Profitability of soil renovation at cereals farms in south-west Finland

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LUONNONVARAKESKUS

Introduction

- Increasing the resource use efficiency of agricultural production is considered as a central element in Sustainable Intensification (SI) of agriculture, which is a promising strategy to satisfy increasing demand for food while reducing negative impacts on farm economy and environment
  - More from less, better utilisation of inputs
- Challenge: Degradation of agricultural soils and resulting crop yield losses are affecting negatively farmers' incomes and environment
  - Soil compaction is a common problem in Finland; often some individual land parcels are compacted
- This study analyses economic profitability of soil renovation investments aimed for tackling soil compaction in a regional context of south-west Finland
  - Is it economically profitable to invest in soil renovation, in reversing soil compaction?

Some results on the profitability of soil renovation in the context of Finland are reported already

- Profitability of sub-surface drainage and soil structure renovation at average North Savo cereals farms
  - Results presented in OPAL mid-term seminar February 5 2018
  - Main results, with some discussion are published in Maaseudun Tulevaisuus 26.2.2018 https://www.maaseuduntulevaisuus.fi/maatalous/artikkeli-1.225798
- This study: Purola, T. & Lehtonen. H. 2020. Evaluating profitability of soil-renovation investments under crop rotation constraints in Finland, to appear in ***Agricultural Systems***
- Some Masters' Thesis:
  - Lappi, P. 2018. Maanparannusinvestointien kannattavuus (Economy of soil structure investments. Masters' Thesis. Univ. of Helsinki / Agricultural Economics https://helda.helsinki.fi/handle/10138/234375
  - Joensuu, M. Salaojituksen kannattavuus – tapaustutkimus peltolohkojen uusinta- ja täydennysojituksesta https://helda.helsinki.fi/handle/10138/306177
- All these are produced in OPAL-Life –project https://www.opal.fi/

Case: Soil structure renovation, farm level impacts
Assume a compacted soil with 30% reduced yield level

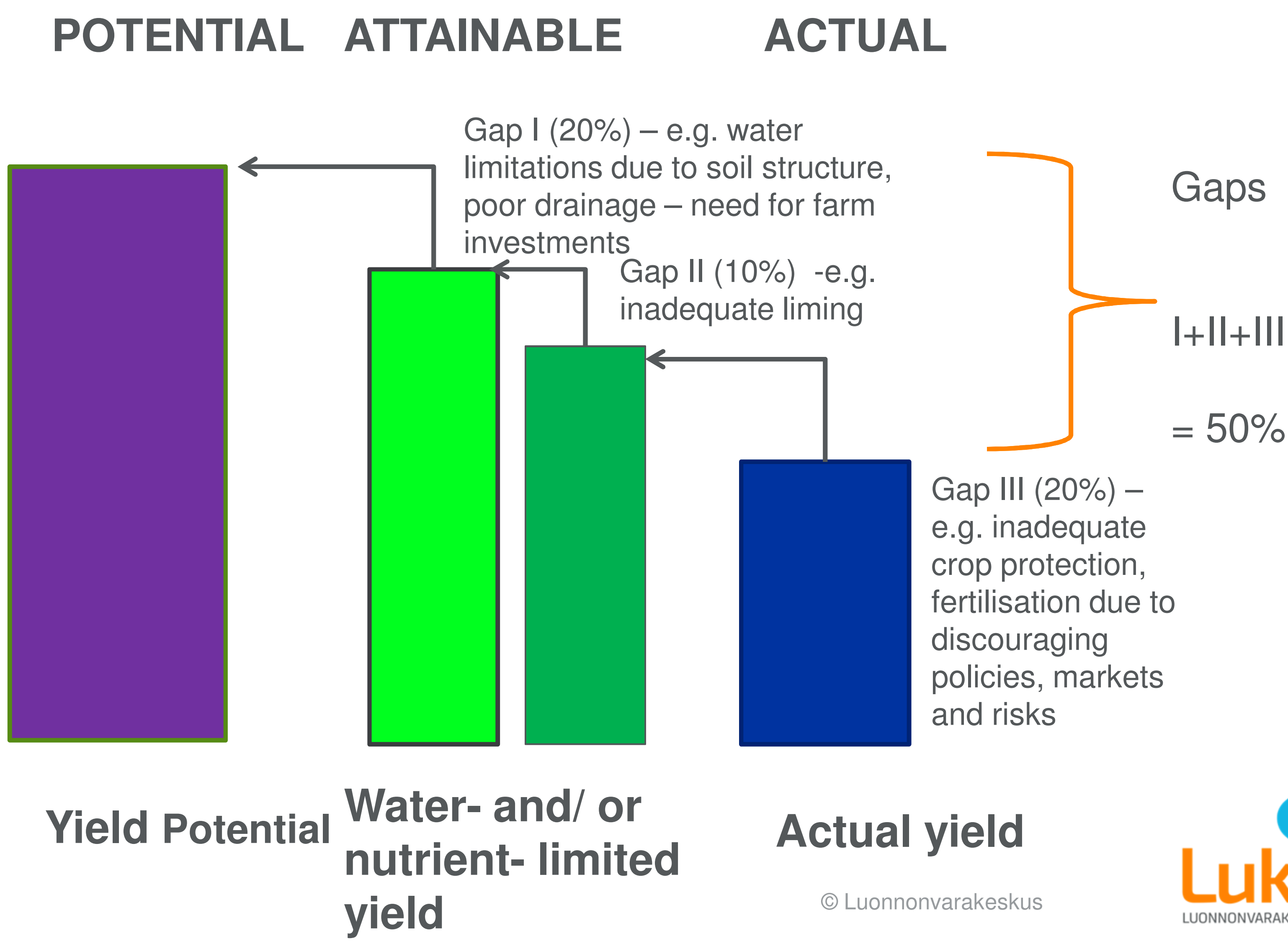
- Year 1: Mechanical sub-soil loosening (”Jankkurointi”) 80 eur/ha + wooden fibres (200 eur/ha) + green manure
- Year 2: Green manure
- Year 3: Green manure
- Years 4-30: Average yields
  - yield level stays at average level if green set aside (grass) or oilseeds are cultivated 3/10 years, at every decade, at the renovated field parcel

No market revenues from green manure during years 1-3 when the farmer receives a subsidy of 365 €/ha (subsidy for set-aside 290+75 €/ha for green manuring) for these parcels. We assume that these practices increase yields back to the same average level as in the other parcels already after 3 years
Assume other field parcels are not prone for soil compaction

Methods: DEMCROP dynamic optimisation based crop rotation model

- We utilise a dynamic economic model of farm management and crop rotation (DEMCROP), applied earlier by Lehtonen et al. (2016, 2014) and Liu et al. (2016), and most recently in Purola et al. (2018)
  - Purola, T., Lehtonen, H., Liu, X., Tao, F. & Palosuo, T. 2018. Production of cereals in northern marginal areas: An integrated assessment of climate change impacts at the farm level. Agricultural Systems 162: 191-204. DOI:10.1016/j.agsy.2018.01.018
- The model comprises farm level dynamic optimisation over a 30-year time span: accommodate
  - (1) the dynamics of soil pH and liming;
  - (2) crop rotation choices with pre-crop effects on yields;
  - (3) the effects of nitrogen fertilisation and fungicide use on crops
- The farm is split into 10 equally sized (5 ha) and shaped field parcels. The distance from parcels to the farm centre varies between 0–7 km, averaging 3 km. 9 field parcels are assumed to be of a mineral soil type, which is the dominant soil type in the region, and 1 of organic soil type

Yield gaps and their drivers



Model structure: Maximise (mean-variance) utility function of a farm cultivating M crops at 10 field parcels over 30 years

See Purola et al. 2018 or Purola & Lehtonen 2020 (forthcoming) for details

$$Max \sum_{t=1}^{30} \sum_{p}^{10} \sum_{i=1}^{M} \frac{1}{(1+r)^t} \left(Y\big(A(p,t,i), p,t,i\big) A(p,t,i) P(i) + S(i) - C(p,t,i) \right)$$

$$- \theta \sum_{t-1}^{H} \sum_{c} \sum_{c2} \frac{1}{(1+r)^t} A' X A$$

Subject to

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

DEMCROP model keeps track of the cultivation history of each field parcel: a yield loss of 5% for cereals if the same cereal as the previous year is cultivated

A(p,t,i) is area allocation for crop *i* on time (year) *t* at field parcel *p*. *Y*(·) is crop yield level, dependent on nitrogen fertilisation level (which, in turn, depends on expected crop and fertiliser prices), past area allocations on field parcel *p* (there are yield losses due to monocultural cultivation). *P(i)* is expected average market price of crop *i*, *S(i)* is subsidy paid per hectare, and *C(·)* is cost per hectare, incl. logistic costs. *X* is covariance matrix of crop specific gross margins calculated based on crop yields and prices of inputs and outputs during 2000–2014

Average input data consisting of crop yields, variable costs and subsidies used in the model

Crop	Average yield kg/ha	Variable cost €/ha	Subsidy €/ha	Price €/ton
Spring wheat	3720	580	650	148
Winter wheat	3896	610	682	148
Feed barley	3814	527	563	128
Malting barley	3815	589	635	153
Oats	3807	510	563	123
Oilseed rape	1734	587	705	285
Set-aside	-	234	390	
NMF[a]	-	244	554	

a) Nature management field, restricted to 15% of the area of the farm, the total area of set-aside and NMF cannot exceed 25%

Model validation for Varsinais-Suomi region

- We checked input and output prices as well farm subsidy information over the simulated model validation period 2000–2014
- After that we simulated our DEMCROP model with the selected risk-aversion parameter (low valued for good reasons; part-time farming, high value of farmland)
- The model outcomes show that crop yields, soil pH, use of nitrogen and fungicides correspond to regional average levels

Land use shares of different crops at each parcel (1–10, with distances 0-5 km), and on average on the whole farm over 30 years, in the base scenario (no soil compaction) assuming average 2000–2014 prices

SWheat = spring wheat; WWheat=winter wheat; FBarley=feed barley; Mbarley=malting barley; Oilseed=oilseed rape; NMF=nature management field (set-aside); Setaside=Other set-aside, not eligible for NMF payments from agri-environmental scheme

	SWheat	WWheat	FBarley	MBarley	Oats	Oilseed	Setaside	NMF
Parcel 1	27%	0%	0%	47%	7%	18%	0%	2%
Parcel 2	30%	0%	0%	47%	3%	20%	0%	0%
Parcel 3	20%	0%	0%	50%	13%	17%	0%	0%
Parcel 4	22%	0%	0%	47%	10%	18%	0%	3%
Parcel 5	20%	0%	0%	47%	8%	17%	0%	8%
Parcel 6	43%	7%	0%	0%	37%	13%	0%	0%
Parcel 7	5%	0%	0%	45%	20%	13%	0%	17%
Parcel 8	15%	0%	0%	27%	20%	12%	0%	27%
Parcel 9	12%	0%	0%	20%	23%	8%	0%	37%
Parcel 10	5%	0%	22%	0%	27%	5%	0%	42%
Farm level average	19.8%	0.7%	2.2%	32.8%	16.9%	14.2%	0.0%	13.5%

Results of the validated model in a case without soil compaction (farm size 100 ha)

Discount rate = 6%

	Low prices	Base prices	High prices
NPV (€) of objective function over 30 years	32 472	44 453	58 740
NPV (€) of risk over 30 years (% of objective)	5.20€ (0.016%)	5.50 (0.012%)	6.00 (0.010%)
Certainty-equivalent gross margin, €/ha	108	148	196
Average pH	5.68	6.10	6.43
Average GHG emissions tons CO2 equiv/ha	3.13	3.34	3.63
Total production, GJ/ha	27 977	33 335	38 930
GHG emissions tons CO2 / GJ	0.112	0.100	0.093
Fungicide treatment frequency	0%	58%	100%
Average yields (kg/ha)			
Spring wheat	3007 (-13.9%)	3492 (3720)	3832(+9.7%)
Winter wheat	NA	3733 (3986)	4305 (+15.3%)
Feed barley	3610 (-1.9%)	3681 (3814)	NA
Malting barley	3228(-13.1%)	3715 (3815)	3901 (+5.0%)
Oats	3439 (-5.5%)	3640 (3807)	3852 (+5.8%)
Oilseed rape	1302 (-19.5%)	1616 (1734)	1759 (+8.8%)

Management scenarios and cases for sensitivity analysis

- **Compacted Parcels (CP) scenario** with 30% crop yield reduction on 2 out of 10 field parcels; **parcels 3 and 7; accept, do nothing**
- **Renovation Scenario (RS):** soil compaction and yield reduction is avoided after a 3-year investment in sub-soil loosening and green manure treatment; **invest in renovating parcels 3 and 7**
    - first 3 years under green manure set-aside imply no market revenues from parcels 3 and 7, and after that, 3 out of 10 years must be allocated to oilseeds or set-aside in field parcels 3 and 7, every decade, to avoid re-compaction
- Average crop prices in Finland 2000–2014 as baseline prices (BP); Prices +20 % (HP); Prices -20 % (LP)
- **Sensitivity analysis: A**ssuming also 10% and 20% crop yield reduction at average crop prices, over a 30-year time span
    - Assuming different **discount rates 0-10%**

Soil management scenario	Price scenario		
	Baseline -20%	Baseline	Baseline +20%
Compacted parcels (CP)	CP -20%	CP BP	CP +20%
Renovation (RS)	RS -20%	RS BP	RS +20%

Parcel specific land allocation (average over 30 years) in the compacted parcels (3 and 7) scenario (CP) and in the renovated soil scenario (RS) with base prices

	SWheat		WWheat		FBarley		MBarley		Oats		Oilseed		Setaside		NMF	
	CP	RS	CP	RS	CP	RS	CP	RS	CP	RS	CP	RS	CP	RS	CP	RS
PARCEL 1	27%	23%	0%	0%	0%	0%	47%	47%	7%	10%	20%	20%	0%	0%	0%	0%
PARCEL 2	27%	23%	0%	0%	0%	0%	47%	47%	7%	3%	20%	27%	0%	0%	0%	0%
PARCEL 3	**38%**	**13%**	**0%**	**0%**	**0%**	**0%**	**0%**	**43%**	**2%**	**5%**	**13%**	**17%**	**0%**	**10%**	**47%**	**12%**
PARCEL 4	20%	20%	0%	0%	0%	0%	47%	47%	13%	8%	20%	22%	0%	0%	0%	3%
PARCEL 5	17%	17%	0%	0%	0%	0%	50%	47%	17%	13%	17%	13%	0%	0%	0%	10%
PARCEL 6	53%	47%	0%	3%	0%	0%	0%	0%	33%	40%	13%	10%	0%	0%	0%	0%
PARCEL 7	17%	13%	0%	0%	0%	0%	0%	30%	7%	15%	2%	13%	0%	10%	75%	18%
PARCEL 8	21%	13%	0%	0%	0%	0%	31%	30%	27%	20%	17%	17%	0%	0%	5%	20%
PARCEL 9	17%	10%	0%	0%	2%	7%	25%	20%	35%	23%	13%	13%	0%	0%	8%	27%
PARCEL 10	15%	0%	0%	0%	17%	25%	0%	3%	40%	25%	13%	7%	0%	0%	15%	40%
AVG.	25.1%	18.0%	0.0%	0.3%	1.8%	3.2%	24.6%	31.3%	18.7%	16.3%	14.8%	15.8%	0.0%	2.0%	15.0%	13.0%

Results on soil renovation investment

Average 2000-2014 crop prices; CP=Compacted soil; RS=Renovated soil

Average crop prices	CP	RS	Difference
Value (€) of objective function over 30 years, per 10 ha	41 460	42 561	2.7%
Average CE gross margin €/ha/year	138	142	2.7%
Average pH	6.10	6.03	-1.2%
Average pH, parcel 3	5.73	5.70	-0.4%
Average pH, parcel 7	5.77	5.71	-1.0%
Average GHG emissions tons CO2 eq/ha	3.32	3.31	-0.4%
Total production, GJ/ha	31 301	32 226	3.0%
GHG emissions tons CO2 / GJ	0.106	0.103	-3.3%
Average yields, kg/ha			
Spring wheat	3214	3478	8.2%
Winter wheat	NA	4099	NA
Feed barley	3596	3673	2.1%
Malting barley	3703	3682	-0.6%
Oats	3515	3608	2.7%
Oilseed rape	1557	1602	2.9%
Percentage of fungicide treatment area (*SW, WW, FB, MB)	44%	51%	

Results on soil renovation investment

Prices +20%; CP=Compacted soil; RS=Renovated soil

High crop prices	CP	RS	Difference
Value (€) of objective function over 30 years, per 10 ha	54 098	56 590	4.6%
Average CE gross margin €/ha/year	180	189	4.6%
Average pH	6.28	6.42	2.3%
Average pH, parcel 3	5.71	6.46	13.1%
Average pH, parcel 7	5.75	6.46	12.2%
Average GHG emissions tons CO2 eq/ha	3.52	3.59	1.9%
Total production, GJ/ha	34 554	38 123	10.5%
GHG emissions tons CO2/GJ	0.102	0.094	-7.7%
Average yields, kg/ha			
Spring wheat	3454	3868	12.0%
Winter wheat	4177	4133	-1.1%
Feed barley	NA	NA	NA
Malting barley	3874	3912	1.0%
Oats	3741	3845	2.8%
Oilseed rape	1689	1782	5.5%
Percentage of fungicide treatment area (*SW, WW, FB, MB)	89%	100%	

Net present value (NPV) and payback time (years) of soil renovation investment at different future crop prices. BP = 2000-2014 prices

CP=Compacted soil; RS=Renovated soil; interest rate 6%

	NPV (€) for 30 years		**Difference (€) RS/CP**	**Difference, €/ renovated parcel/ year**	**Payback time, years**
Price scenario	CP	RS			
-20%	30 451 (-26.6%)	31 233 (-26.6%)	782 (2.6%)	13	11
BP	41 465	42 566	1 102 (2.7%)	18	8
+20%	54 103 (30.5%)	56 596 (33.0%)	2 492 (4.6%)	42	11

NPV of future certainty-equivalent income (€) in the renovation scenario (RS) and the compacted parcels (CP) scenario assuming -10%, -20% and -30% crop yield reduction, the difference between scenarios and per renovated field parcel, also calculated per year, and per renovated field parcel per year, and the payback time of the investment (years). Baseline prices 2000–2014 are assumed. Discount rate = 6%.

	NPV (€) for 30 years		Difference (€) RS/CP	Difference, €/ renovated parcel/ year	Payback time, years
Assumed crop yield loss at compacted parcels	CP	RS			
-10%	42 797	42 566	-231 (-0.5%)	-4	>30
-20%	42 007	42 566	560 (1.3%)	9	13
-30%	41 465	42 566	1 102 (2.7%)	18	8

Net present values of certainty equivalent gross margins calculated in the case of compacted parcels (CP) and renovation (RS) scenarios with different discount rates

Discount rate	Payback time, years	CP Avg. pH	RS Avg. pH	CP NPV €	RS NPV €	Difference in NPV	Difference
0%	10	6.48	6.66	92 862	98 406	5 544	6.0%
1%	10	6.44	6.62	79 267	83 998	4 731	6.0%
2%	10	6.41	6.56	68 421	72 051	3 630	5.3%
3%	12	6.36	6.51	59 708	62 529	2 820	4.7%
4%	10	6.31	6.38	52 438	54 641	2 203	4.2%
5%	11	6.25	6.31	46 480	48 218	1 738	3.7%
6%	8	6.10	6.03	41 465	42 566	1 102	2.7%
7%	10	5.90	5.85	37 150	38 177	1 027	2.8%
8%	11	5.68	5.68	33 494	34 423	929	2.8%
9%	12	5.68	5.68	30 779	31 449	670	2.2%
10%	14	5.66	5.66	28 422	28 888	466	1.6%

Discussion

- Soil renovation increases production of higher valued crops, but the utilization of the whole production potential of a farm is dependent on crop prices
  - We found that the full increased production potential may not be utilized after the renovation investment if not utilized already without the investment; incentives for set aside
  - Effects on production volumes may be smaller than expected; this depends on future prices
  - Soil renovation my decrease logistic costs of a farm
- It is important to account for needed restrictions on crop rotation to avoid soil compaction after the renovation investment
- Nevertheless the field parcel-specific restrictions to avoid soil compaction after the renovation are important to be accounted for in evaluating the profitability of soil renovation at the farm level, since avoiding soil compaction is one part of more sustainable production strategy

Conclusions

- Our results show profitable soil-renovation investments for compacted soil as they produce a positive net present value assuming 2000–2014 average crop prices, at all discount rates 0-10% when 30% yield decrease due to soil compaction is assumed
- The payback times are appr. 8–11 years, depending on the discount rate, largely independent on crop prices
- Higher than average future crop prices would increase the value of soil renovation investment significantly while lower prices would have a relatively smaller effect on the profitability
- One may recommend soil-renovation investments as a profitable long-term investment in a typical case, but one cannot recommend the soil renovation if no significant yield gains are possible, or if only low valued crop are to be produced
- Long payback times imply that policy incentives (not only subsidies for green manure) may be needed to realise other possible benefits (e.g. reduced nutrient leaching)

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