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Sustainable Bioenergy
Solutions for Tomorrow

BEST WP4 TASK 4.2

Assessing and solving sustainability issues of agribiomass chains: final results of sustainability assessment

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Environmental sustainability framework for agribiomass chains

- In the task 4.2, a framework for ecological sustainability of agribiomass based bioenergy production has been created based on a literature review and the discussions at the 1st WP4 workshop held on 18.11. 2013

- The framework was tested with two raw materials: cereal straw (for combustion) and turnip rape (for biodiesel)

Environmental impacts of agribiomass production

Challenge	Causes	Solutions	Indicators
Climate change	Fertilization, liming, energy use, cultivation of peatlands	Optimal fertilization, good yield level	Greenhouse gas emissions
Eutrophication	N & P fertilization, volatilisation of ammonia from manure	Optimal fertilization, practices following manure spreading	N & P balance
Land use/soil quality: erosion	Soil tilling, absence of vegetation cover in winter, field slope steepness, soil texture	Reduced tilling, wintertime vegetation cover or stubble specially on land with high erosion risk	Erosion
L/s: loss of organic matter	Removal of plant residues, exclusive use of mineral fertilizers	No removal of plant residues, use of organic fertilizers	Organic matter decline, annual C input
L/s: compaction	Use of heavy machinery in wet conditios	Optimal field operation times	Compaction risk
Ecotoxicity	Use of plant-protection products	IPM	Ecotoxicity
Biodiversity	Monoculture, use of plant-protection products, land use change, invasive species	Crop rotation, IPM, no clearance of new fields	Change of total field are during the last 20 years, Indicators for the biodiversity of agri-environments (population trends of farmland breeding birds, butterflies and arable weeds)
Use of non-renewable natural resuorces	Machinery, drying of cereals	Use of renewable energy, organic fertilizers	Share of renewable energy (%), share of organic fertilizers (%), P balance
Water use and quality	Irrigation, eutrophicating and acidificating emissions	No cultivation in arid areas, optimal fertilization, energy efficiency	Use of irrigation water, freshwater availability
Low efficiency of farming	Unsuitable weather conditions, low soil fertility, choice of plant species and cultivar	Long-term soil fertility maintenance, choice of suitable plant species and cultivars, plant breeding	Yield level, land area use

Environmental sustainability framework for agribiomass chains: units and improvement options

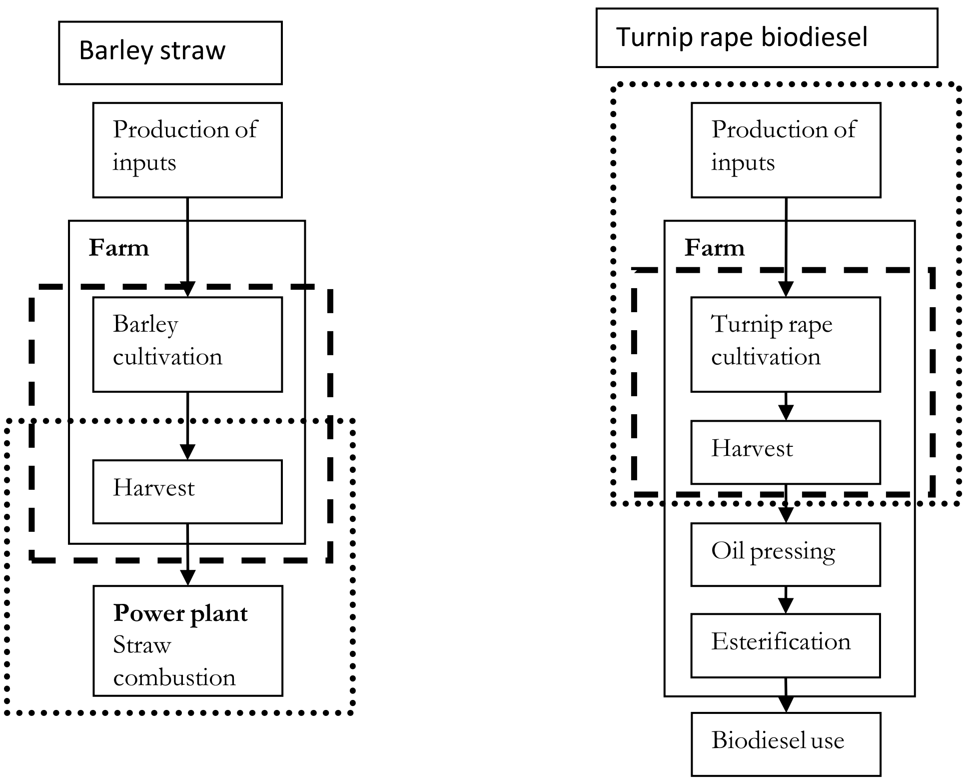
Challenge	Indicator(s)	Unit	Quantitatively assessed improvement options	Impacts allocated to residue biomasses
Climate change	GHG-emissions	g CO_2-eq./MJ	optimal yield	Yes, excluding cultivation phase
Eutrophication	N balance	kg N /MJ	otimal yield	Yes
	P balance	kg P /MJ	otimal yield	Yes
Soil erosion	Erosion	kg eroded soil /MJ	optimal yield, spring ploughing, direct seeding	No
Soil organic matter decline	Change in soil organic carbon level	kg C loss/MJ	optimal yield, cover crops	No
	Annual soil C input	kg C input/MJ	optimal yield, cover crops	Yes
Compaction	Compaction risk	-	-	-
Ecotoxicity	Ecotoxicity	-	-	-
Biodiversity	Share of new field area	change of total field area during the last 20 years, %	-	Yes
	Agri-environment biodiversity indicators (birds, butterflies, arable weeds)	-	-	-
Use of non-renewable natural resources	Share of renewable energy	%	-	Yes
	share of organic fertilizers	%	-	Yes
	P balance	kg P /MJ	optimal yield	Yes
Water use	Use and availability of irrigation water	-	-	-
Low efficiency of farming	Land area use	ha/MJ	optimal yield	No

System description and functional unit

- The assessment restricted to include only the cultivation phase and transportation to power plant, because main purpose of the study was to concentrate to the cultivation phase
    - However, in case of GHG emissions, also transportation of straw to power plant and straw combustion was included
- All effects from the cultivation of barley (except those caused by the removal of residues itself) are allocated to the grain yield, because straw is a residue from cereal cultivation
- The functional unit was MJ energy

System description

- Simplified illustration of the selected bionergy chains
  - Narrow broken line: system boundaries of GWP assessment,
  - Thick broken line: system boundary of other impacts



Reference situtation

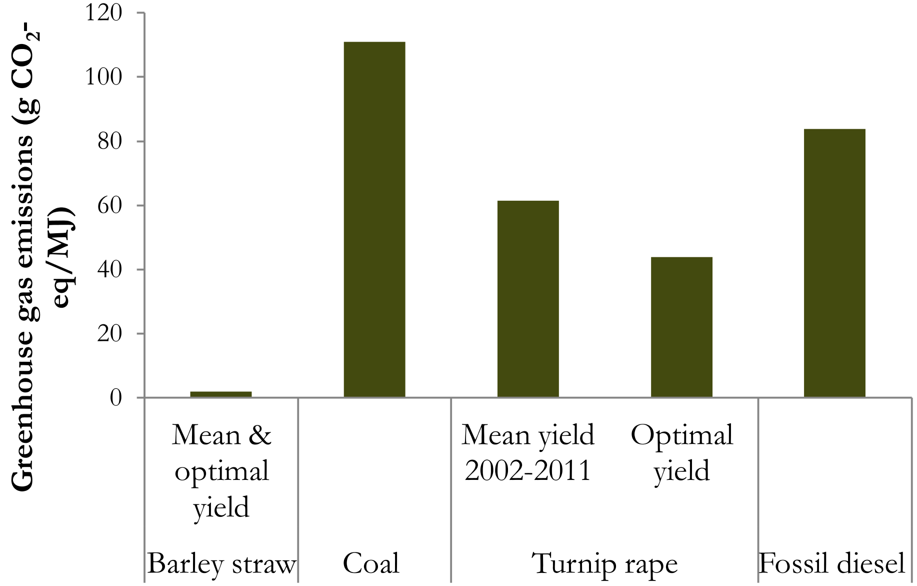
- To determine the sustainability of the production of the selected biofuels, they were compared with a reference situation
- In the case of the indicator greenhouse gas emissions, the reference was a comparable fossil fuel:
  - Barley straw: coal
  - Turnip rape biodiesel: fossil diesel
  - Comparison is done based on the results per energy yield (MJ)
- Related to the other numeric indicators, fossil fuels don't have similar kind of environmental effects as the selected biofuels
- Therefore, the reference situation was identified as a situation in which bioenergy is not produced, namely barley production without straw removal
  - Comparison is done based on the results per land area (ha)
- In the case of the biodiversity indicator, change of total field area during the last 20 years, the reference is the situation 20 years ago

Data used: Yield levels and fertilization

- Field parcel specific data from Pro Agria Advisory Centres
  - Mean yield (time period 2002-2011)
    - » barley straw 2575 ± 767 kg/ha
    - » turnip rape 1347 ± 456 kg/ha
  - Fertilizer (N & P) use
- Optimal yields calculated from the results of official variety trials performed in the years 2006-2013 (Laine et al. 2014)
  - barley straw 4236 ± 300 kg/ha
  - turnip rape 1926 ± 60 kg/ha

Climate change: greenhouse gas emissions

- Assessed according to Life Cycle Assessment (LCA) methodology
- Emissions taken into account, and their characterization factors were according to EU Directive (2009/28/EC):
  - CO_2 = 1
  - CH_4 = 23
  - N_2O = 296



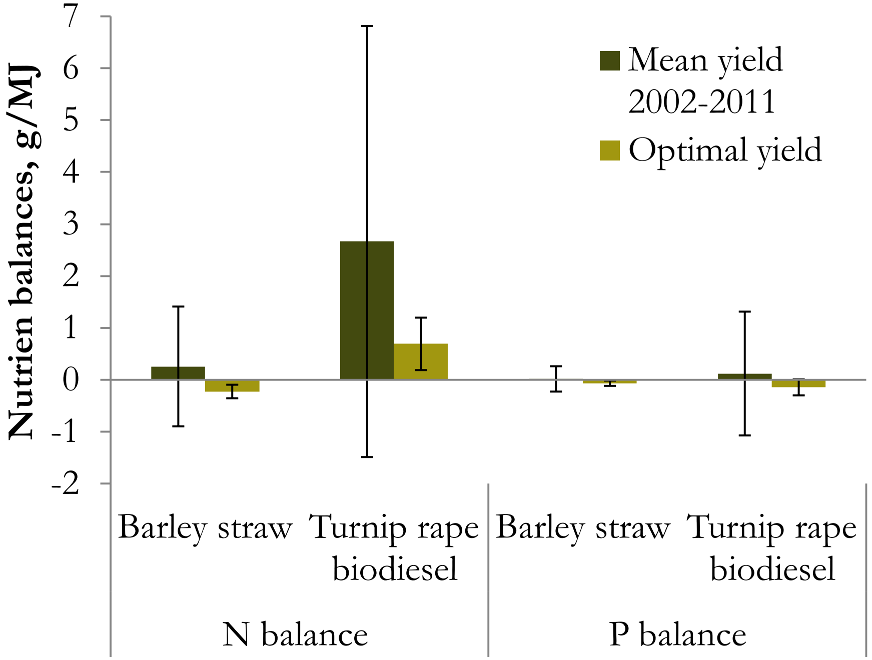
- All emissions from barley cultivation are allocated to the grain yield
- Emissions from collection and transportation is dependent on load and distance, so hectare yield does not affect to the results of barley straw

Eutrophication: N & P balance

- Calculated with the formula:

Nutrient balance (kg/ha)= Input to field (in fertilizers) – removal in yield (grains, straw)

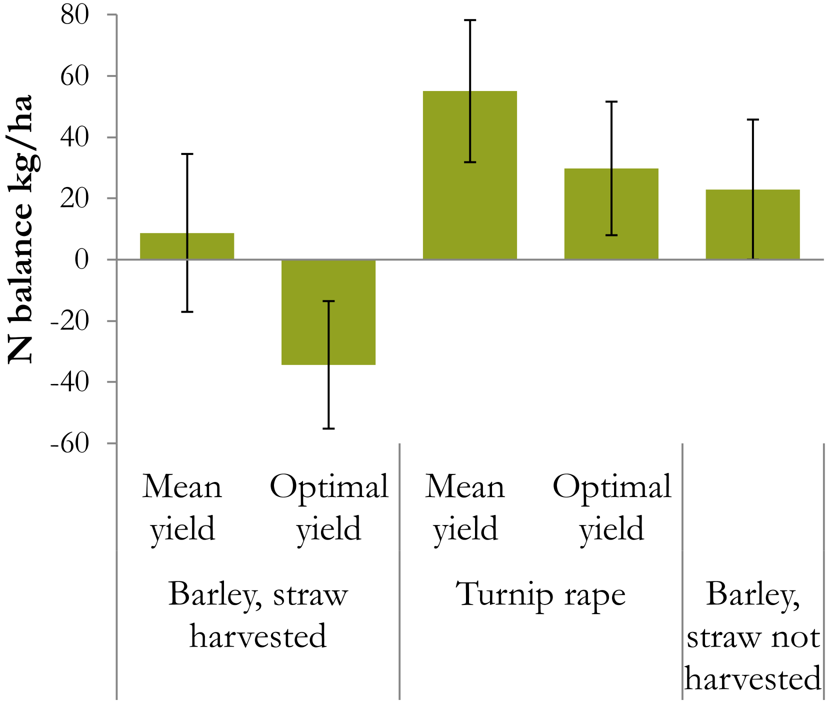
- Results per energy yield

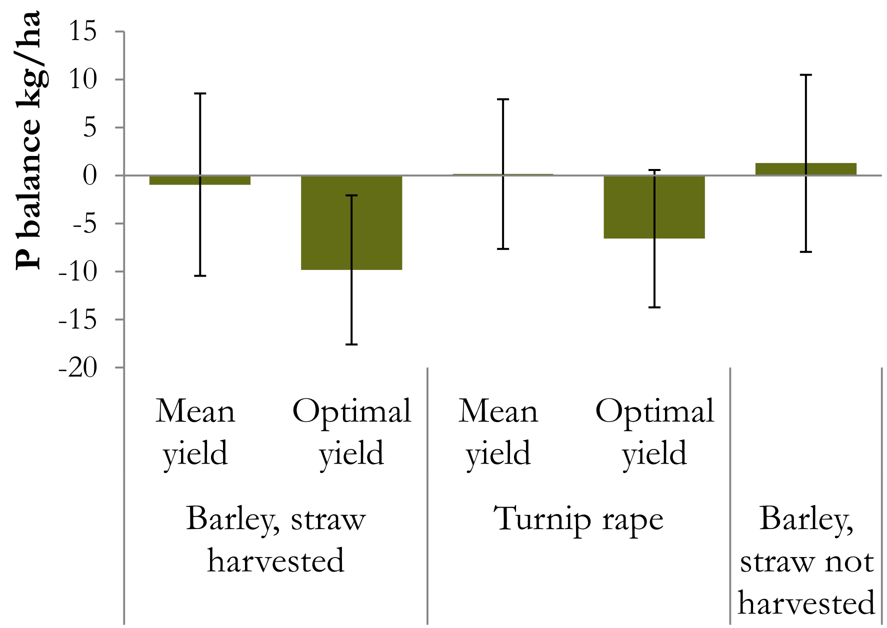


- Optimal yields can result in negative balances, which is not sustainable in the long term

Eutrophication: N & P balance

- Results per field area, compared to reference situation

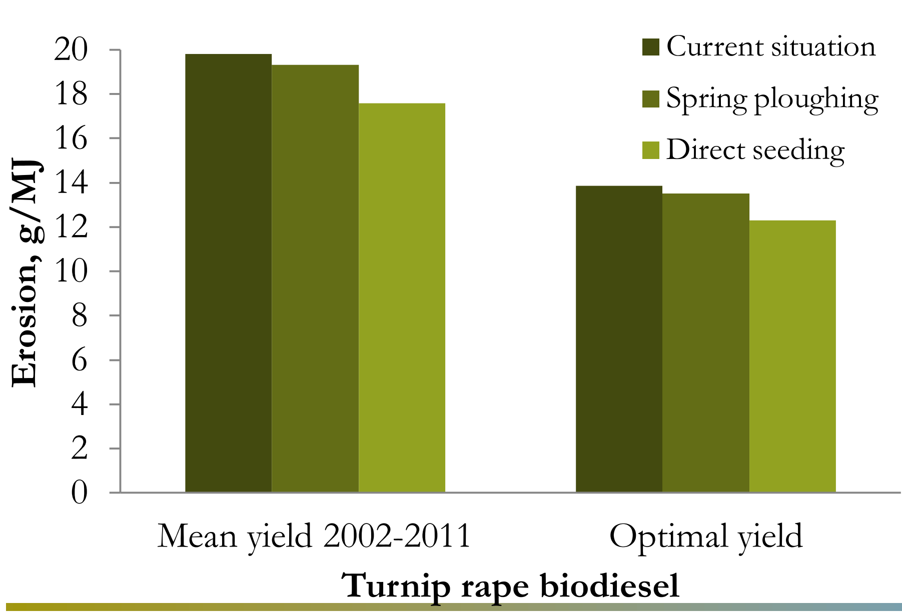


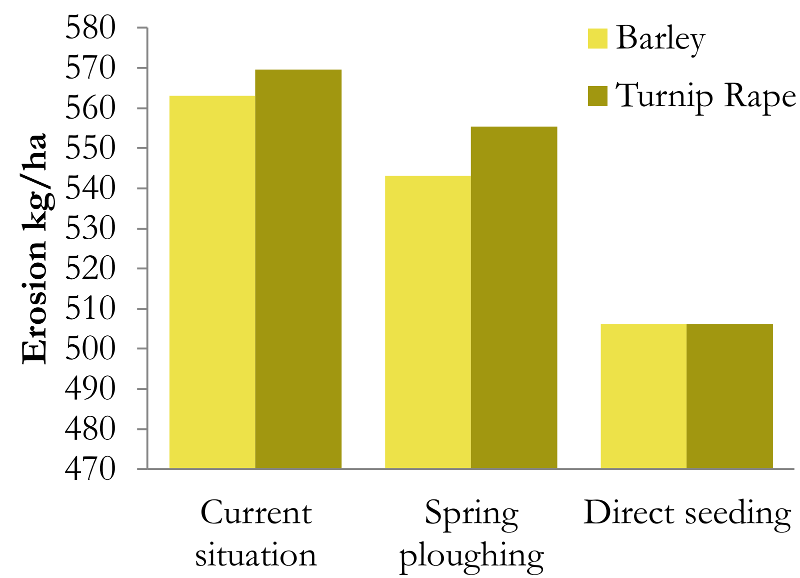


- Nutrient leaching can also be decresed by cover crops (Lemola et al. 2014) and liming (Valkama et al. 2013)

Soil erosion

- Calculated with the VIHMA –model (Puustinen et al. 2010), considering current (Tike 2010) and potential soil tilling options
- The model doesn't make a difference if straw is harvested from the field or not, so erosion impact was not allocated to straw when calculating results per energy yield





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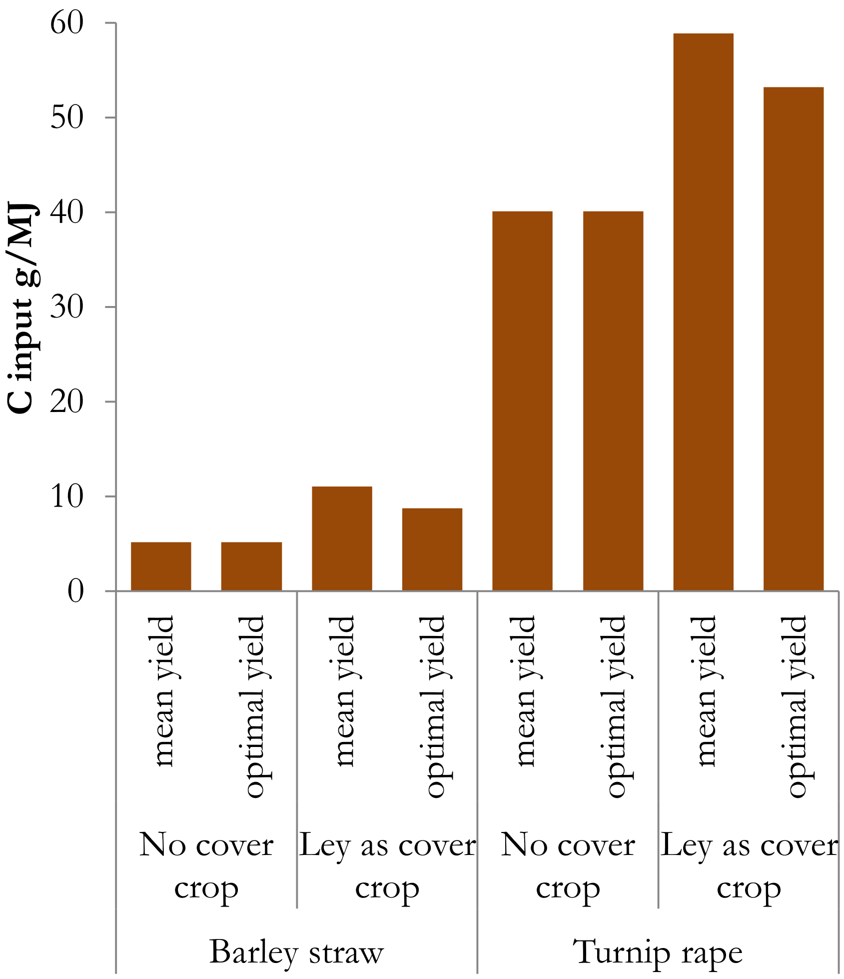
Soil organic matter decline

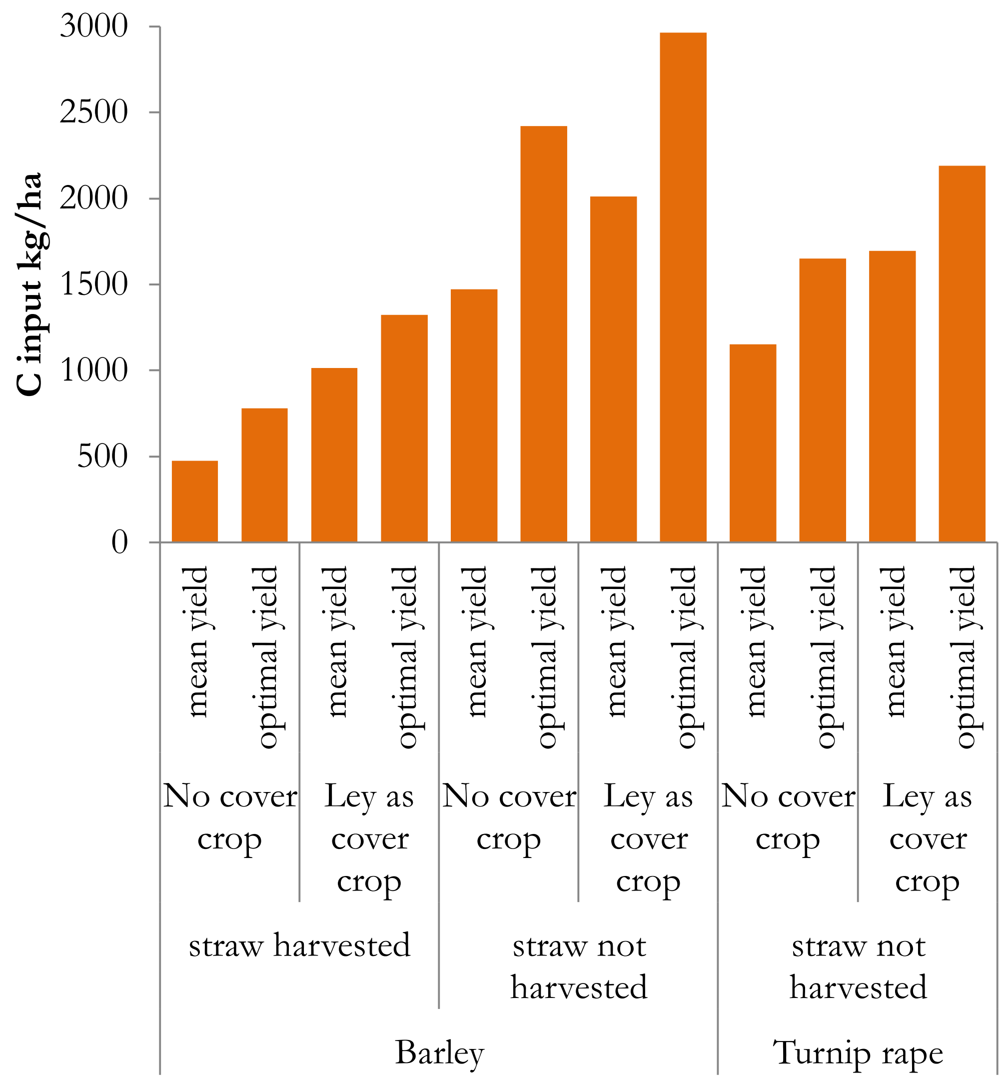
- We were unable to use the Finnish soil carbon model Yasso07 (Tuomi et al. 2009) due to lack of data
- Instead, soil organic matter decline was assessed with two indicators:
  1. Annual C loss
     - » Based on the estimate that Finnish field soil carbon stock declines at a rate of 220 kg/ha/year (Heikkinen et al. 2013)
     - » Results for turnip rape biodiesel:
       - – Mean yield 7,6 g/MJ
       - – Optimal yield 5,3 g/MJ
     - » No impact is allocated to the barley straw
  2. Annual C input
     - » Describes the effects of straw removal and improvement options (optimal yield and use of cover crops)

Soil organic matter decline: Annual C input

- The carbon input from crop residues left on the field after harvest
  - Calculated as described by Karhu et al. (2012) using the following coefficients and estimates:
    - » Harvest indexes and dry matter contents (Pahkala et al. 2009)
    - » Shoot to root values (Pietola & Alakukku 2005)
    - » Ley biomass values (Riesinger 2010)
    - » Estimate of stubble biomass left after barley straw removal (5 % of shoot biomass, Karhu et al. 2012)
  - Results per energy yield and field area are presented on the next slide

Soil organic matter decline: Annual C input





Soil compaction

- Soil compaction is caused primarily by the use of heavy machinery in wet conditions (Alakukku et al. 2003)
- There is no up-to-date statistic data available on the machinery used in the production of arable crops in Finland
- However, the trend of tractor weight increase in the 90s (Ministry of Agriculture and Forestry 1999) is likely to continue as the tractor power class has continued to increase in the early 2000s (MTT Vakola 2004)
- Field operations with a medium to high risk of soil compaction include almost all operations necessary in the production of both barley and turnip rape: ploughing in late autumn or early spring, seedbed preparation, harvesting and fertilization
- Recommendations based on quantitative guidelines for machine/soil interactions are not yet available (Alakukku et al. 2003)

Ecotoxicity

- Comprehensive crop specific ecotoxicity assessments cannot yet be made due to lack of statistical data on the use of plant protection products
- We refer here to the more general results of Räsänen et al. (2014) including all Finnish arable crop production
  - The most common substance group was herbicides (ca.75 % of use)
  - Fungisides had the largest impact (ca. 85 % of potential ecotoxicity) despite their small usage (ca.18 % of use)
  - The fungicide prochloraz that is used on cereals and oilseed crops had the third highest ecotoxicity impact of all studied substances (54 different active incredients)

Biodiversity: change of total field area during the last 20 years, %

- Calculated based on the change in total cultivation area of each crop during the period 1994-2013 (FAOSTAT 2014)
- Results:
  - Barley – 2 %
  - Oil crops (turnip rape & oilseed rape) – 21 %

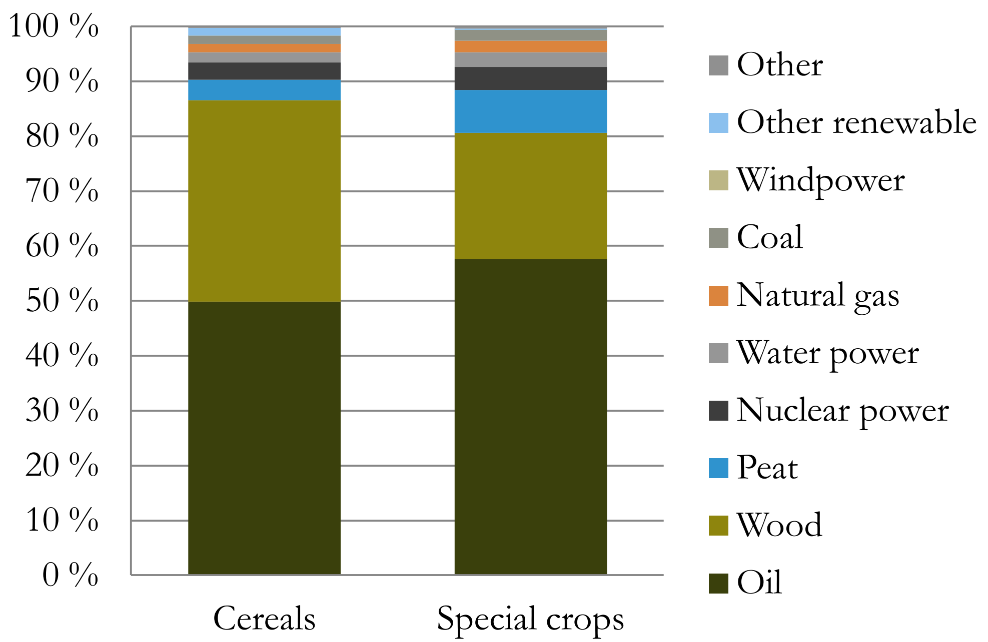
- As the cultivation area of barley or turnip rape has not increased no land transformation effects on biodiversity are assumed

Biodiversity: Population trends of farmland breeding birds, butterflies and arable weeds

- The same indicators are included in the indicator system describing the state and development of the diversity of the farming environment as a whole, to be used in Finnish agricultural policy making (Tiainen 2007, Tiainen et al. 2007)
- For a couple of decades after the 1960s, the abundance of both farmland birds and arable weeds decreased substantially, farmland butterfly populations have only been monitored since 1999 (biodiversity.fi 2014)
- During this millennium, there are more bird species that have increased their numbers than those that have decreased their numbers (Kuussaari et al. 2014)
- At the same time, no significant changes have occurred in the butterfly and arable weed populations on conventional fields (Kuussaari et al. 2014, Salonen & Hyvönen 2014)
- On organic fields, on the contrary, weed density and biomass have increased so much that they harm yield production significantly (Salonen & Hyvönen 2014)

Use of non-renewable natural resources: Share of renewable energy

- The share of renewable energy (wood, water, wind & other renewable) of farm energy use is
  - 40 % in cereal production
  - 26 % in special crop (including turnip rape) production



- References: Tike (2010) and Yrjänäinen (2011)

Use of non-renewable natural resources: share of organic fertilizers

- In Finland, manure is the most frequently used organic fertilizer

Crop	Share of manured field area of total P fertilized field area, %	Share of manure P of total P applied, %
Barley	32,1	34,8
Turnip rape	8,1	8,5

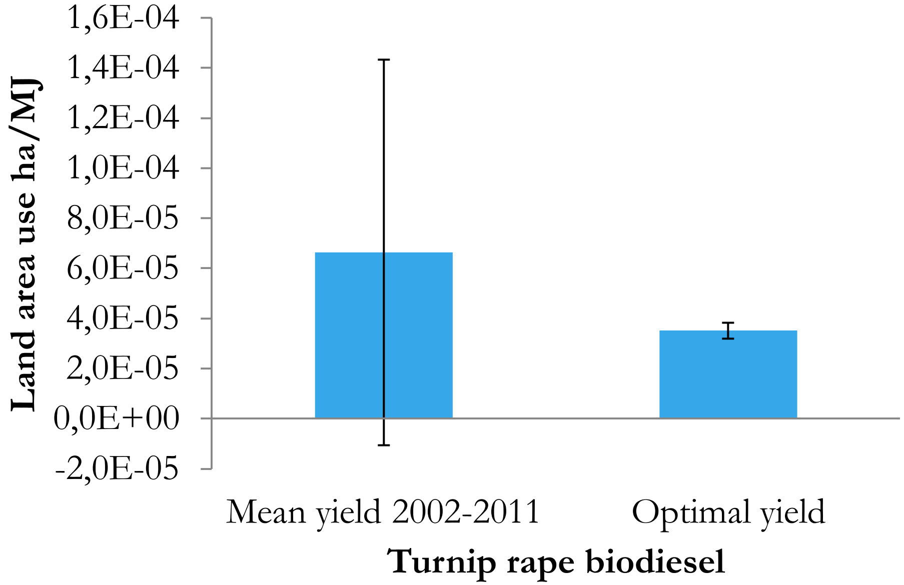
- According to Ylivainio et al. (2014), current manure P with soil P reserves would cover plant P fertilizer requirement, if manure could be evenly spread

Water use and quality

- Irrigation of other arable field crops than potato and horticultural crops is minimal: about 0,2 % of the total cultivation area (Tike 2010)
- Water withdrawal for agricultural use in Finland was in 2005 3,07 % of total water withdrawal (FAOSTAT 2014)
- Around 92 % of the used irrigation water is surface water, ca 5 % groundwater and 2 % tap water (Tike 2010)
- Only 1,5 % of the total actual renewable freshwater resources were withdrawn in Finland in 2006 (FAO-AQUASTAT 2013)
- Based on this data, it can be claimed that the use of irrigation water is at a sustainable level in all Finnish crop production
- Also, assessing the water use, water availability should also take into account, and there is not water shortage in Finland

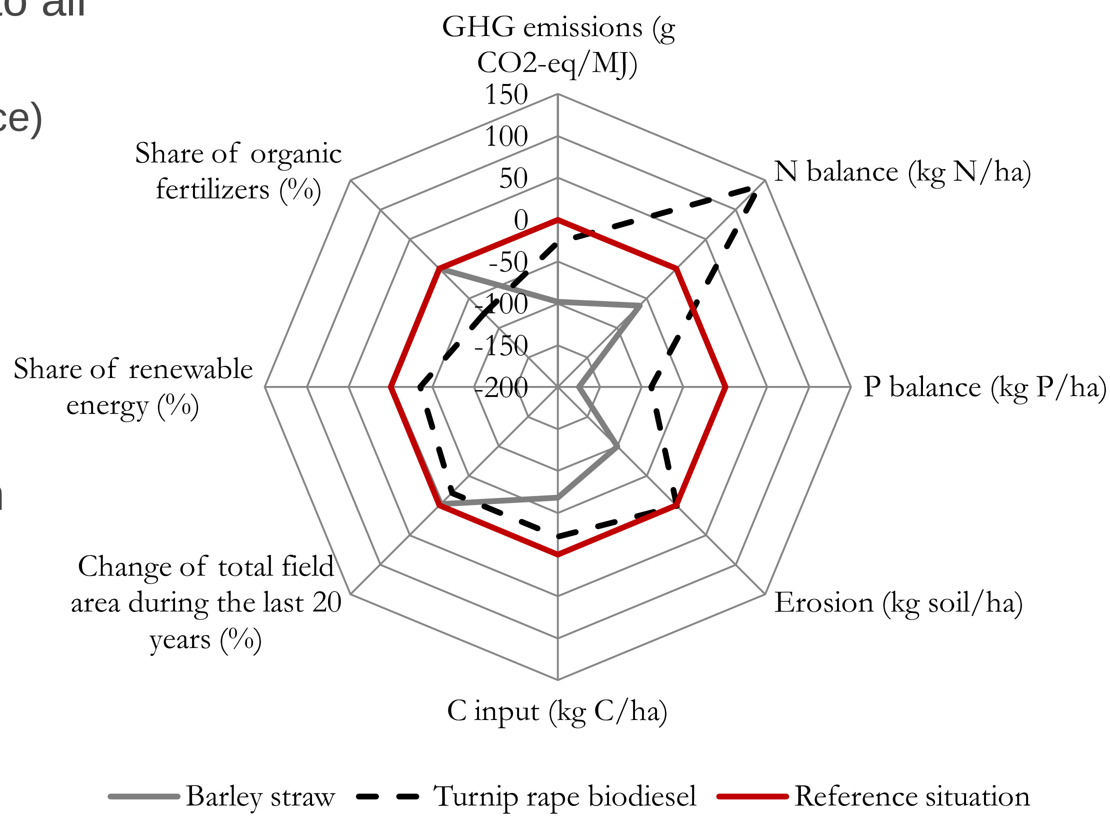
Low efficiency of farming: land area use

- Calculated using the yield level data from Pro Agria Advisory Centres (time period 2002-2011)
- Straw is a residue from cereal cultivation, so its production is not considered to require land area



Summary of results: net impact of current state related to reference situation in numeric indicators, %

- Barley straw performs better than turnip rape biodiesel related to all indicators except:
  - C input (lower than reference)
  - P balance (dangerously lower than reference)
- No erosion effects are allocated to barley straw
- N balance is remarkably high in turnip rape production
- C input in the production of both biofuels is lower than the reference



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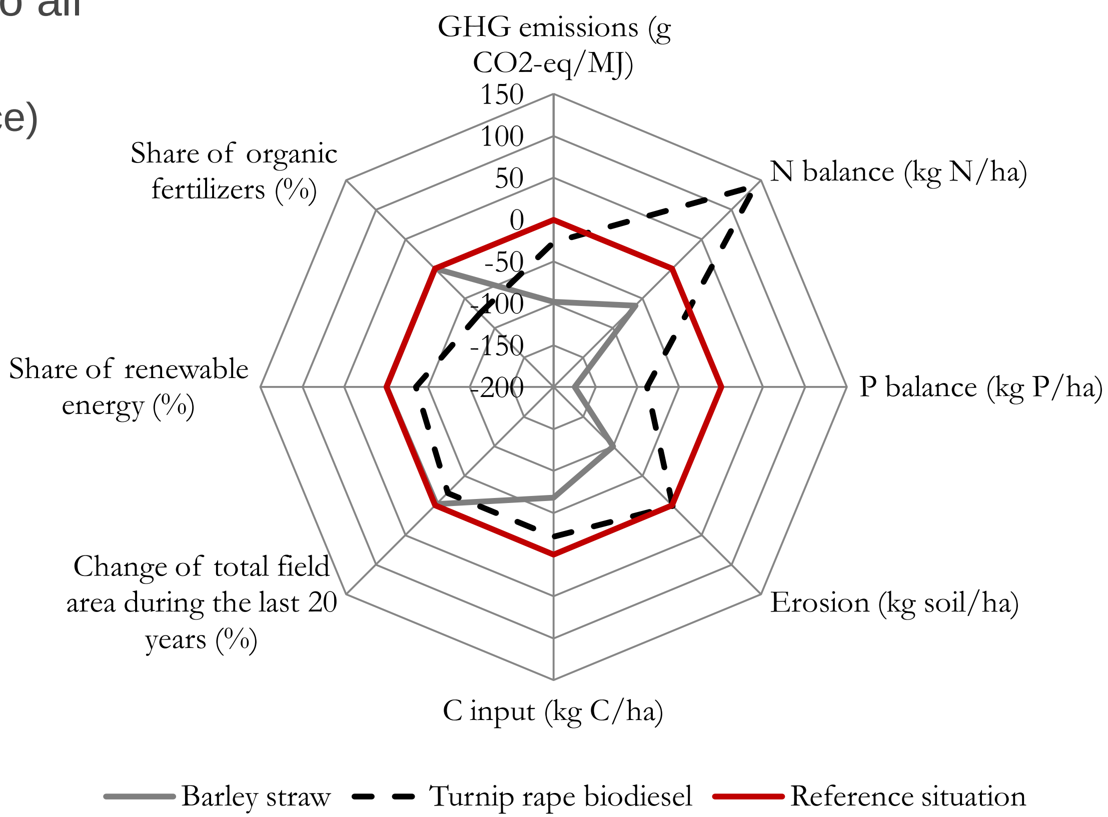
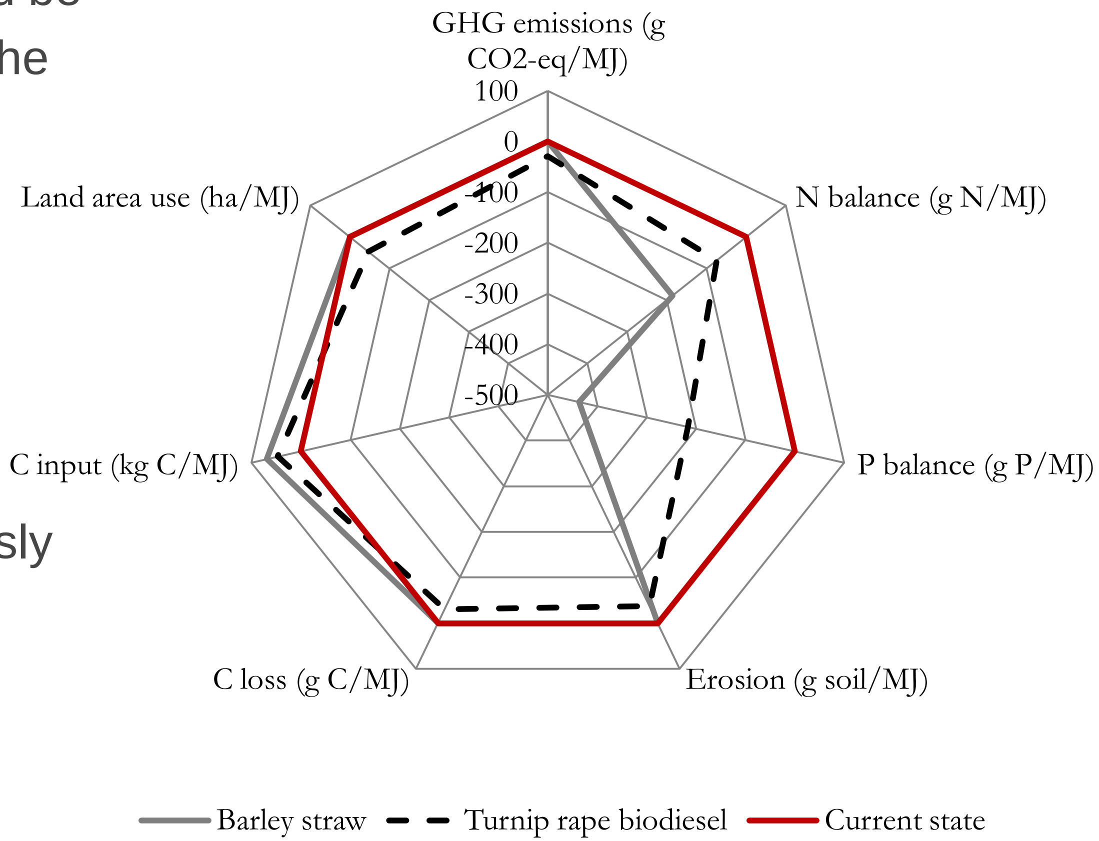


Summary of results: effect of quantitatively assessed improvement options, %

- The indicator values could be remarkably improved by the selected improvement options

- The reduction in the N balances of barley straw and P balances of both biofuels seems dangerously big, suggesting potential nutrient deficiency



Comments and research needs

- There were several indicators that could not be quantitatively assessed in this study
  - Several quantitative indicators could not be used due to lacking crop specific data (change in soil C level, ecotoxicity, agri-environment biodiversity indicators, water use)
  - Soil compaction lacks a suitable assessment method

- Especially the assessment of biodiversity effects needs attention due to its importance
  - Lindner et al. (2014) are currently developing a promising life cycle assessment method for biodiversity impacts

References

- Alakukku, L., Weisskopf, P., Chamen, W.C.T., Tijink, F.G.J., van der Linden, J.P., Pires, S., Sommer, C. & Spoor, G. 2003. Prevention strategies for field traffic-induced subsoil compaction: a review: Part 1. Machine/soil interactions. Soil and Tillage Research 73: 145-160.
- Biodiversity.fi 2014. http:// http://www.biodiversity.fi/en/ [visited 18.7.2014]
- European Commission 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30. *Official Journal of the European Union* 5.
- FAO-AQUASTAT database 2013. Water resource information by country/territory and Millennium Development Goal Water Indicator. Available at: http://www.fao.org/nr/water/aquastat/maps/AQUASTAT_water_resources_and_MDG_water_indicator_March_2013.pdf
- FAOSTAT 2014. Agricultural production. Cited 12/23 2014. Available in the Internet: http://faostat3.fao.org/faostat-gateway/go/to/home/E.
- FAOSTAT 2014. Water withdrawal for agricultural use. Agri-environmental indicators. Cited 6/2014. Available on the internet: http://faostat3.fao.org/faostat-gateway/go/to/download/E/EW/E
- Heikkinen, J., Ketoja, E., Nuutinen, V. & Regina, K. 2013. Declining trend of carbon in Finnish cropland soils in 1974-2009. Global Change Biology 19: 1456-1469.
- Karhu, K., Gärdenäs, A.I., Heikkinen, J., Vanhala, P., Tuomi, M. & Liski, J. 2012. Impacts of organic amendments on carbon stocks of an agricultural soil — Comparison of model-simulations to measurements. *Geoderma* 189–190: 606-616.
- Kuussaari, M., Heliölä, J., Herzon, I., Tiainen, J. & Ekroos, J. 2014. Luonnon monimuotoisuus maatalousalueilla. In: Aakkula, J. & Leppänen, J. 2014. Follow-up study of the impacts of agri-environment measures (MYTVAS 3) – Final report. Maa- ja metsatalousministeriö 3/2014.
- Laine, A., Högnäsbacka, M., Kujala, M., Niskanen, M., Jauhiainen, L., & Nikander, H. (2014). Virallisten lajikekokeiden tulokset 2006-2013 (Results of official variety trials 2006-2013). MTT Raportti 128. Jokioinen.
- Lemola, R., Valkama, E., Suojala-Ahlfors, T., Känkänen, H. & Turtola, E. 2014. Alus- ja kerääjäkasvien potentiaali vähentää maatalouden aiheuttamaa typpikuormitusta. Teoksessa: Kerääjäkasvit – hyötyä viljelijälle ja ympäristölle. TEHO Plus –hankkeen julkaisu 6/2014.
- Lindner, J. P., Niblick, B., Eberle, U., Bos, U., Schmincke, E., Schwarz, S., Luick, R., Blumberg, M. & Urbanek, A. 2014. Proposal of a unified biodiversity impact assessment method. 9th International Conference LCA of Food San Francisco, USA 8-10 October 2014.
- Ministry of Agriculture and Forestry 1999. Uusiutuvien luonnonvarojen kestävän käytön yleismittarit. Julkaisuja 3. Helsinki, Finland: Ministry of agricutlture and Forestry. 169 p.
- MTT Vakola 2004. Maatalous - ja metsäkoneiden myynti 2000–2002. (Sales of agricultural and forestry machines 2000-2002) Cited 10/4 2013. 2004. Available on the Internet: http://jukuri.mtt.fi/bitstream/handle/10024/441066/TILASTOKOKO.pdf?sequence=1.

References

- Pahkala, K., Hakala, K., Kontturi, M. & Niemeläinen, O. 2009. Peltobiomassat globaalina energianlähteenä. *Maa- Ja Elintarviketalous* 137.
- Pietola, L. & Alakukku, L. 2005. Root growth dynamics and biomass input by Nordic annual field crops. *Agriculture, Ecosystems & Environment* 108: 135-144.
- Puustinen, M., Turtola, E., Kukkonen, M., Koskiaho, J., Linjama, J., Niinioja, R. & Tattari, S. 2010. VIHMA – A tool for allocation of measures to control erosion and nutrient loading from Finnish agricultural catchments. *Agriculture, Ecosystems & Environment* 138: 306-317.
- Riesinger, P. 2010. Agronomic challenges for organic crop husbandry. Academic dissertation. Helsinki University, Department of Agricultural Sciences.
- Räsänen, K., Ratilainen, A. K. & Kurppa, S. 2014. Pesticide usage data for the application of the research to be utilized for IPM actions? Poster presentation at SETAC Europe 24th Annual Meeting 11-15 May Basel.
- Salonen, J. & Hyvönen, T. 2014. In: Aakkula, J. & Leppänen, J. 2014. Follow-up study of the impacts of agri-environment measures (MYTVAS 3) – Final report. Maa- ja metsatalousministeriö 3/2014.
- Tiainen, J. 2007. Maatalousympäristön luonnon monimuotoisuusindikaattorit. Loppuraportti. Riista- ja kalatalouden tutkimuslaitos.
- Tiainen, J., Rintala, J., holopainen, J., Piha, M., Seimola, T., Vepsäläinen, V. & Väisänen, R. A. 2007. Biodiversity indicators of Finnish agri-Environments: a breeding bird indicator. In: Salonen, J., Keskitalo, M. & Segerstedt, M. (eds.) 2007. Peltoluonnon ja viljelyn monimuotoisuus (Biodiversity in farmland) Maa- ja elintarviketalous 11: 215-232.
- Tike 2010. Tike, Farm Structure Survey, Agricultural Census 2010. Cited 12/20 2013. 2010. Available on the Internet: http://www.maataloustilastot.fi/en/farm_structure.
- Tuomi, M., Thum, T., Järvinen, H., Fronzek, S., Berg, B., Harmon, M., Trofymow, J.A., Sevanto, S. & Liski, J. 2009. Leaf litter decomposition—Estimates of global variability based on Yasso07 model. *Ecological Modelling* 220: 3362-3371.
- Valkama, E., Salo, T., Esala, T. & Turtola, E. 2013. Nitrogen balances and yields of spring cereals as affected by nitrogen fertilization in northern conditions: A meta-analysis. Agriculture, Ecosystems and Environment 164: 1-13.
- Virtanen, Y., Usva, K., Silvenius, F., Sinkko, T., Nurmi, P., Kauppinen, T., & Nousiainen, J. 2011. Peltoenergian tuotantojärjestelmien ympäristövaikutukset. *MTT, Helsinki. MMM. 98s.*
- Ylivainio K, Sarvi M, Lemola R, Uusitalo R & Turtola E 2014 Regional P stocks in soil and animal manure as compared to P requirement of plants in Finland. Baltic Forum for Innovative Technologies for Sustainable Manure Management. WP4 Standardisation of manure types with focus on phosphorus. MTT Report 124.
- Yrjänäinen, Heli. 2011. Sähkön hiilijalanjälki Suomessa (Carbon Footprint of Electricity in Finland, in Finnish). Master of Science Thesis, Tampere Univerity of Technology, Electrical Engineering, 76 pages