Pros and cons of using ensiled grass as the raw material for an on-farm green biorefinery

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Let’s take full benefit of the green biomass via biorefining

- Grass is an abundant resource which may also provide several ecosystem services
- It could be utilized more efficiently as a raw material for green biorefineries to broaden the current use (mainly as a feed for ruminants and horses)
- There is a vast amount of knowledge and existing efficient technology regarding grass cultivation, preservation and quality that has accumulated from the livestock sector
- We can use this information and apply it to the novel uses of green biomass

Grass potential in many areas is underexploitet

- Increase production level on current grass fields by adjusting management factors
- Increase field area in intensive grass production (e.g. from fallow areas, peat lands)
- traditional use of grass as ruminant feed is not increasing - surplus grass available


Photo: Luke Marketta Rinne

Grass composition varies greatly due to:

- Plant species (and variety)
- Stage of development of the plants
- Growth cycle (primary vs. regrowth)
- Fertilization
- Annually varying weather conditions
- Soil type
- Presence of weeds
- Age of the ley

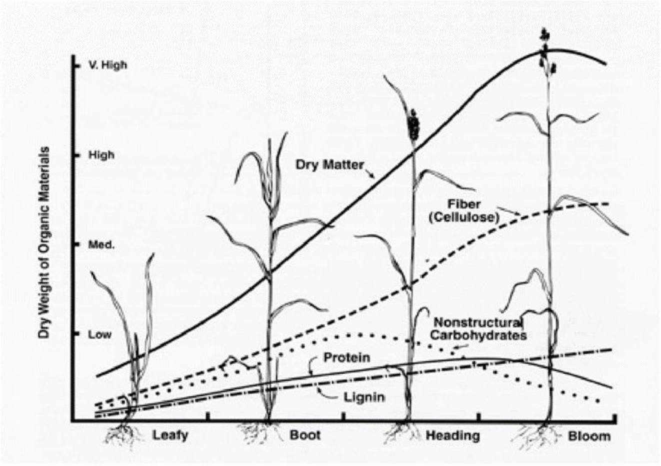


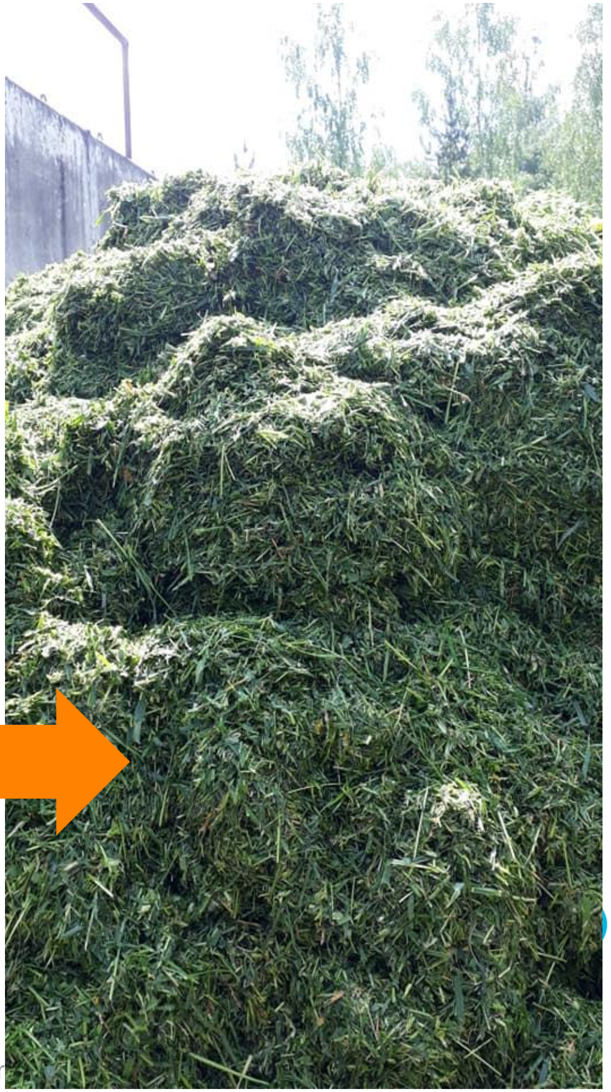
Figure 2: Forage dry matter and quality

Source: White, H. and D. Wolf. 'Controlled Grazing of Virginia Pastures': Virginia Cooperative Extension Publication Number 418-012, July 1996.

There is scope to modify the grass crop based on the requirements of the particular process

Fresh grass is moist and easily spoiled

- In traditional feed use, drying as hay or fermenting to silage are used to stabilize the material
- Ensiled grass could serve as the feedstock for green biorefineries



Photos: Luke/Marketta Rinne

Typical Finnish grass silage is well preserved and highly digestible

Source: Farm silage samples anaysed by Valio Ltd. laboratory

	Grass silages (1998-2012)		
	n	Mean	SD
Dry matter (DM; g/kg)	110192	321	108.9
In DM (g/kg)			
Crude protein	110190	147	26.6
NDF	100094	541	46.1
Indigestible NDF	57723	79	26.8
D-value	110188	674	35.0
pH	110094	4.2	0.44
In DM (g/kg)			
Lactic acid	110084	44.6	21.24
Volatile fatty acids	110094	12.8	10.40
Water sol. carbohydrates	110106	60.8	45.70
In N (g/kg)			
Ammonium N	110092	44	24.8
Soluble N	110092	413	129.9
Silage DM intake index	109353	102.5	8.24

Reference: Salo, T., Eurola, M., Rinne, M., Seppälä, A., Kaseva, J. & Kousa, T. 2014. The effect of nitrogen and phosphorus concentrations on nutrient balances of cereals and silage grass. MTT Report 147: 36 p. Available at: http://jukuri.mtt.fi/bitstream/handle/10024/482918/mttraportti147.pdf

Fresh or ensiled grass for a green biorefinery?

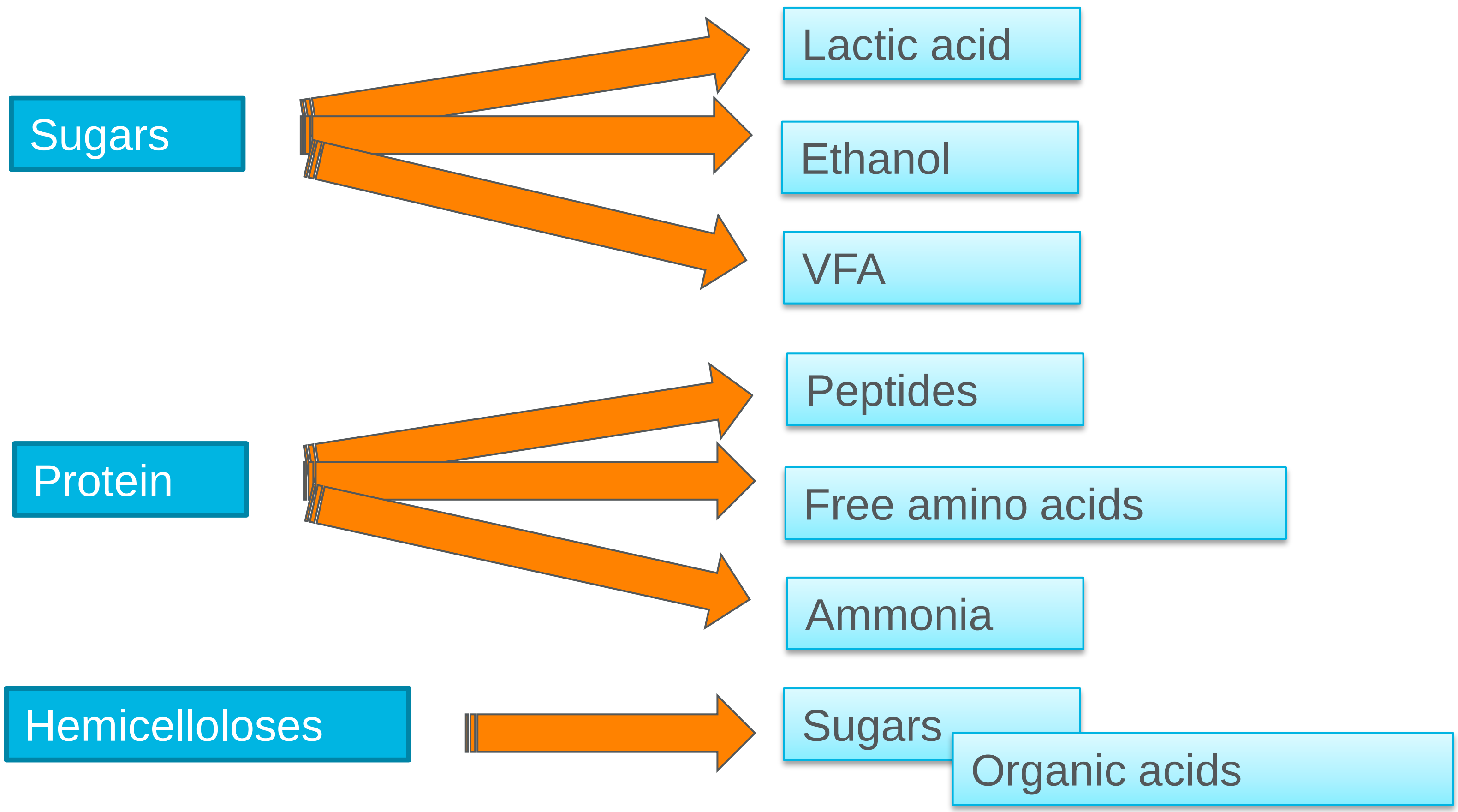
- Positive for silage:
  - Efficient harvesting and storage technologies in place
  - Stable raw material provides a year-around feedstock availability
  - Better control on the quality of the raw material
  - Ensiling can be modified by using wilting, additives to manipulate the fermentation process which may even act as a pretreatment for the actual process
  - The products are ”semi” stable
  - If they are used in a continuous further use or processing, no storage of them is needed

- Negative for silage:
  - Some dry matter losses
  - Sometimes poor fementation quality may occur
  - Part of the protein is degraded during ensiling
  - The protein can no longer be precipitated by acid or heat treatment

Direct comparisons of grass and silage are lacking.

How does ensiling affect the biorefinery process yields?

Fermentation causes changes in chemical composition during ensiling



The extent of changes can be manipulated by prewilting, proper ensiling management and by silage additives

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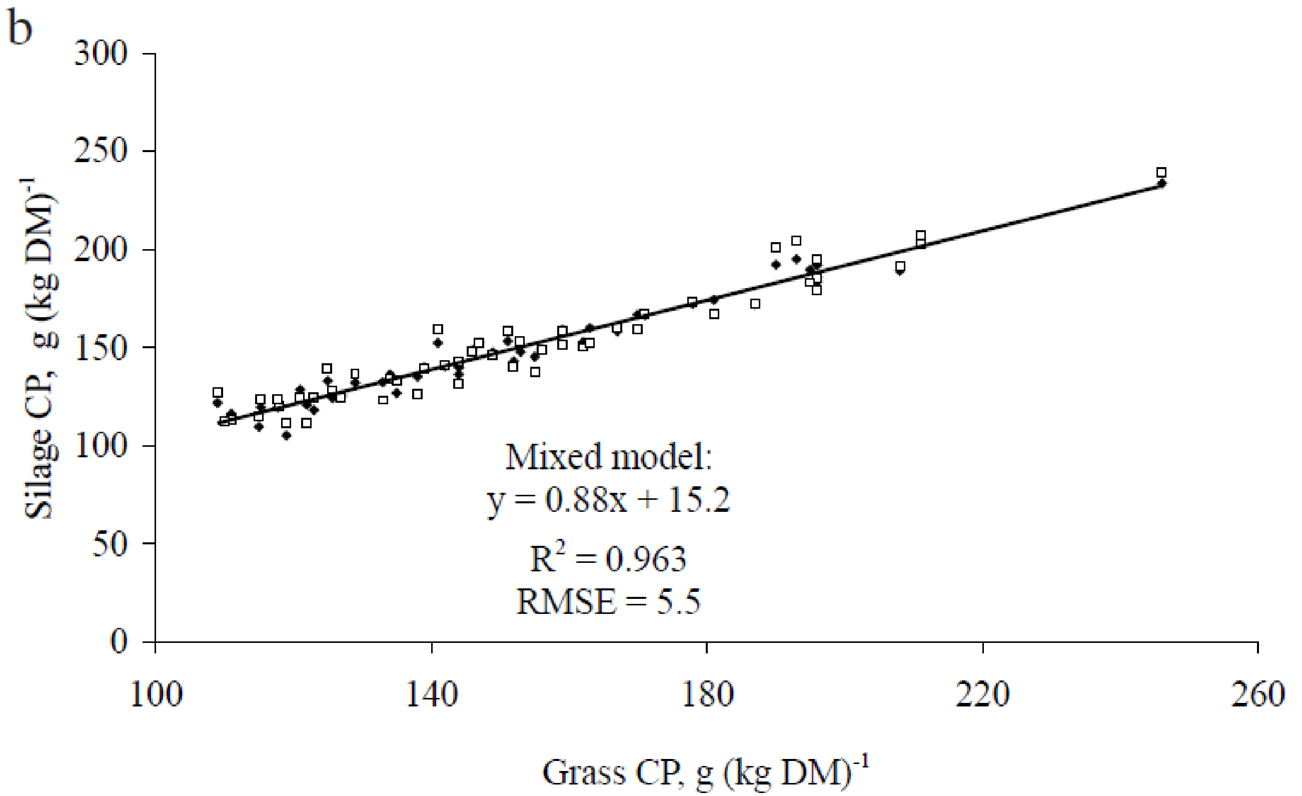
Practically no change in crude protein concentration due to ensiling



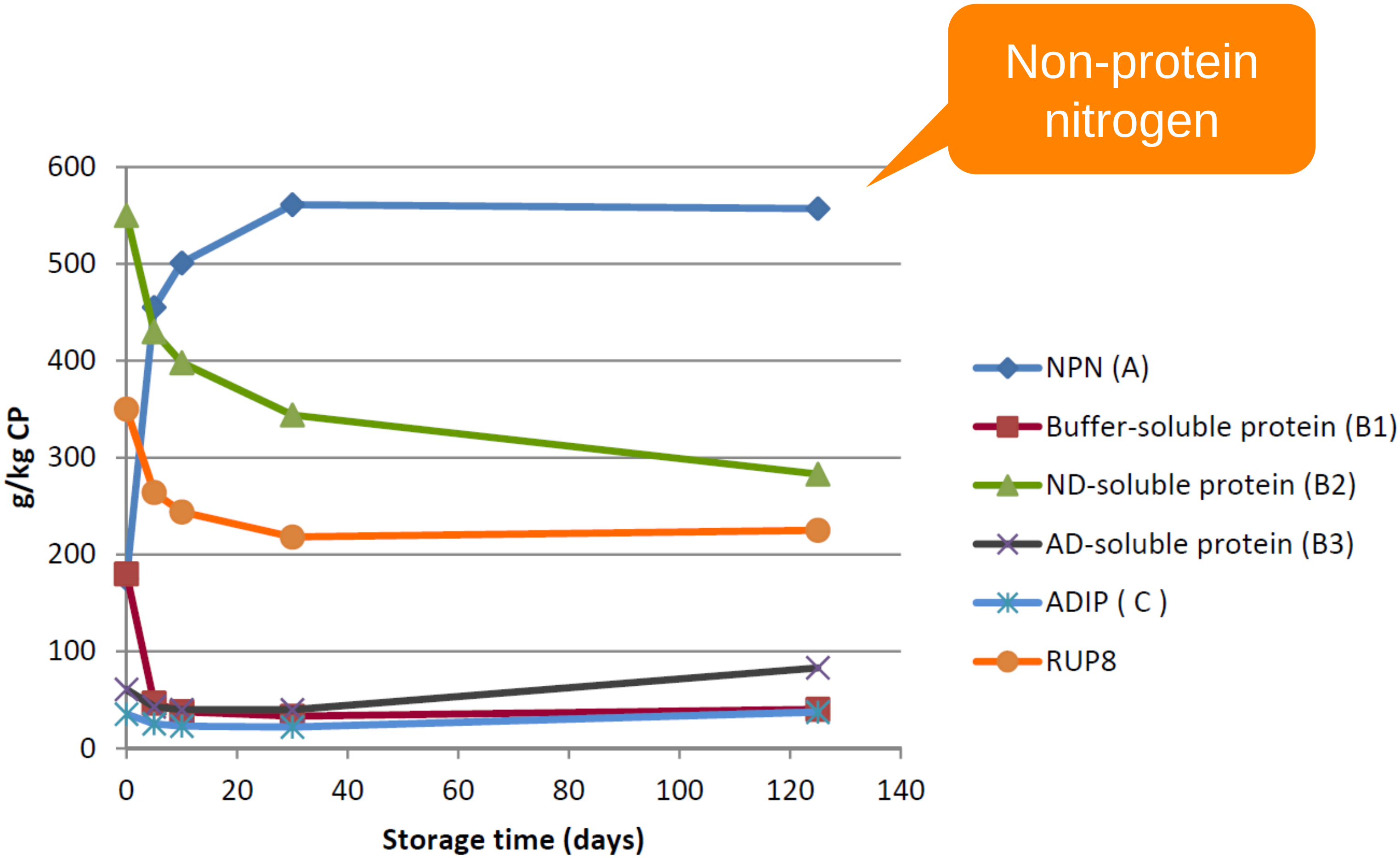
Huhtanen, P., Nousiainen, J. & Rinne, M. 2005. Prediction of silage composition and organic matter digestibility from herbage composition and pepsin-cellulase solubility. Agricultural and Food Science 14: 154-165. http://journal.fi/afs/article/view/5805.

Forage crude protein (CP)

- Forage nitrogen (N) is analysed and crude protein presented as:
  - N × 6.25
- Nitrogenous compounds in grasses are in different forms
  - The greatest single protein is RUBISCO enzyme related to photosynthesis with a relatively good amino acid composition
  - Part of protein is bound to cell walls – not extractable (not even by rumen microbes)
- About 80 % of fresh forage CP is true protein
  - The amount of true protein decreases during ensiling as plant enzymes and microbial activity (enterobacteria and clostridia) degrade proteins

Changes in CP fractions during ensiling of grass silage.

Values are means over untreated and additive-treated silages, n=9.



Nadeau, E., Richardt, W., Murphy, M., Auerbach, H. 2012b. Protein quality dynamics during wilting and preservation of grass-legume forage. Proc. The XVI Int. Silage Conf. pp. 56-57. Hämeenlinna, Finland, 2-4 July 2012.

The final degradation product of silage CP is ammonia

- The proportion of ammonia is also a sensitive indicator of general fermentation quality of silage:

Ammonia N, g/kg total N	Description
< 50	Very well fermented
50 – 100	Well fermented
100 – 150	Moderately fermented
>150	Poorly fermented

- Note that in good quality silage, less than 5 % of N is in the form of ammonia!
- The various degradation products such as peptides and amino acids are still valuable for monogastrics
- Partial hydrolysis of proteins may in some cases even improve their utilization – but remains to be proven in this context

Let’s put grass into good use in novel applications!

- It is a revolutionary idea to utilize forage in large scale in intensive pig production!
- We need to liberate the soluble components of forage from the fibre matrix to make them suitable for pigs
- We tried to generate a simple but attractive concept to do that

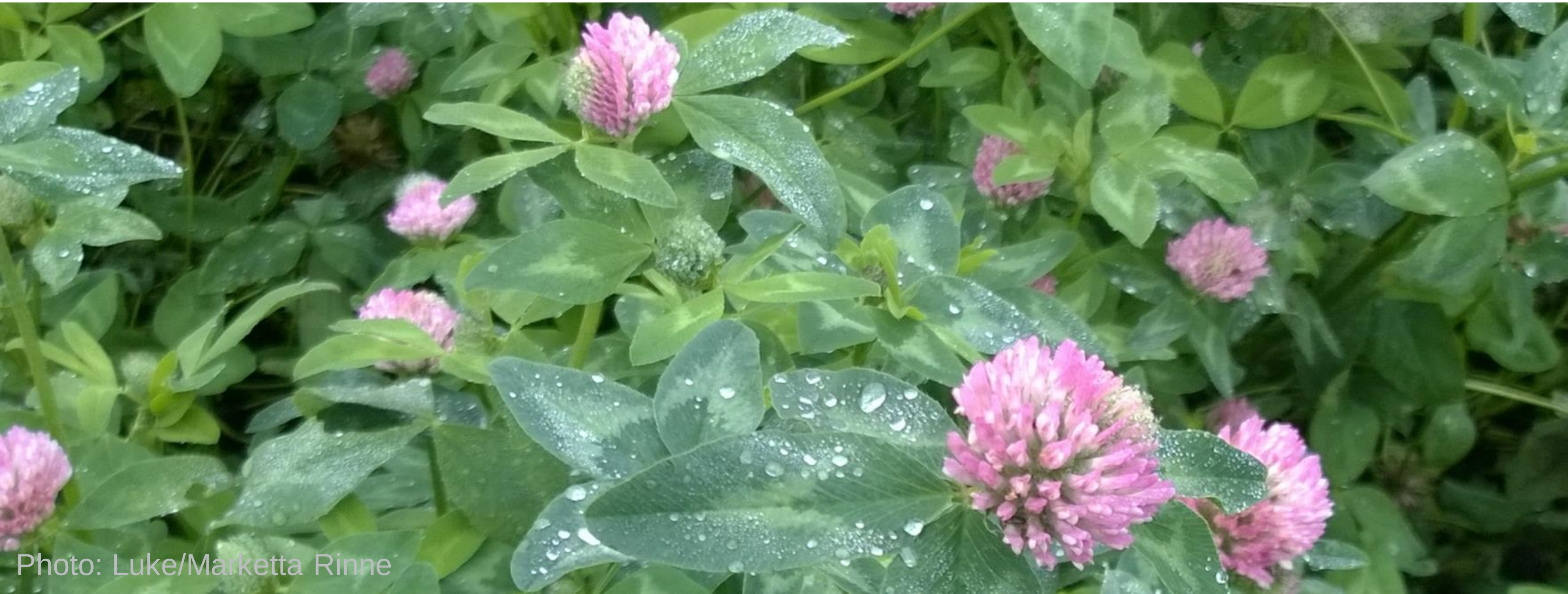


Photo: Luke/Marketta Rinne

Simple example of a green biorefinery concept for pigs

Photo: ©Luke /Niina Pitkänen

Grassland production

Improves crop rotation, soil structure , biodiversity and allows higher manure spreading per hectare

Harvesting and preservation of grass

Efficient existing technology via contracting available

Fits well in the common liquid feeding system of pigs

Provides protein, sugars, organic acids and minerals

Mechanical fractionation

Liquid fraction

Liquid feed for pigs (and cows)

Solid fraction

Biogas (ruminant feed, hydrolysation)

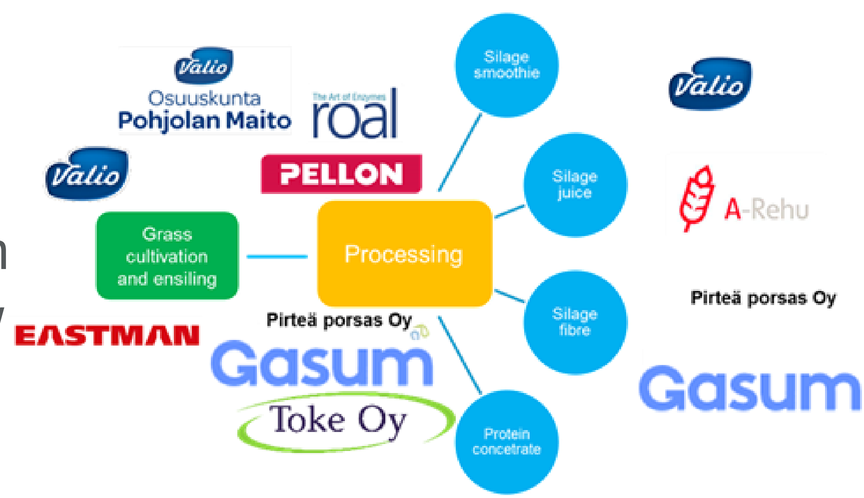
Suits with pig slurry in biogas production

Simple screw press has low investment and operating costs

At Luke Finland, we looked at the different steps of a simple pig farm grass silage biorefinery

- Effects of different types of silage raw materials and additive treatments on silage extraction, and quality & stability of fractions
- Juice suitability for pig feeding
- Use of solid fraction
  - Biomethane production potential
  - Hydrolysis for further industrial use
  - Suitability as a feed component for dairy cows
- Effects on pig farm nutrient balance and economics

- Innofeed project (2015-2018)
- Funded by Business Finland
- VTT & Luke + company consortium
- www.ibcfinland.fi/projects/innofeed/

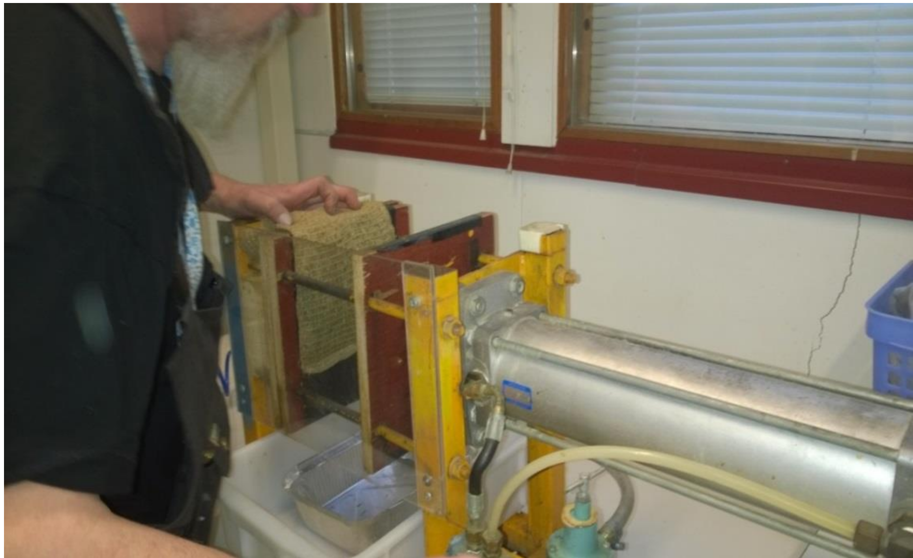


We prepared pilot scale silages to look how management factors affect the extraction

- Grass species
- Wilting
- Silage additives
- Primary growth vs. regrowth

We used different methods for liquid-solid separation

Photos: ©Luke / Marketta Rinne



Production of silage juice at farm scale

We combined all our data from the extractions and conducted a meta-analysis on the results:

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Grass and Forage Science WILEY

ORIGINAL ARTICLE

Grass silage for biorefinery—A meta-analysis of silage factors affecting liquid–solid separation

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Abstract

This meta-analysis based on 19 studies from Finland comprising 43 grass silages was undertaken to evaluate the effect of silage quality on liquid yield, liquid composition and retained compounds in liquid using four different liquid–solid separation methods. Silages were classified according to species (grass, clover or a mixture of them), additive treatment (no, biological or formic acid-based additive) and harvest (primary growth or regrowth). A mixed model regression analysis with random study effect was used to evaluate the impact of silage characteristics on biorefinery efficiency. There was a large variation in silage quality in the data set. Silage dry-matter concentration was the characteristic most highly correlated with liquid yield for all separation methods, and when used as an independent variable in the model, it resulted in the best predictions. The liquid–solid separation methods presented a great variation in the liquid yield, ranging from 0.26 to 0.56 when silage dry-matter concentration was standardized to 250 g/kg. There was no effect of additive treatment and harvest in the estimation of the biorefinery potential, but species was a significant variable in predicting liquid yield for the laboratory-scale presses with higher liquid yield for mixed grass and legume. The high correlation between silage quality and liquid yield and liquid composition provides potential to predict the biorefinery potential based on equations developed for each separation method. This information can be used to modify the silage production systems so that they best meet the requirements of a green biorefinery process.

KEYWORDS
biomass, fractionation, processing, screw press, separation

Description of data used in the analysis

Variable	*n*	Mean	*SD*	Min	Max
Silage DM, g/kg	32	236	43.7	138	289
Silage ash, g kg^{-1} DM	32	83	20.2	52	118
Silage CP, g kg^{-1} DM	32	140	39.4	84	215
Silage NDF, g kg^{-1} DM	14	451	63.9	342	609
Silage IVOMD, g kg^{-1} OM	14	734	33.1	646	804
Liquid yield[a]	32	0.315	0.1259	0.108	0.542
Liquid DM, g kg^{-1} DM	31	103	30.4	33	149
Liquid CP, g kg^{-1} DM	31	189	62.9	84	331
Liquid ash, g kg^{-1} DM	30	162	57.7	80	282
DM retained in liquid	32	0.131	0.0660	0.011	0.283
CP retained in liquid	31	0.186	0.1159	0.073	0.492
Ash retained in liquid	30	0.339	0.1735	0.114	0.833

Look at the maximums! There is plenty of scope to optimize.

Franco, M., Hurme, T., Winquist, E. & Rinne, M. 2019. Grass silage for biorefinery – A meta-analysis of silage factors affecting liquid-solid separation. Grass and Forage Science, DOI: 10.1111/gfs.12421.

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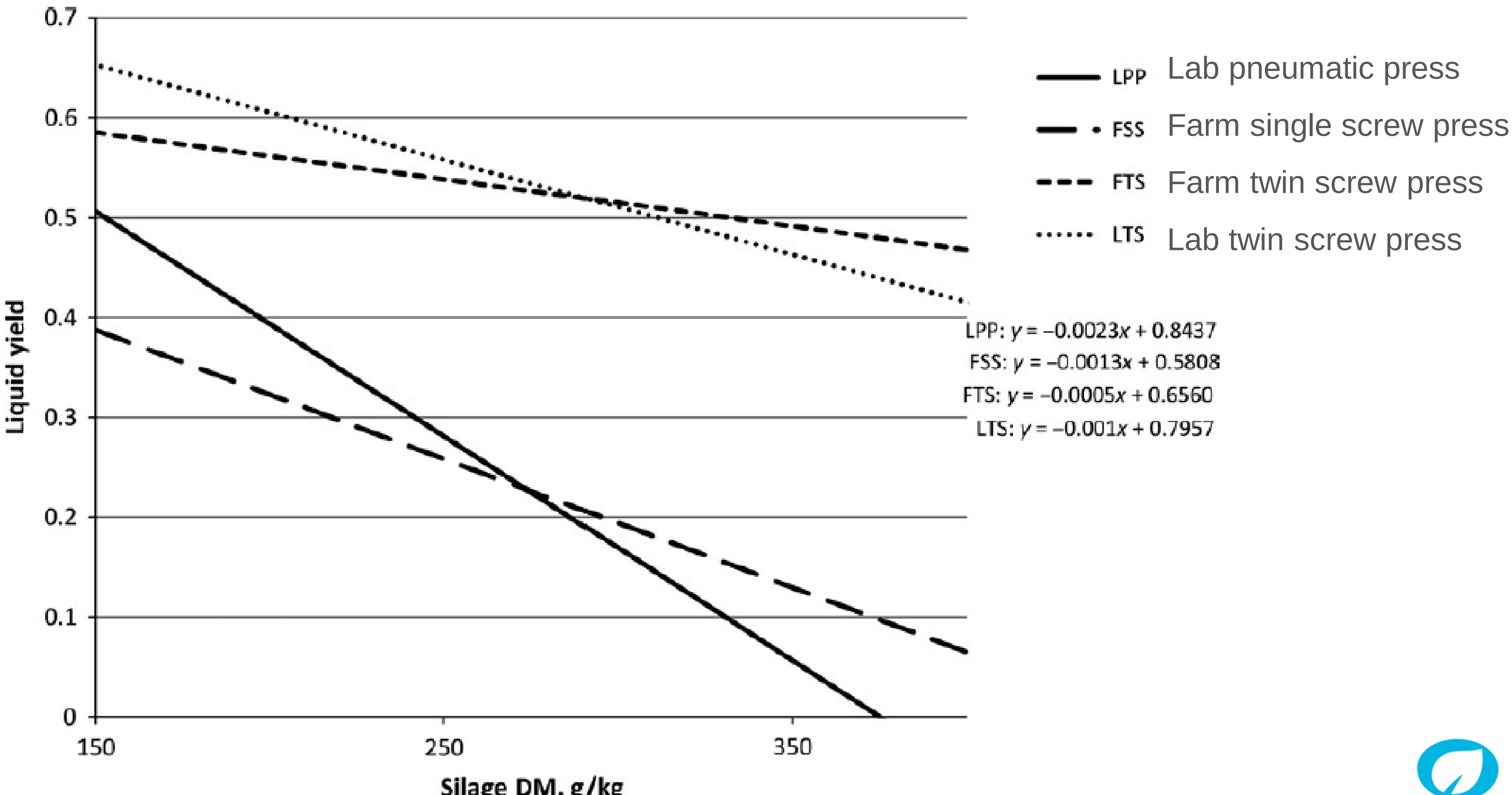
Liquid yield declined at different intensities when silage DM increased depending on the extraction method.



Franco, M., Hurme, T., Winquist, E. & Rinne, M. 2019. Grass silage for biorefinery – A meta-analysis of silage factors affecting liquid-solid separation. Grass and Forage Science, DOI: 10.1111/gfs.12421.

What we learned from the meta-analysis?

- Do not wilt the silage too dry – or no liquid will come out…
  - One possibility is to add water at processing to wash the solubles out
- If you want protein into the liquid, there needs to be plenty of it in the raw material as well
- Minerals are very efficiently exctracted into the liquid
  - High potassium may be a limiting factor in some applications
- In our limited data set, adidtive tretament or harvest did not affect the extraction but it was higher when red clover was included with grass
- Do not look at the means, look at the maximums!
  - Our systems were far from optimized, we were in the early phases of learning the techniques

Grass or clover for a green biorefinery?

- Both are suitable for a green biorefinery
- Clover as a legume can fix atmospheric nitrogen and is not dependent on N fertilization
  - Reduced environmetal loads of producing and transporting mineral fertilizers
- But grass efficiently utilizes high amounts of manure N
  - Which may be a great benefit e.g. on a pig farm, where field area and logistics of manure spreading can limit production
- Make choices according to the particular case

Silage juice production was succesful

- The twin screw press performed well with estimated throughput up to 1000 kg silage per hour
- The yields for a grass silage with DM of 264 g/kg were as follows:
  - Juice proportion (of original silage fresh weight) 488 g/kg
  - Juice dry matter 100 g/kg
  - DM proportion retained in juice 0.182
  - Ash proportion retained in juice 0.774
  - CP proportion retained in juice 0.575

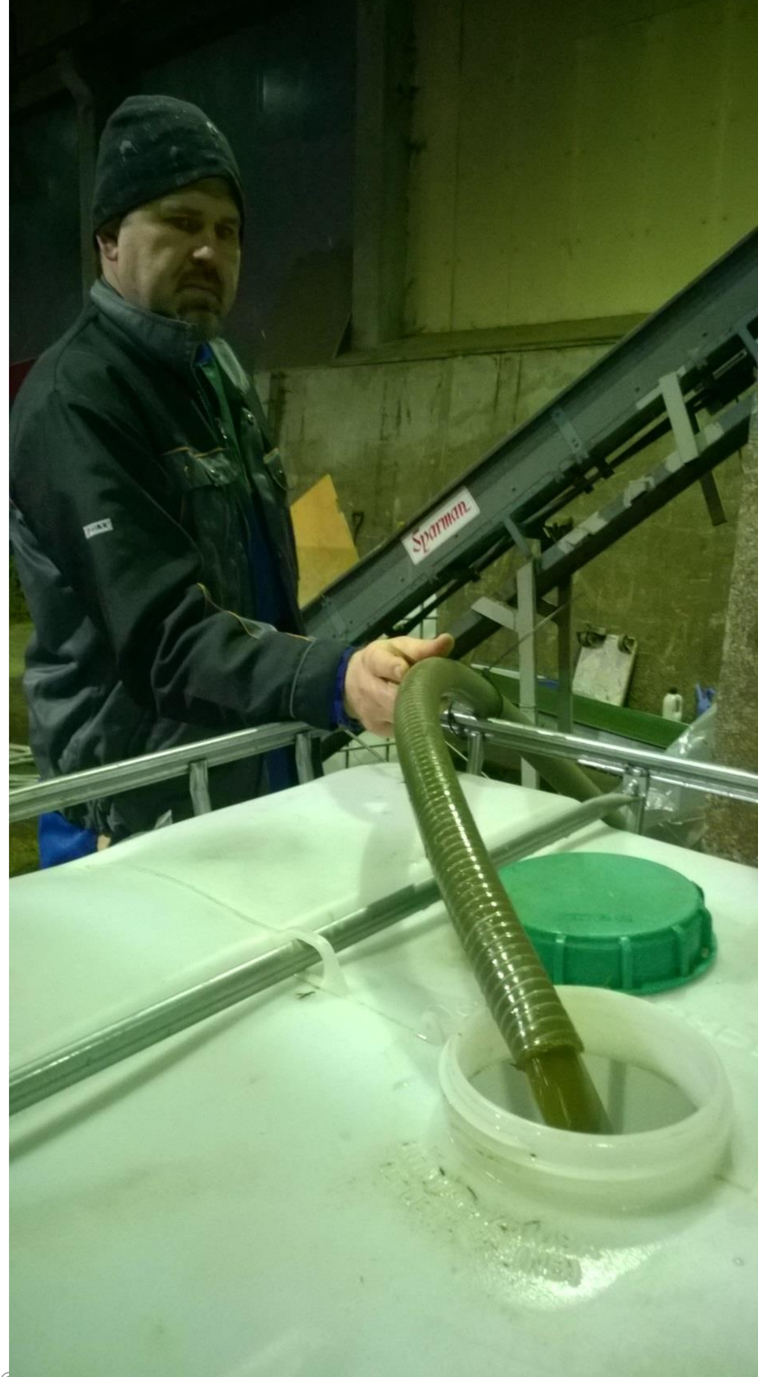
Photo: Marketta Rinne / Luke

Palatability trial with pigs

- The pigs readily consumed silage juice when it was mixed with pelleted complete feed
- The daily growth rate was excellent but the measuring period was too short to make conclusions
- The proportion of silage juice in the diet was low (12 % of energy intake)
- Silage juice provided fermentation end products and formic acid (6.6 g/kg – it was used as additive when making the silage) to the pigs which may stabilize the liquid feed and the intestinal digesta of the pigs


Photo: ©Antti Hyppönen

For the on-farm growing pig experiment during spring 2018, silage juice was pumped into IBC containers and transported to the farm once a week



Photos: Marketta Rinne, Luke

Growing experiment with pigs

- 200 pigs during finishing growth period of ~ 2 months were included
  - Control feeding
  - Experimental feeding receiving 1-3 l of silage juice per day
- Measurements: feed intake, daily growth rate, carcass and meat quality, faecal microbiome
- There were no problems with feed palatability
- The results in perfomance were similar among groups


Photo: ©Antti Hyppönen

Perfomance of growing pigs in the silage juice feeding experiment

	Control (n=112)		Silage Juice (n=88)	
	Gilts	Barrows	Gilts	Barrows
Live weight, kg				
In the beginning	62.8	63.0	60.9	63.3
In the end	124.9	124.3	122.8	123.8
Daily growth rate, g	1183	1187	1164	1155
Energy intake, MJ NE/day	34.2	36.0	33.1	34.7
Feed efficiency, MJ NE/kg	29.5	31.1	28.9	30.7
Carcass weight, kg	92.0	91.8	90.8	91.5
Taste panel score	14.3	15.2	13.4	16.4

Keto et al. Luke, unpublished.

The silage pulp can be used for biogas - or as we did, feed it to ruminants

The physical appearance of the pulp was modified by the extraction in the twin screw press.

Milk production potential of silage solid fraction (PULP)

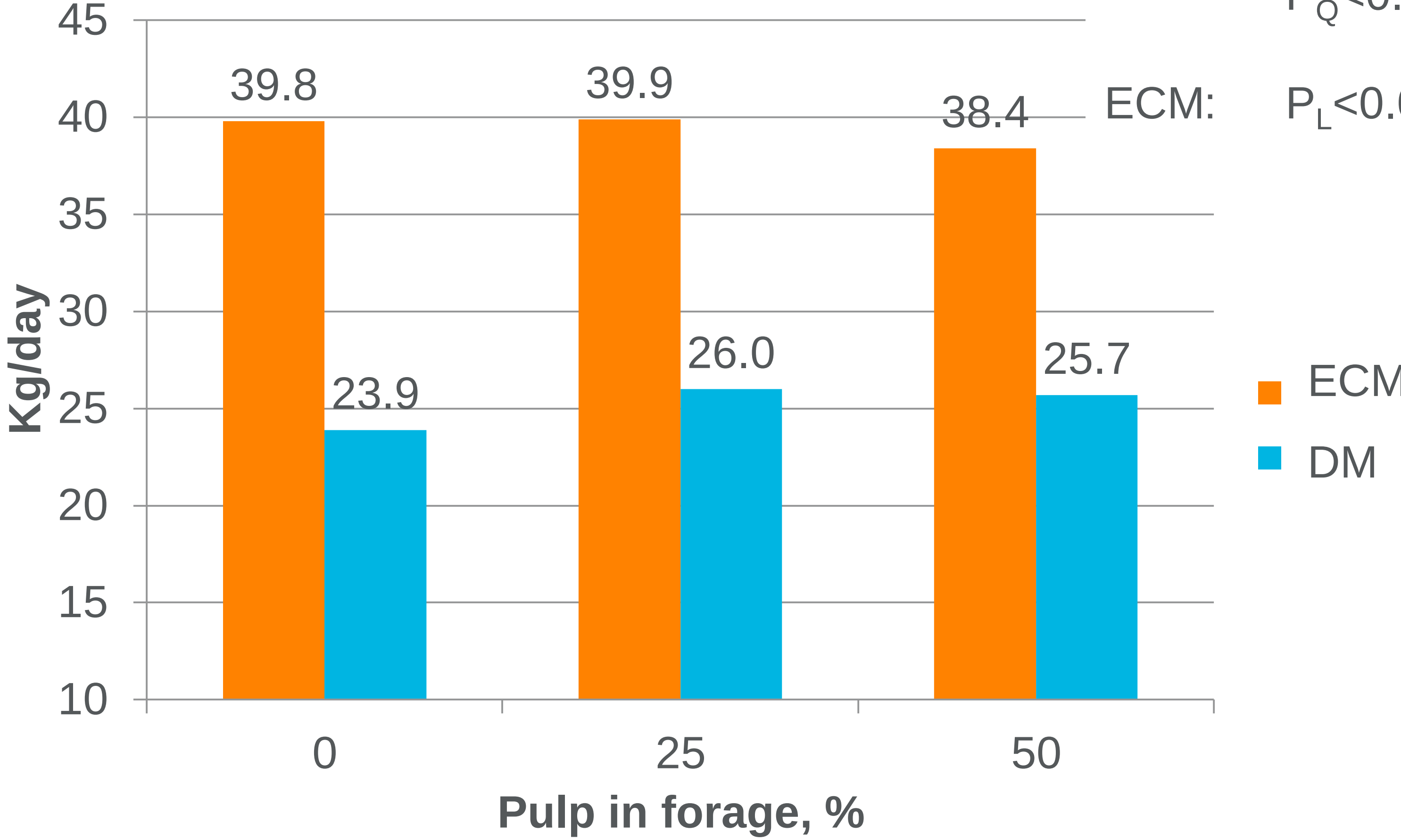
- The experiment was conducted at Luke Jokioinen during spring 2018
- 2 periods of 21 days each
- 24 dairy cows
- 3 dietary tretaments
  - Original silage (SIL)
  - SIL 75 % + PULP 25 %
  - SIL 50 % + PULP 50 %
- Measurements: Feed intake, milk production, milk compoistion, diet digestibility, rumen fermentation

Kuva: Marketta Rinne, Luke

Separated silage pulp as a feed component for dairy cows: Total dry matter (DM) intake increased but energy corrected milk production (ECM) decreased.

DM: $P_L<0.001$
$P_Q<0.001$

ECM: $P_L<0.05$



Savonen, O., Franco, M., Stefanski, T., Mäntysaari, P., Kuoppala, K. & Rinne, M. 2018. Grass silage for biorefinery - Dairy cow responses to diets based on solid fraction of grass silage. Proc. 9th Nordic Feed Science Conference, Uppsala, Sweden, 12-13 June 2018. Pages 55-60. Availabe at: https://www.slu.se/globalassets/ew/org/inst/huv/nfsc/nfsc2018/nfsc-2018_proceedings_corr_e-version.pdf.

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What did cows think about grass juice?

- A palatability trial of 5 days was conducted at Luke with fresh silage juice
  - The cows consumed their juice portion (up to 20 kg per day) with no problems
- Fortifying the TMR of dairy cows with silage juice could offer benefits on a dairy farm:
  - Increased proportion of grass based feeds (non-human edible) in dairy diets without increased rumen fill and decerased total DM intake and production
  - Potentially increased amount of intestinally available amino acids due to passage of soluble proteins in the liquid phase before being degraded in the rumen
  - The solid part could be directed to dry cows and heifers on the fram with lower nutrient requirements
  - The concept should be experimentally tested

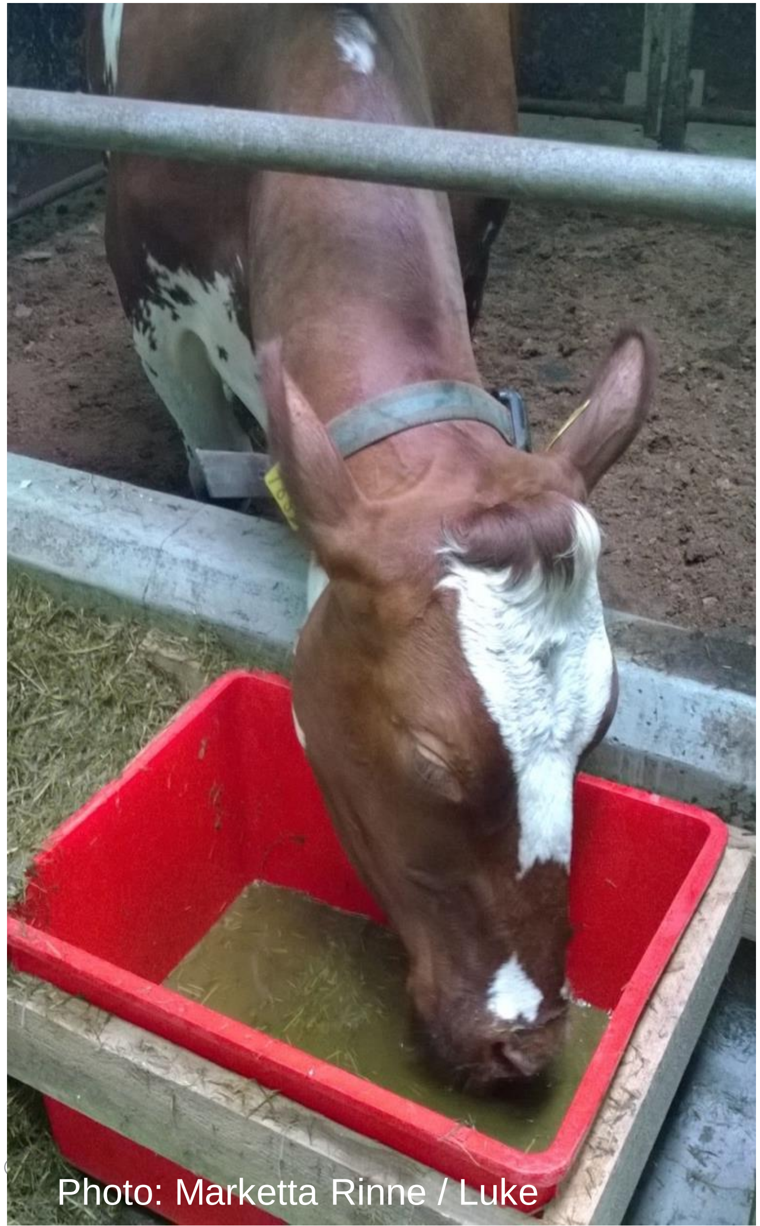
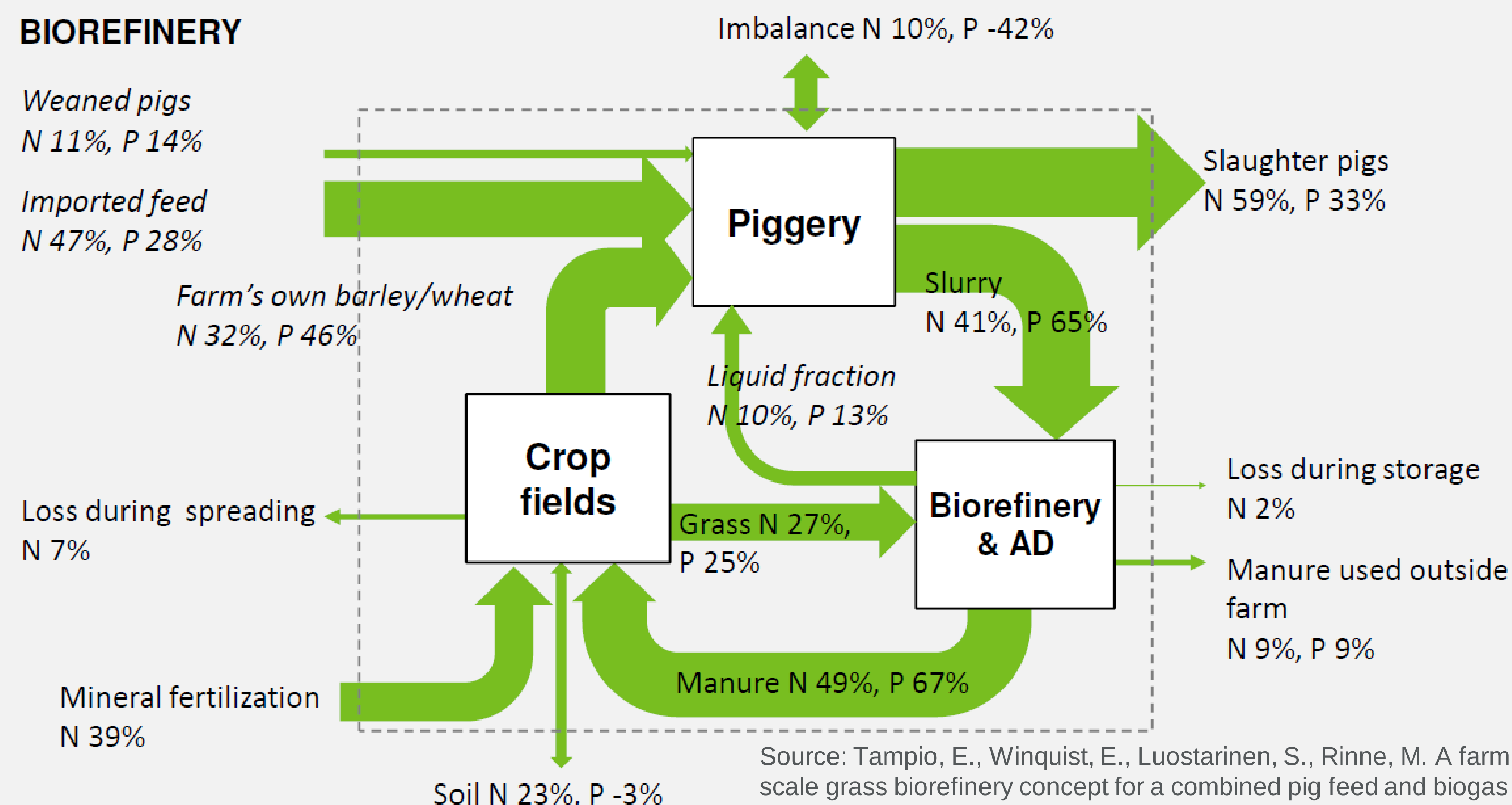


Photo: Marketta Rinne / Luke

The analyses of the nutrient flows and economic performance give some positive indications

Many things to consider including agri-environmental programs



Source: Tampio, E., Winquist, E., Luostarinen, S., Rinne, M. A farm-scale grass biorefinery concept for a combined pig feed and biogas production. *Submitted to Water Science & Technology.*

Multiple benefits of producing novel grass based feeds

- Increase of self sufficiency at farm, region and national level
- New markets for grass
  - Increased grass cultivation with potential benefits in nutrient use efficiency, soil structure, soil carbon sequestration, biodiversity, improved rural livelihoods
- Possibility of including grass into crop rotation of pig farms
  - See above plus possibility to use more manure per hectare than for cerels
- Including grass based products in pig diets increases the proportion non-human edible feeds in their diets
- Grass juice may act as a natural feed component having a positive effect on intestinal microbiota
- It is not simple to estimate the value of all these aspects in economic terms

What next? Even more revolutionary ideas needed!

– Grass based products for human food consumption!?

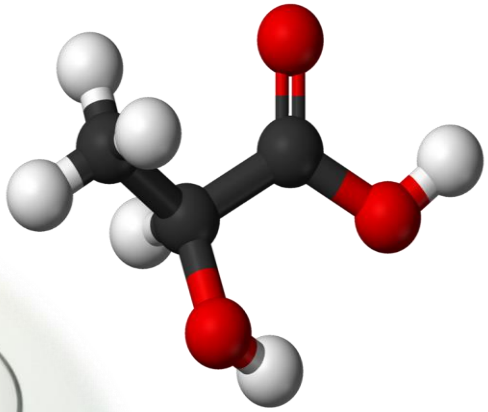


Photo: Marcia Franco / Luke

Photo: Marketta Rinne /Luke

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We warmly welcome papers on green biorefineries!

Scientific programme

Meeting the future demands for grassland production:

- Crop physiology, plant breeding and nutrient utilization
- Grasses in animal nutrition
- Grasslands and environment
- Novel technologies in farm management and economy
- Knowledge transfer and consumer perceptions

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Thank you!

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