price; MP=Median Price; HP=High Price)

		Specialized cereals farm			Other crop farm		
		LP	MP	HP	LP	MP	HP
Average Yields	Spring wheat [3068]	2670 (-14.5%)	3190 (3.8%)	3364 (8.8%)	-	-	-
	Winter wheat [3066]	-	-	-	-	-	-
	Barley [3000]	2555 (-17.4%)	2958 (-1.6%)	3203 (7.9%)	2704 (-9.9%)	2942 (-1.9%)	3207 (6.9%)
	Oats [2786]	2469 (-12.9%)	2898 (3.9%)	3034 (8.2%)	2538 (-8.9%)	2855 (2.5%)	3036 (9.0%)
	Hay [3615]	3191 (-13.3%)	3795 (4.7%)	3963 (8.8%)	3138 (-13.2%)	3634 (0.5%)	3886 (7.5%)
	Oilseed [1305]	1106 (-18%)	1368 (4.6%)	1452 (10%)	-	-	-
Share of fungicide treated barley		0	0	116	0	0	97
Average pH		5.59	6.50	6.63	5.59	6.28	6.61

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Multi-regional development paths for Finnish agriculture until 2050 (from Dremfia)

- Demand, supply and prices
  - Milk (18 processed dairy products), beef, pigmeat, poultry meat, eggs
  - Cereals (barley, malting barley, oats, spring wheat, winter wheat, rye, mixedgrain, oilseeds, food potato, starch potato, sugarbeet)
  - Grass (silage (2 intensity levels), dry hay, semi-permanent grassland (>5year old)
  - Endogenous animal feeding (roughage, grain based feeds, protein feeds, industrially processed feedstuffs)
  - Open set-aside, green set-aside
- Demand
  - Demand of each commodity is largely given based on trends or current demand
  - A limited scope for changes in given for the total demand (rather inelastic food demand observed in Finland, as in many developed countries)
  - Population is exogenous (Statistics Finland)
- EU-price level drives the model: www.agri-outlook.org
  - Endogenous wedge between domestic and EU prices due to logistic costs

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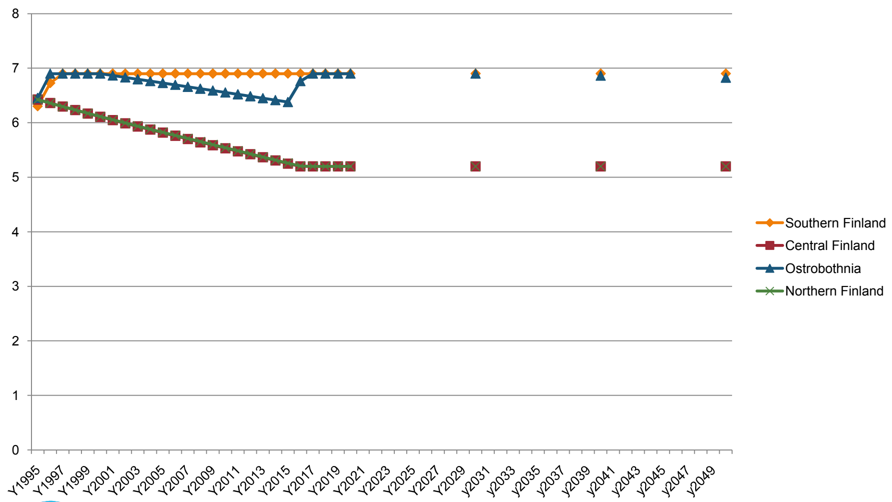
Soil pH development in the Dremfia sector model after adjusting to low/medium disease pressure – moderate price expectations



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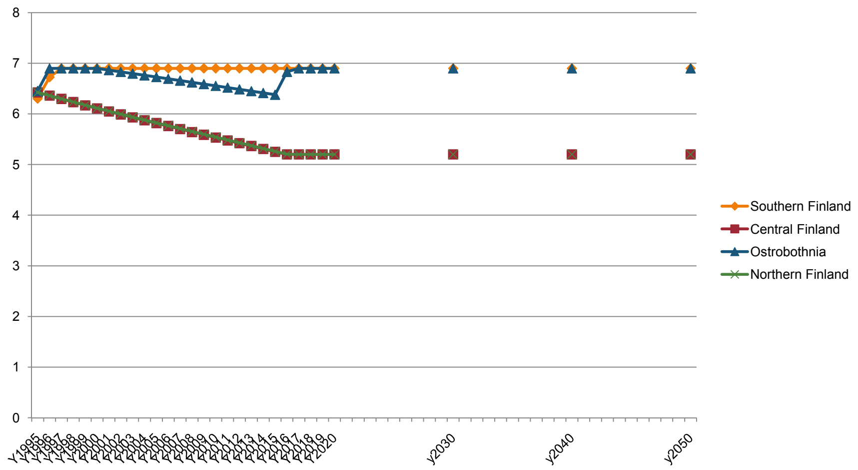
Soil pH in the Dremfia sector model after adjusting to low/medium disease pressure – high price expectations (+20%)



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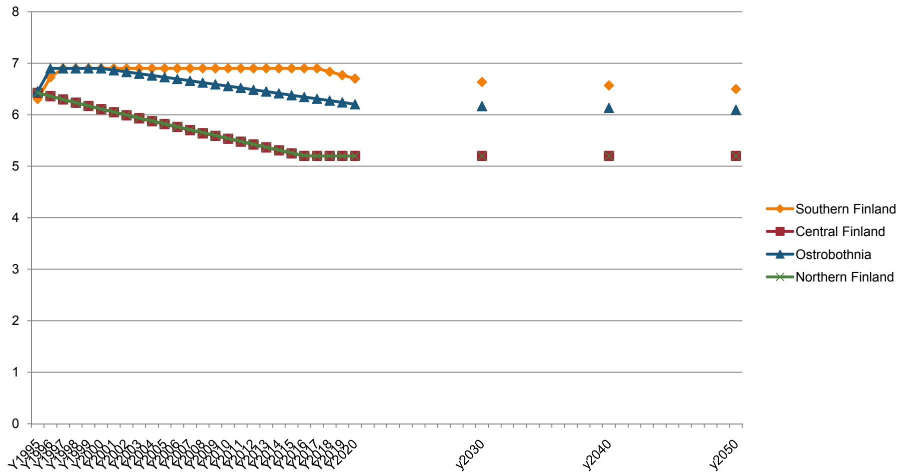
Soil pH in the Dremfia sector model after adjusting to low/medium disease pressure – low price expectations (-20%)



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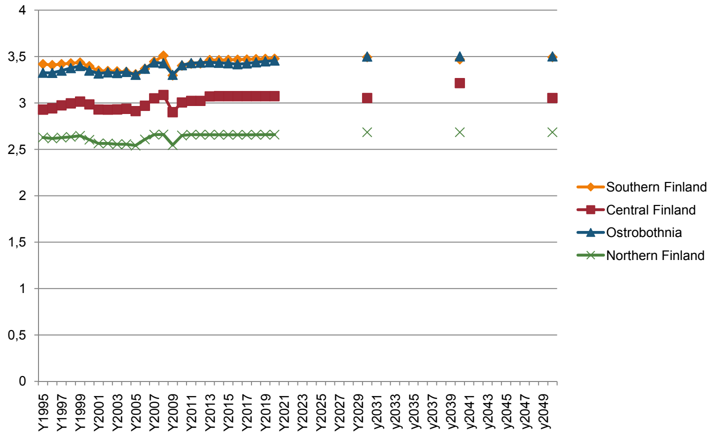
Yield development (barley, tons/ha) in the Dremfia sector model after adjusting to low/medium disease pressure – moderate price expectations



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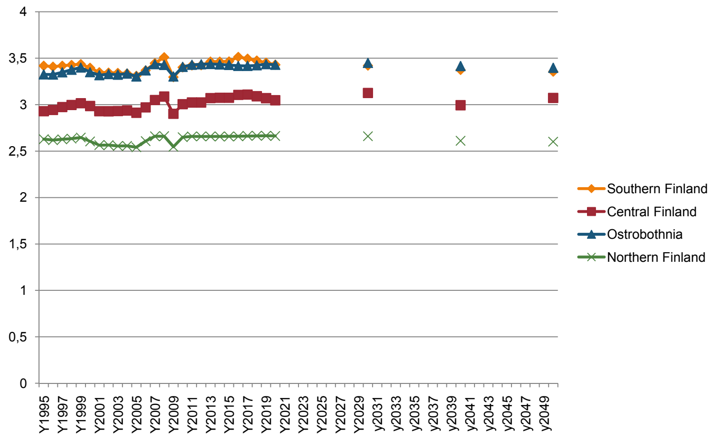

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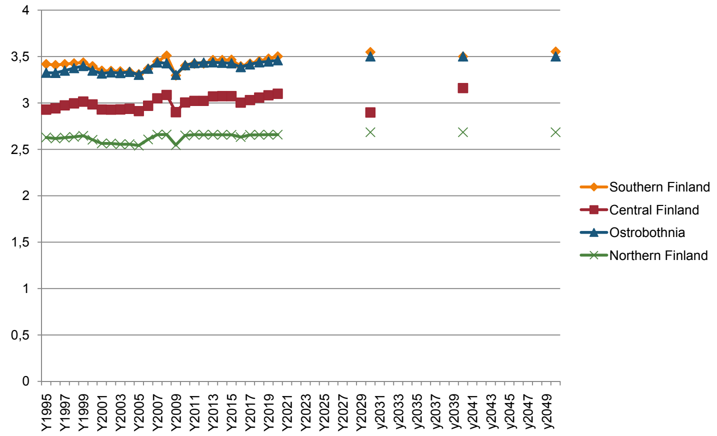

How to ensure consistent links between farm and sector level models?

- Any bottom-up based approach (even based on a well-founded bio-physical models and results) from field and farm level to sector level does not guarantee consistent model behavior and economic analysis at the sector level
  - Optimisation models should produce in-point solutions, and show smooth supply response, rather than jumps between corner solutions
  - Farm level analysis results need to be carried over to representative farms of the existing well-behaved sector models

How to carry farm level adjustments to the sector level?

- Direct incorporation of farm level production/cost functions and choice sets leads to increasing number of dimensions
  - Sector models tend to be large and complex already
  - However, some direct incorporation is possible and works (e.g. liming)
- Short-cuts / simplifications needed
  - Economic farm level dynamic crop rotation models can show net benefits of certain types of crop rotations => certain relative shares of land allocated to specific crops
  - Joint crop activities explicitly require the simultaneous cultivation of all the specified crops under certain range of cropping shares, as a condition for the derived productivity changes (following McCarl 1982)
  - joint-crop activities, could be included into a sector model yielding economic equilibria for 10-year periods such as 2030, 2040 and 2050
  - However, adding too few choice sets is problematic as well

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Key market and policy issues identified

- Prices
  - Input prices
    - Value of agricultural inputs currently 1.5 times higher than the value of agricultural output produced
    - Energy and fertilisation taxes of various kinds affects agriculture
    - Price of labour, construction costs (affected by public regulations)
  - Output prices
    - Milk and meat prices with respect to crop and feed prices
- Agricultural policies
  - Production linked national payments important
  - Area based subsidies and entitlement conditions
    - Changes may imply big changes on land markets
  - Fertilisation limits, nutrient leaching abatement policies
    - From restrictive / passive policies to encouraging schemes?

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Conclusion

- Dynamic land use per field parcel + fertilisation, fungicide use and soil improvements (e.g. liming), can be combined into a same model
  - Simplifications and compromises necessary in sector level modelling
- Does sector level optimisation (competitive markets) drive regional level management and medium/long-term adaptations?
  - Key management choices simulated tend to increase regional differences in productivity => increased specialisation
- Sector level analysis shows less adaptation than farm level
  - Competition for land, limited demand
- Significant data work required for tailoring farm level options at the sector level, BUT a promising avenue for integrated, multidisciplinary adaptation research (team work)

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