Harvesting, logistics and upgrading of herbaceous biomass from verges and natural areas for use in thermal conversion

TKI BBE Park Cuijk

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Colophon

Abstract

In this experimentally focussed project optimised sustainable supply chains for Dutch herbaceous biomass sources (roadside grass and grass from natural environments) have been developed that are able to deliver raw materials of sufficient quality and acceptable costs for thermal conversion in the Cuijk multi-fuel power plant. Thermal conversion of these streams for CHP production will be the short-term solution for the economic use of these streams as alternative to composting and anaerobic digestion. This relatively short-term solution – the realisation of full economic value chains – potentially will be a first step to even more sustainable valorisation strategies for the longer-term, in which added-value biobased products will be separated from these streams upstream of the combustion process delivering residues to be used for CHP production. Within this project, harvesters have worked closely together with biomass suppliers (Krinkels, Natuurmonumenten), a biomass handler (Den Ouden Groep), an end-user (Essent), and a knowledge institute (WUR-DLO), to be able to make available full chain expertise necessary for the development of the sustainable supply chains.

The main goal of this project was to analyse if it is technically possible, environmentally favourable and economically profitable to use herbaceous biomass from verges (roadsides) and natural areas as raw material for combustion in the Cuijk facility of Essent for the production of CHP (combined heat and power).

It can be concluded that it is technically possible to harvest roadside/nature grass with hardly any soil contamination and that the potassium and chlorine content of the harvested material can be reduced by 70% by both natural leaching and artificial soaking meeting the fouling and corrosion thresholds for thermal conversion. Depending on the necessary capex and opex, artificial soaking potentially is the most promising pre-treatment option for grassy materials due to the relatively low biomass loss (10%) during pre-treatment, the controlled process producing a fixed amount of processed biomass within a fixed timeframe, and the high CO_2eq-reduction potential (3000-5700 kg CO_2eq/ha.year for respectively nature and roadside grass chains).

A first estimate valued herbaceous/grassy biomass (50% moisture and of a reasonable quality) at €17.5 to €22.5 per ton delivered (50% moisture). Projected delivery costs of pre-treated grassy materials of minimally 50 € per ton delivered show that significant further chain optimisation and/or a significant take-away fee will be necessary to result in a potential attractive business case.

Executive Summary

In this experimentally focussed project optimised sustainable supply chains for Dutch herbaceous biomass sources (roadside grass and grass from natural environments) have to be developed that are able to deliver raw materials at sufficient quality and acceptable costs for thermal conversion in the Cuijk multi-fuel power plant. Thermal conversion of these streams for CHP(combined heat and power) production will be the short-term solution for the economic use of these streams as alternative to composting and digestion. This short-term solution – the realisation of full economic value chains – potentially will be a first step to even more sustainable valorisation strategies for the longer-term, in which added-value biobased products will be separated from these streams upstream of the combustion process delivering residues to be used for CHP production. Within this project, harvesters have worked closely together with biomass suppliers (Krinkels, Natuurmonumenten), a biomass handler (Den Ouden Groep), an end-user (Essent), and a knowledge institute (WUR-DLO), to make available full chain expertise necessary for the development of the sustainable supply chains.

The main goal of this project was to analyse if it is technically possible, environmentally favourable and economically profitable to use herbaceous biomass from verges (roadsides) and natural areas as raw material for combustion in the Cuijk facility of Essent for the production of CHP.

Technical constraints: Potential technical constraints are both a) the contamination of herbaceous biomass streams with soil and other debris, and b) the quality of these steams (high ash, potassium, chlorine contents) potentially causing slagging, fouling and corrosion during thermal conversion. Current mowing and collection methods, like flail and rotary mowing, experimentally monitored, result in biomass heavily polluted by sand and (roadside) garbage. This makes the biomass unusable for direct use as raw material for most added value applications. In our harvesting experiment however, harvester operators showed to be able to produce grass with hardly any soil contamination by make some slight adjustments in procedures. The additional costs of mowing and harvesting with low contamination could not be quantified.

Nature grass sampled throughout the Netherlands contains significant amounts of potassium and chlorine, and very low sulphur amounts. In combination with other elements, including silica, ash fouling/slagging and corrosion is expected to occur during biomass combustion. Application of thermal conversion quality indicators (for slagging and fouling) showed that all of the analysed nature grass samples do not meet compliance thresholds for ash fouling and slagging. This means that fouling and slagging (agglomeration) is likely if not certainly to occur when these samples are used for combustion as such. Based on calculating chlorine concentration-based indicators, almost all natural grass samples will have the tendency to lead to corrosion during combustion.

Fouling and corrosion indicators showed that reducing potassium and chlorine by 70% would lead to grassy materials that are in or very near to the fouling and corrosion thresholds. Experimental work on both natural field leaching and artificial soaking showed that the 70% reduction goal of both potassium and chlorine can be met by both types of pre-treatment.

Environmental aspects: Concerning the environmental aspects both for roadside grass and nature grass 4 valorisation cases were assessed, viz.: composting (reference-case), anaerobic digestion for CHP (combined heat and power), combustion (Cuijk) with upstream natural leaching for CHP, combustion (Cuijk) with upstream artificial soaking for CHP. All grass valorisation cases will result in a significant CO_2eq-reduction replacing their fossil alternatives for CHP production. The specific CO_2eq-reduction potential of thermal conversion with upstream biomass pre-treatment will be about 3 times the amount of that of digestion. Considering the pre-treatment options for thermal conversion, artificial soaking will result in an approximately 35-40% higher CO_2eq-reduction potential than natural leaching, mainly caused by the lower biomass loss (10 vs. 30%) during pre-treatment. The CO_2eq-reduction potential of roadside grass is in all cases over 50% higher than that of natural grass, mainly caused by the higher annually harvested amount (14 vs. 8 tonnes (as is), two harvests a year).

Economics: A first estimate valued herbaceous/grassy biomass (50% moisture and of a reasonable quality) at €17.5 to €22.5 per ton delivered (50% moisture) compared to at least €30 for wood chips. Projected delivery costs of pre-treated grassy materials of minimally 50 € per ton delivered show that significant further chain optimisation and/or a significant take-away fee will be necessary to result in a potential attractive business case. Contractors Krinkels and Den Ouden, and nature conservancy Natuurmonumenten, have indicated that based on the results presented they may not be able to deliver pre-treated roadside and natural grass at such a price level that the further exploitation of a profitable business case based on CHP production at Cuijk could be possible for all stakeholders involved. Delivery of these materials to other markets, like for example the cardboard industry, potentially will result in a more interesting business-case for these partners.

Conclusion: It can be concluded that it is technically possible to harvest roadside/nature grass with hardly any soil contamination, and that the potassium and chlorine content of the harvested material can be reduced by 70% by both natural leaching and artificial soaking. The fouling and corrosion thresholds for thermal conversion can then be met in many cases and will very likely be sufficiently low that the material can be used when mixed with wood (chips). Depending on the necessary capex and opex, artificial soaking potentially is the most promising pre-treatment option for grassy materials due to the relatively low biomass loss (10%) during pre-treatment, the controlled process producing a fixed amount of processed biomass within a fixed timeframe, and the high CO_2eq-reduction potential (3000-5700 kg CO_2eq/ha.year for respectively nature and roadside grass chains). A first estimate valued herbaceous/grassy biomass (50% moisture and of a reasonable quality) at €17.5 to €22.5 per ton delivered (50% moisture). Projected delivery costs of pre-treated grassy materials of minimally 50 € per ton delivered show that significant further chain optimisation and/or a significant take-away fee will be necessary to result in a potential attractive business case.

Content

1. Introduction

1.1 Background

Mobilizing new biomass streams is crucial for various reasons, viz.: bioenergy has to provide a significant contribution to meet the Dutch Renewable Energy policy goal of 14% in 2020 (16% in 2023), and within a future Bio(based) Economy bioenergy will remain an essential link in the realisation of sustainable biorefining chains. A major challenge of the energy sector is to be able to produce secondary energy carriers based on sufficient available and affordable sustainable biomass resources.

RWE/Essent investigates the potential of unlocking herbaceous (grassy) biomass for thermal conversion into electricity and heat. The biomass energy facility at Cuijk (annual input ≈ 220 ktonne biomass producing 25 MW_e and 50 MW_{th}) is used as a demonstration facility for this purpose.

A significant part (5 Mt dry basis) of the biomass available in the Netherlands that can be used to feed the Bio(based) Economy – i.e. for the production of biobased products (chemicals, materials) and/or bioenergy (power, heat, fuels) – consists of herbaceous biomass. Depending on different scenarios, it is expected that about 5-40% (0.3-2.1 Mt DM) of these potentially available raw materials will be used for power and heat production in 2020 (see Table 1).

Table 1. Expected use of Dutch herbaceous (grassy) biomass for power and heat in 2020 [Koppejan et al., 2008]

Biomass type	[kton dry base]	
	Gross production based on 2009 data and extrapolations	Use for power and heat production in 2020
Straw	935	94-187
Grass straw (seed production)	85	4-9
Wet crop residues	985	0-297
Wet crop residues horticulture	356	70-140
"Vanggewas" for energy	70	14-28
Grass from natural areas	1.080	54-378
Roadside (verge) grass	640	32-512
Heath	146	0-44
Reed	40	0-16
Energy crops agriculture	9.9	0-99
Other energy crops	(500)	25-250
Wet biomass build environment	490	0-25
Meadow grass for refining	(10.000)	0-200
Total:	5337	293-2185

1.2 Problem definition

In spite of the fact that a large amount of Dutch herbaceous (grassy) biomass resources potentially are available for energy (and other non-food) applications, for the time being it is not known how the geographic availability, timeframe of production, volumes and compositions (relatively high water content and low energy density) will meet to the requirements set by the downstream equipment available (the Cuijk power plant of RWE/Essent) to process them into secondary energy carriers. In general it is believed that high capital intensive modifications of the existing thermal conversion facility will be necessary to process these streams.

Also it is not known how the herbaceous (grassy) biomass resources potentially can be influenced positively and sustainably upstream of the conversion process – by for example optimised harvesting management and technology, storage, logistics, and low-cost pre-treatment – so that they will meet the downstream conversion process requirements, requiring no or only limited facility modifications.

Two clear technical bottlenecks can be found in the production chain of herbaceous biomass for utilisation by means of thermal conversion:

1. Contamination with soil and other debris
2. Quality of the biomass for thermal conversion (high ash content and high K and Cl contents)

With respect to the contamination with soil and other debris, this is a problem for all herbaceous biomass valorisation options that currently are being considered, including: thermal conversion, anaerobic digestion and biorefinery for fibres or fuels/chemicals. Contamination is especially a problem when herbaceous biomass is sourced from road verges and from natural areas. This type of biomass is available at low cost but requires new harvesting management and logistical systems to make them applicable raw materials instead of waste streams that have to be carried away.

With respect to the high ash, K and Cl content, this quality issue is typically a concern for thermal conversion, but may also pose a challenge for other applications, such as pulp production or biorefinery, though to a lower degree. The project may therefore also benefit other applications of herbaceous biomass.

Beside these technical constraints there are also potential non-technical barriers that potentially will influence the availability of herbaceous biomass resources for new applications, like: existing contractual appointments, sustainability requirements principals, ...

1.3 Objective

The goal of this project is to develop optimised sustainable supply chains for Dutch herbaceous (grassy) biomass that can deliver biomass raw materials at sufficient volumes, quality and acceptable costs for thermal conversion processes (Cuijk multi-fuel power plant of Essent/RWE).

1.4　Approach

Quality improvement and/or cost reduction opportunities to maximise overall chain sustainability

Area (source) management
Delivery raw materials instead of waste streams
Materials production vs. other area aspects?

Harvesting management
Delivery raw materials on spec
When, how, how often?

Grass from natural environments
Roadside grass
Reed

Storage, pre-treatment & logistics
Matching raw materials supply (quality, volumes) to plant requirements

Cuijk multi-fuel CHP plant
Technological, environmental and economic constraints on raw materials use

Residues

Added-value Bio-based Products

Herbaceous (grassy) biomass delivery chain for thermal conversion (incl. production, harvesting, storage, pre-treatment and logistics); each link in the chain offers the opportunity for quality improvement and cost reduction of the herbaceous biomass materials

Figure 1. Scheme project approach

At the start of the project, the following activities were foreseen:

1) Supply chain description and design

For different locations and types of herbaceous (grassy) biomass (roadside grass and grass from natural environment) a description will be made of the current practise concerning herbaceous (grassy) biomass handling (harvesting, storage, logistics) and use (reference cases). Together with all project partners new optimised biomass handling systems will be designed that potentially will be able to deliver raw materials at sufficient quality and acceptable costs to be thermally processed in the Cuijk multi-fuel power plant. The types of biomass types dealt with are: roadside grass and grass from natural environments.

2) Harvesting tests

For each type of biomass (location) the current harvesting system will be evaluated, and the biomass will be tested for contamination (manual harvest without contamination compared to machine harvest). For each type/location a set of improvements, will be defined (by contractors with practical experience and collaborating researchers). Harvested biomass that can be delivered at sufficient quality and acceptable costs will be selected for further testing. The system will be compared on biomass quality, costs, and environmental impact.

3) Pre-treatment and storage tests

The selected materials from 2 will be exposed to controlled leaching at lab-scale to determine what field options could work under natural conditions. Ultimate, proximate analysis and ash melting point analysis will be determined to analyse if the harvesting and storage methods are effective, and if the biomass is of sufficient quality for thermal conversion at Cuijk and similar sites.

4) Sustainability analysis & assessment non-technical bottle-necks

The results of the tested biomass (harvesting and pre-treatment/storage) supply systems will be compared on their ability to deliver biomass of sufficient quality and acceptable costs for thermal conversion in the Cuijk power plant. The most promising supply systems will be assessed on their overall sustainability (economics, ecological and social aspects). Other constraints will be discussed.

5) Qualitative assessment sustainable valorisation chains for the longer-term

By handling herbaceous biomass streams as raw materials for CHP production potentially making money (however, mainly subsidy-based), instead of waste streams for composting costing money, a first very important step will be made in making available full biomass supply chains for economic attractive use. In the longer-term these supply chains could be further upgraded to even more added value ones, potentially becoming independent from financial governmental support, by upstream separation of added-value biobased products out of these streams, using residues produced for CHP production. In this activity a short qualitative overview will be given of other herbaceous valorisation chains based on open literature. Main focus will be on the link with the Cuijk power plant, viz. the type, composition and volumes of the residues potentially produced.

6) Reporting

The results will be reported by FBR with input from all project partners in a confidential report (this report) for the project partners. A more generalised summarising report (executive summary) will be made for the subsidising body, and for dissemination to a wider audience.

7) Test in practice @ 500 ton scale

As next step, following this project, a supply system should be designed for full-scale integrated testing at a 500 ton scale.

During the project execution – due to advanced insight – the following changes to the initial activity plan were made:

1) It was decided to focus the activities on the potential short-term valorisation opportunities of herbaceous biomass by combustion in the Cuijk power plant of Essent/RWE. Concerning the qualitative assessment of sustainable valorisation chains for the longer-term (act.5); this activity was only dealt with very briefly as part of the sustainability analysis and the assessment of non-technical bottle necks (act.4).

2) The planned workshop on valorisation of herbaceous (grassy) biomass (part of act.7) – with the main goal of informing a wider public – was replaced by the preparation of 2 additional documents, viz.:

 a) Scientific Paper on "Analysis and ash fouling/agglomeration potential grass samples in the Netherlands" – based on the results presented in chapter 3. – to be submitted for publication.
 b) Generic Publication on "Maaisel als duurzame bron – Van afvalstroom naar energie" – published in "Vakblad Natuur Bos Landschap, no.118, October 2015.

3) The test in practice @ 500 ton scale (act.8). A go/no-go decision concerning this large-scale test may be taken in 2015/2016depending on re-deployment of the Cuijk facility.

1.5   Set-up report

- Chapter 2.: Supply chain description and design
- Chapter 3.: Analysis and ash fouling/agglomeration potential of 25 grass samples from the Netherlands
- Chapter 4. Effect harvesting method on biomass quality for thermal conversion purposes
- Chapter 5.: Field leaching tests
- Chapter 6.: Soaking tests
- Chapter 7.: Sustainability analysis & assessment non-technical bottle-necks, incl. potential longer-term valorisation opportunities
- Chapter 8.: Discussion & Conclusions

2.   Supply chain description and design

2.1   Introduction

Verge grass along roads, and other types of infrastructure, is generally mowed at least one, and often two or more times per year, depending on the specific demands at the site. Different methods exist for mowing and removing the grass. In our experience (WUR-DLO), current mowing and collecting methods always lead to grass/biomass being heavily polluted by sand and road side garbage (Figure 2). The ash content can be as high as 40% (of dry matter). This makes the biomass unusable for added value applications, such as: biogas production, thermal conversion and biorefining, unless the garbage and sand is removed at additional cost.

Figure 2. Verge grass from road sides collected showing garbage pollution (left) and sand pollution (right) [pictures: Wageningen UR – Food and Biobased Research (WUR-FBR)]

Two general methods of mowing can be employed, viz.: flail mowing and rotary mowing.

2.2   Flail mowing

Flail mowing (Figure 3), often used as roadsides, is quite robust and is best used to provide a rough cut where contact with loose debris occurs. Flail mowing is often used in suction mowing near the roadside and around roadside objects. The mowed material is then immediately removed into a trailer wagon behind the tractor. This makes mowing and removing the biomass in one go possible which is important for limiting traffic disruption.

The suction generated by the mower will also remove garbage and soil material thereby contaminating the mowed biomass. If flail mowing is employed it will not be possible to produce mown grass with no or low soil contamination.

Figure 3. Flail mowing explained and suction mowing [pictures: Wikipedia, www.nemos.nl, WUR-FBR]

2.3 Rotary mowing

Rotary mowing is similar to normal grass mowing on farms. Rotary mowing is often employed in areas further removed from the road edge where less obstacles are found. This mowing method is also employed when mowing natural areas. After mowing, the grass is generally left to dry for a few days, after which the biomass is raked together and removed by a loader wagon (Figure 4).

2.4 Discussion & conclusions

Rotary mowing (Figure 4) does not necessarily lead to soil contamination, if measures are taken as described by Holshof et al (2014). This method has been applied for the experiment in Chapter 4.

Figure 4. Rotary mowing, raking and loading by bandwagon illustrated [pictures: WUR-FBR]

Presence of mole heaps, and tractor tracks, will lead to heavy pollution of sand in the mowed biomass if rotary mowing is applied (Figure 5).

Measures to avoid contamination may include employing a higher mowing height, levelling the surface with a "grass roller" (see Figure 5), and controlling moles and other rodents. See Holshof et al (2014) for more info.

Figure 5. Sources of soil contamination illustrated [pictures: WUR-FBR]

3. Analysis and ash fouling/agglomeration potential of 25 grass samples from the Netherlands

3.1 Introduction & methodology

Based on a set of grass samples that were collected and analysed in 2009 by partner Natuurmomenten, an analysis was made of the suitability of nature grass as a feedstock for combustion. The goal was to identify the composition and fouling and corrosion potential of different grass samples, and to assess the potential benefits of leaching out nutrients, and other minerals, such as K, Na and Cl, with the objective to improve combustion behaviour.

Goals of this part of the project were to:
- Provide an overview of variability in composition in 25 samples that were sampled throughout the Netherlands.
- Based on commonly used indicators, assess the potential of ash agglomeration and corrosion problems that would occur during combustion of grass.
- Illustrate potential benefit of leaching/washing out certain minerals from the grass, in order to improve combustion behaviour, and in particular, reduce ash fouling problems.

Terms used in this paragraph:
- Slagging: Deposit formation on heat transfer surfaces of energy conversion equipment from the adhesion of sticky particles under the influence of radiative heat transfer (e.g. flames).
- Fouling: Deposit formation on the cooler surfaces of energy conversion equipment either by the adhesion of sticky particles and or condensation of particles transported by combustion gases from hot zones to cooler zones.
- Bed agglomeration: Loosely bound particles become more dense, forming a compact hard mass, and stick to common bed material (sand). It leads to reduced heat transfer and de-fluidisation of combustions systems.

3.2 Results

3.2.1 Origin of samples
- 25 grass samples were collected by hand from 15 locations in the Netherlands
- Compositional data of these samples were collected and provided by Natuurmonumenten, based on laboratory analysis
- Sampling dates: June 2009, July 2009, and September 2009
- Most samples contained about 30% dry matter (70% moisture) at time of collection
- GPS locations of most locations were recorded
- During sampling, information of the type of vegetation was included for most samples
- During sampling, type of land management (code) recorded; examples: N.01.03, N.06.01, N.10.01 etc.

Figure 6 shows the geographical distribution of the collected samples. Besides 25 grass samples, one sample of reed was also collected, as well as one sample of "sluiksel" (a residual product that remains after collection of reed for building/thatching purposes).

Figure 6. Geographical distribution of sampling spots

3.2.2   Chemical analysis

Chemical analysis of the grass included: elemental analysis of the grass (sulphur, chlorine, fluorine, carbon, hydrogen, nitrogen, oxygen), total ash concentration, volatile matter, and higher heating value. In addition, the mineral composition of the ash was determined, for both macro-elements (silica, aluminium, iron, calcium, magnesium, sodium, titanium, phosphor and potassium) as well as minor inorganic elements (antimony, arsenic, beryllium, cadmium, … , zinc). During the course of this part of the study, no combustion tests or ash fusibility tests were conducted.

3.2.3   Fouling and corrosion indices

In order to estimate the tendency to cause fouling and corrosion in direct combustion boilers, the following indices were used:

Alkali index for Fouling/Slagging (source: Miles et al, 1996) which is based on the total amount of sodium and potassium oxides, divided by higher heating value:

$$\text{Alkali Index (AI)} = (Na_2O + K_2O)/HHV$$

According to Miles et al, the following thresholds for ash fouling can be used, when estimating the tendency for fouling during biomass combustion: AI < 0.17: slagging/foulig not likely, 0.17 < AI < 0.34: probably fouling, AI > 0.34: fouling.

Fouling index (source: Teixeria et al, 2012) based on Base/Acid ratio (B/A), where:

$$B/A = (Fe_2O+CaO+MgO+Na_2O+K_2O))/ (SiO_2+Al_2O_3+TiO_2)$$

According to Teixeria et al, the following thresholds for the Base/Acid ratio can be used, when estimating the tendency for fouling during biomass combustion: B/A < 0.6: low, 0.6 < B/A < 1.6: medium, B/A > 1.6: high.

In addition, a number of other Fouling and Corrosion indices were also used to indicate the fouling tendency of grass. These additional indicators are summarised in Table 2.

Table 2. Additional agglomeration and corrosion indicators [Essent]

Agglomeration indicators	Threshold
(Na+K)/(2S+Cl) ratio	<1
(Na+K+Si)/(Ca+P+Mg) ratio	<2
(K+Na)/Si ratio	<0,6
K2O+Na2O+SiO2 (% ash)	<50%
Corrosion-indicators	**Threshold**
Cl (wt-%)	< 0,2 wt-% (in blend)
S:Cl ratio	> 4 (higher risk)

3.2.4   Average ash composition

Figure 7. Average mineral composition (% dry weight) of 25 grass samples

Main components in order of magnitude are: silica, potassium, calcium, phosphor, sodium, and magnesium. In general, samples contain only very minor amounts of iron and aluminium, which indicates that the samples are not contaminated with soil particles.

Not shown in Figure 7 are other major elements in biomass, including chlorine and sulphur. The analysis indicated that chlorine concentrations in the grass samples are significant (weighted average of 0.72 wt%, with a range of 0.14 to 1.90 wt% on dry biomass basis). Sulphur concentrations are relatively low: the average concentration is 0.28 wt%, with a range of 0.11 to 0.56 wt% on dry biomass basis.

3.2.5   Concentration of ash, major elements

Figure 8. Ash concentration (% dry basis) of 25 grass samples ranked from low to high concentration

Ash concentrations, depicted in Figure 8, range from 3.3 to 12.5 % dry weight, with a weighted average of 7.9%. As can be seen from the figure, about one quarter of the samples have ash contents lower than 6%, whereas one quarter of the samples have ash contents higher than 10%.

Higher heating values, as shown in Figure 9, against ash content, range from 17.5 MJ/kg to 20 MJ/kg, with a weighted average of 18.7 MJ/kg, which is quite typical for any lignocellulosic biomass feedstock. As represented in the figure by a trend-line, a higher ash concentration in the samples can be associated with a decrease in heating value. Illustrating that the energy content (HHV) of this material (dry and ash free) should be very similar.

Figure 9. Ash concentrations of 25 grass samples ranked from low to high concentration

Table 3. Summary of sample location, collection date, management type, and concentrations (dry matter) of ash, potassium, and chlorine of 25 grass samples

Sample ID	Location*	Collection Date	Management Type	Ash	Potassium	Chlorine
1	Dintelse gorzen	17-Jun-09	N.01.03	10.5	2.17	0.61
3	Peizermaden	15-Jun-09	N.01.03	9.5	2.53	0.98
32	Peizermaden	15-Sep-09	N.01.03	7.2	0.66	0.90
48	De Wieden	08-Sep-09	N.06.01	5.8	0.91	0.71
4	De Wieden	16-Jun-09	N.10.01	3.3	0.47	0.27
5	Dommel-beemden	23-Jun-09	N.10.01	7.8	1.56	0.61
5.1	Weerribben	22-Jul-09	N.10.01	5.7	0.60	0.15
6	De Klencke	15-Jun-09	N.10.02	6.0	2.21	0.64
7	Peizermaden *a*	15-Jun-09	N.10.02	5.12	0.76	0.56
8	Sint Anthonis	23-Jun-09	N.10.02	5.47	0.35	0.46
34	Peizermaden *a*	15-Sep-09	N.10.02	7.6	0.85	1.16
11	Schelde: Zak van Zuid-Beveland *b*	17-Jun-09	N.12.01	8.2	1.97	0.61
36	Zak van Z-Beveland *b*	29-Sep-09	N.12.01	12.5	1.74	0.79
37	Zak van Z-Beveland	16-Sep-09	N.12.01	9.1	1.35	0.70
12	Zuid Beijerland	25-Jun-09	N.12.01	10.1	2.13	0.71
14	Plancken Wambuis	15-Jun-09	N.12.02	8.1	2.18	0.56
15	Mantingerveld	15-Jun-09	N.12.02	5.39	1.12	0.59
40	Mantingerveld	15-Sep-09	N.12.02	6.3	1.16	0.57
16	Slabroek	23-Jun-09	N.12.02	6.5	0.33	0.65
17	Wijstgronden	23-Jun-09	N.12.02	10.5	0.61	0.99
19	NH-Midden: Weidse Polders *c*	17-Jun-09	N.12.03	7.0	0.86	0.48
41	NH-Midden: Weidse Polders *c*	16-Sep-09	N.12.03	12.0	1.83	0.88
22	Wormer- en Jiperveld *d*	16-Jun-09	N.13.01	7.4	1.31	0.76
46	Wormer- en Jiperveld *d*	15-Sep-09	N.13.01	11.3	2.01	1.90
23	Beetsterzwaag	22-Jul-09	N13.01	8.3	0.72	0.70
26	Weerribben Sluiksel	7 – July-09		4.41	0.45	0.16
27	Weerribben Riet	7 – July-09		3.51	0.19	0.06

* Note: locations with same cursive letter are taken at exact the same location but at different dates

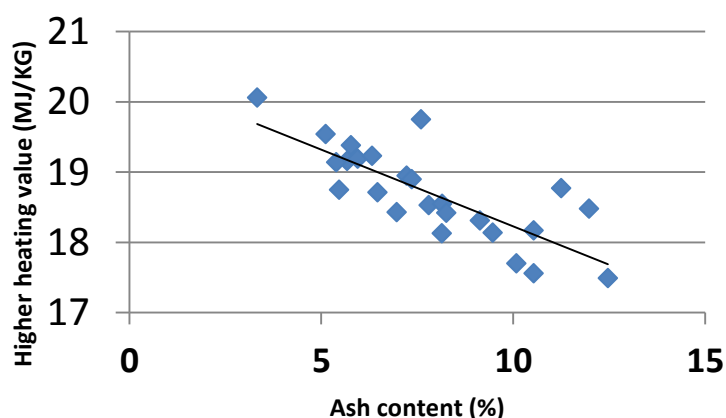Table 3 presents the sample location, collection date, management type, and concentrations (dry matter) of ash, potassium, and chlorine of all the 25 grass samples, plus the two additional samples of reed and "sluiksel". As far as collection date is concerned, it shown that in all cases where two samples were collected on different dates in the season, a sampling date in September leads to a higher ash concentration (e.g. locations Peizermaden, zak van Zuid Beveland, Weidse Polders, and Wormer- en Jiperveld) compared to the material sampled in June.

Based on available soil maps, the clay and silt concentration for most of the locations was identified, in order to correlate the soil type with ash and major elements in the grass. Table 4 presents the average, minimum, and maximum ash, potassium, sodium and chlorine concentrations of the grass samples, categorised by three major soil types. As can be seen in the table, grass derived from clay soils appear to have somewhat higher ash, potassium, sodium, and chlorine concentrations compared to grass grown on sandy soils. Concentrations of clay for the intermediate soils are based on only two locations, and therefore the data for grasses from this soil category are thought to be not representative. No apparent effect of management type on composition was seen.

Table 4. Ash, potassium, sodium and chlorine concentrations in grass, categorised by soil type

		Ash (wt %)	Potassium (wt %)	Sodium (wt %)	Chlorine (wt %)
Heavy clay, medium heavy clay, light clay; n = 7	average	8.4	1.5	0.15	0.98
	Min	5.1	0.7	0.07	0.56
	Max	11.3	2.5	0.25	1.90
Zware zavel (lutum 17 - 25%) n = 4	average	10.0	1.8	0.18	0.70
	Min	8.2	1.3	0.13	0.61
	Max	12.5	2.1	0.21	0.79
Sandy soils (lutum < 8%); n = 11	average	7.1	1.1	0.11	0.63
	Min	3.3	0.4	0.04	0.27
	Max	12.0	2.2	0.22	0.99

Alkali index and Base-to-Acid ratio

Figure 10 presents the alkali index of the 25 samples, along with major thresholds at which ash fouling is estimated to occur. It shows that combustion of the samples, based on their current potassium and sodium content as well as the heating value, will certainly lead to fouling as the index of most samples by far exceeds the 0.34 threshold. In four cases however (sample IDs 16, 4, 5.1 and 8 which have alkali indices just at the 0.34 threshold), blending the grass with other, more benign fuels, may lead to a feasible application.

Figure 10. Alkali Index (Miles et al, 1996) of 25 grass samples

Figure 11 presents the Base to Acid ratio of the 25 samples, along with major thresholds at which ash fouling is estimated to occur. This index shows a slightly better trend compared to the Alkali index: in about 40% of the samples "medium" fouling is indicated to occur, which also indicated that blending of the grass with other more benign fuels could lead to low fouling for a larger number of the samples.

Figure 11. Base to Acid ratio (Teixeira et al , 2012) of 25 grass samples

3.2.6 Other Ash Agglomeration and Corrosion Indicators

Agglomeration indicators

Table 5 presents results of calculating four different agglomeration indicators that are all based on different combinations of the concentrations of the main inorganic elements, including Na, K and Si. These results show that the majority of the samples do not meet the threshold, indicating that ash agglomeration during the combustion of these samples is very likely to occur. For two indicators, however, about one third of the samples score below the threshold, indicating that combustion could be feasible for these samples, without major agglomeration issues.

Table 5. Overview of 4 agglomeration indicators and results for 25 grass samples

Agglomeration indicators	Threshold	Average	Minimum	Maximum	% of grass samples compliant (lower than threshold
(Na+K)/(2S+Cl)	<1	1.2	0.6	2.5	36%
(Na+K+Si)/(Ca+P+Mg)	<2	2.3	0.8	5.5	36%
(K+Na)/Si	<0,6	1.2	0.4	10.5	16%
K2O+Na2O+SiO2	<50%	57.3	19.8	76.1	24%

Corrosion index

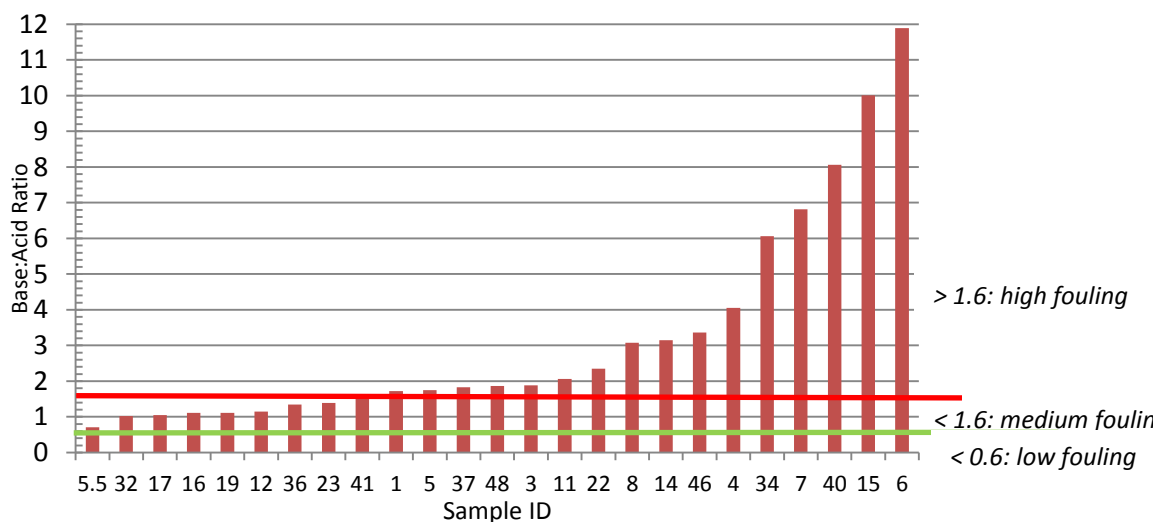Table 6 shows the scores for two corrosion indicators, which are based on either chlorine concentration in the biomass or a ratio of sulphur and chlorine concentrations. For the first chlorine-based indicator, just one sample is below the threshold for corrosion, meaning that almost all samples would be prone to lead to corrosion. It should be noted that in general, the chlorine concentrations indicated in the analyse are quite high, especially when compared to other types of herbaceous biomass common in the Netherlands.

The second corrosion indicator which is based on sulphur to chlorine ratio, shows that the samples by far exceed the threshold at which corrosion is thought to occur. However, the question is whether this particular indicator is relevant for grass, as sulphur concentrations are quite small, in particular when compared to chlorine concentrations.

Table 6. Overview of corrosion indicators and results for 25 grass samples

Corrosion indicators	Threshold	Average	Minimum	Maximum	% of grass samples compliant
Cl (wt-%)	< 0,2 wt-% (in blend)	0.72	0.15	1.90	4%
S:Cl ratio	> 4 (higher risk)	0.39	0.19	0.96	0%

3.2.7 Potential benefit of leaching potassium, sodium and chlorine on fouling potential

Effect of removing K and Na on fouling potentials

Figure 12 shows the effect of removing potassium on the alkali index. Results show that, compared to the index of the original material that reducing 50% of K leads to a drastic reduction of the alkali index, although most samples would still be in the "certain fouling" region. However, reducing potassium by 70% would lead to a further improvement, as most of the samples would be in or very near to the "probably fouling" threshold, and blending these fuels with other biomass fuels could lead to a feasible fuel blend from ash fouling perspective. As presented in other parts of this study (Chapter 5), as well as previously published work, it is feasible to reduce potassium concentrations by 70% or more by simple water leaching of the material.

Figure 12. Effect of removing potassium on the alkali index

Figure 13 shows the effect of removing potassium and sodium on the alkali index. Results show that reducing 50% of K and Na would lead to the majority (60%) of the samples be located in the "medium fouling" region (threshold of 1.6). In addition, reducing potassium and sodium by 70% would lead to most of the samples would be below or very near the "low fouling" threshold of 0.6.

Figure 13. Effect of removing potassium and sodium on Base to Acid ratio

Table 7 shows the effect of removing K and Na on two of the main agglomeration indicators from Table 4. Removing 50% and 70% of K and Na would lead to 60% and 80% of the samples meeting the threshold for ratio of K and Na to Si. This is a vast improvement, although many samples would not fall within safe limits for ash agglomeration potential. This could be overcome by blending the grass with more benign fuels. Removing K and Na on the second agglomeration index (total of K, Na and Si concentrations) has a lower effect, which is mainly due to the significant silica concentration in the samples.

Table 7. Effect of potassium and sodium removal on Agglomeration potential

Agglomeration indicators	Assumed removal of K and Na (% of original)	Average	Minimum	Maximum	% of grass samples compliant
(K+Na)/Si ratio threshold < 0.6	50	0.90	0.20	4.40	60%
(K+Na)/Si ratio threshold < 0.6	70	0.49	0.10	2.51	80%
K2O+Na2O+SiO2 (% ash) Threshold < 50%	50	48.7	14.6	76.2	36%
K2O+Na2O+SiO2 (% ash) Threshold < 50%	70	50.7	15.7	75.3	40%

Table 8 shows the effect that removal of chlorine by rain or controlled leaching would have on the corrosion potential. Results of the chlorine-based indicator show that 50% removal of chlorine would not have a large effect on the corrosion potential: only two of the samples would meet the threshold. However, when 70% of chlorine is removed from the grass, more than half of the samples meet the threshold for corrosion, based on chlorine concentrations. As noted before, the very high chlorine concentrations in the grass samples are a large factor here.

Table 8. Effect of removing Cl on the corrosion potential

Corrosion-indicators	Assumed removal of Cl (% of original)	Average	Minimum	Maximum	% of grass samples compliant
Cl (wt-%)	50	0.36	0.07	0.95	8%
Cl (wt-%)	70	0.22	0.04	0.57	56%

3.3 Discussion & conclusions

Composition of grass
The samples were harvested by hand, therefore we can assume that the composition depends on the plan physiology and not on contamination which is often the case with machine mowed samples. The low iron content of the samples confirms that soil contamination was very low or absent.

Grass sampled throughout the Netherlands contains significant amounts of potassium and chlorine. In combination with other elements, including silica and sulphate, ash fouling and corrosion is expected to occur during biomass combustion. In general, sulphur concentrations in grass are very low.

The ash concentration of most grass samples is within the 5 to 8 wt-% range, and several samples showed ash concentrations higher than 10 %. Keep in mind that these ash concentrations are most likely to be physiological (and not due to contamination with soil) as the samples were taken by hand and contamination with soil is therefore unlikely. The higher heating value generally follows from the ash concentration (more ash leads to a lower HHV), and is 18.7 MJ/kg on average, which is representative for lignocellulosic biomass.

In a number of cases, a sampling date later in the season (September versus June) leads to a higher ash concentration. The logic could be that in September there are more older leaves that have accumulated more Si and other minerals.

Grass sampled from clay soils generally contain higher amounts of ash, potassium, sodium and chlorine, compared to grass sampled from sandy soils.

<u>Fouling and corrosion indicators</u>

Application of thermal conversion quality indicators that are based on mineral composition show that most of the analysed 25 grass samples do not meet compliance thresholds for ash fouling and agglomeration, which means that fouling and agglomeration is most likely if not certainly to occur when these samples are used for combustion. However, a few samples could be used in a fuel blend with more benign fuels (wood).

Based on calculating chlorine concentration-based indicators, almost all samples would have tendency to lead to corrosion during combustion.

<u>Potential benefit of removing major inorganic elements (potassium, chlorine) from grass</u>

Results show that reducing 50% of potassium in the grass leads to a drastic reduction of most fouling and agglomeration indicators, although the majority of samples would still have the tendency to lead to fouling. Reducing potassium by 70% would lead to a further improvement, and most of the grass samples would be in or very near to the "probably fouling" threshold. As presented in other parts of this study, as well as previously published work, it is feasible to reduce potassium concentrations by 70% or by simple water leaching of the material.

Reducing chlorine concentrations by 70% would likely reduce the tendency for fouling, as was indicated by the chlorine-based corrosion indicator. Tests of leaching are presented in Chapters 5 and 6.

4. Effect harvesting method on biomass quality for thermal conversion purposes

4.1 Introduction

Biomass (grass) harvested from road sides and nature conservation areas has few applications. It has generally been left behind or used for composting. New applications including the production of biogas, thermal conversion for heat and electricity production and biorefining for the coproduction of biobased products and bioenergy are becoming relevant. For the thermal conversion option – the technology focused on within this project – several challenges exist, viz.:

- High ash content
- Soil/contamination in the harvested product
- Ash agglomeration due to high potassium content and
- Corrosion problems due to high chlorine and potassium content

Soil contamination is caused by mowing/harvesting of the fresh product. The choice of the harvesting moment related to the field and weather circumstances, the state of the product (young, old, lodged) probably can reduce some of the problems with ash and sand.

To estimate the effect of the harvesting method on contamination with soil /sand an experiment was set up at two locations in the Netherlands in June of 2014. Biomass was mown and collected from a nature conservation area and from road verges.

4.2 Materials & methods

The harvesting experiment was executed at two sites. One site was in a nature conservation area in the province Noord Brabant. The soil was a wet sandy soil, with a very low nutrient content. This site was harvested on June 6th. The other site was a road verge adjacent to the A6 highway in the province Flevoland with a very light young marine clay. This site was harvested on June 5th. The sites differed in botanic composition, soil type and management.

The 'clean working' protocol objects were mown with a two wheel Agria mower with a one side cutter bar. From the 'clean working' objects, grass was sampled, raked and collected by hand, directly after mowing. The 'mowing as usual' objects were sampled direct after mowing, one day and two days after mowing, by raking the product by hand and take a sample. Also after one and two days material was raked with a rake machine and collected by a load wagon (and sampled in the wagon).

The total layout for both experimental sites is presented in Table 9. for the road bank side and Table 10. for the nature conservation side.

On the road verge side 4 rows of 15 meter length were mown with the Agria mower (cutter bar, representing clean mowing) and 4 rows with the disc mower and collected directly. Also 4 rows were mown with the disc mower to dry for one or two days. Two rows were collected and sampled after one day and two rows after two days.

Table 9. Roadside harvest methods used

Mowing method	Harvest (sample) moment	Harvest method	Replications
Agria cutter bar	Direct after mowing	By hand	4
Machine disc mower	Direct after mowing	By hand	4
Machine disc mower	One day after mowing	By hand	2
Machine disc mower	Two days after mowing	By hand	2
Machine disc mower	One day after mowing	Mechanical raked and loaded	2
Machine disc mower	Two days after mowing	Mechanical raked and loaded	2

The layout at the nature conservation site is presented in Table 10. No drying was included here. There was an extra treatment here, instead of collecting grass directly by hand, the material was raked and collected mechanically.

Table 10. Harvesting methods used at the natural area site

Mowing method	Harvest (sample) moment	Harvest method	Replicates
Agria cutter bar	Direct after mowing	By hand	4
Machine disc mower	Direct after mowing	Mechanical raked and loaded	4
Machine disc mower	Two days after mowing	By hand	4
Machine disc mower	Two days after mowing	Mechanical raked and loaded	4

In total the field experiment consist of 64 (road bank side) + 32 (nature conservation side) = 96 plots (biomass samples). At the start of the experiment, details (botanic composition, weather circumstances) and disturbances (wheel damage, mole heaps) were recorded. Every sample was analysed for DM and ash content. A chemical analysis was done to measure the mineral content (Na, K, Mg, Ca, P, S, Cl, Mn, Zn, Fe). The fresh product was weighted to calculate the DM yield at harvest time.

4.3 Results

Table 11 shows the average ash content across all the samples, and the difference between the average ash content of samples taken by hand and taken after mowing (ash effect of machine mowing), and by hand before and after machine raking and loading (ash effect of rake + loader wagon).

Table 11. Composition and yield of harvested biomass from road side and natural area

Location:		A6 road side	Natural conservation area
Ash cont. average of all samples (on 4*16 = 64 samples)	% of DM	8.10	6.04
Ash effect of machine mowing	% of DM	-0.32	0.32
Ash effect of rake + loader wagon	% of DM	**1.12†**	0.15
Yield	Ton DM/ha	2.72	6.01
Analysis by BLGG (on 4*6 = 24 samples)			
% Ash	% of DM	7.82	6.13
Sodium	g/kg	0.88	0.89
Potassium	g/kg	15.19	16.65
Magnesium	g/kg	1.87	1.39
Calcium	g/kg	7.42	5.21
Phosphor	g/kg	1.86	1.98
Sulphur	g/kg	1.74	2.36
Chlorine	g/kg	6.82	6.25
Kat.Anion difference	meq/kg	125.71	141.38
Manganese	mg/kg	90.29	346.38
Zink (mg)	mg/kg	34.33	42.44
Iron (mg)	mg/kg	295.04	147.44
Iron effect of rake + loader wagon		**249‡**	18.33
Ash effect of rake + loader wagon (based on measurement by BLGG)		**0.89**	0.06

†The difference in ash content between hand collected samples and loader wagon collected samples was significant at p< 0.068. ‡ The difference in iron content between the samples collected by hand and by loader wagon was significant at p<0.055.

The average ash content was 8.1 % for the road side samples, and 6.0 % for the natural area samples.

The difference between the average ash content of samples taken by hand, taken after mowing and taken after raking and loading was taken as measure of contamination. No significant difference in ash content was observed between the different mowing and collection methods. Though biomass collected by hand had 1.12% lower ash content than biomass collected by loader wagon at road verge plots. This was not statistically significant though p< 0.068). The higher iron (Fe) content of samples harvested by loader wagon compared to hand collected samples (p< 0.055) indicated that the loader wagon may increase contamination of collected biomass.

4.3.1 Overall view

The dry matter yield (kg/ha) did vary between the different fields, not only over the locations but also within the location. At the harvesting moment (start of June) the average DM yield varied between 800 kg DM/ha and 9000 kg DM/ha with an average of 3700 kg DM/ha.

The average data from the chemical analysis of the mineral content of the biomass is presented in Table 12.

Table 12. Average, minimum and maximum mineral content (ash: % DM, others: g/kg DM) of biomass from a road bank and a nature conservation area

Element	Average value			Minimum		Maximum	
	Overall	Road side	Nature	Road side	Nature	Road side	Nature
Ash	7.1	7.8	6.1	5.6	3.9	11.3	8.9
Na	0.89	0.88	0.89	0.5	0.4	1.6	1.6
K	15.8	15.2	16.7	10.8	10.1	19.8	22.5
Mg	1.7	1.9	1.4	1.3	1.0	2.6	1.8
Ca	6.5	7.4	5.2	3.9	2.9	12.3	9.4
P	1.9	1.9	2.0	0.9	1.5	2.9	2.8
S	2.0	1.7	2.4	1.2	1.8	2.5	3.4
Cl	6.6	6.8	6.3	4.9	2.9	9.0	10.1
Zn	37.6	34.3	42.4	20	21	56	66
Fe	236	295	147	88	60	851	400

Iron (Fe) seems to be high in biomass from the road bank. This element is strongly correlated to the high soil contamination. Statistical analysis using REML, was used to test if the treatments have a significant effect on the ash content and K and Cl content of the biomass during the process time in the field.

Correlations between the measured minerals are given in Figure 14. The darker the colour the stronger the correlation. The yellow-red colour means a positive correlation, the green-blue colours a negative correlation.

Figure 14. Correlations between mineral contents in a biomass

The correlations between mineral content and DM yield are low, probably due to the small range of samples. The ash content is negative correlated with the DM-yield. This seems logical as areas with low biomass yields will likely have a higher soil to biomass ratio. Ash and Iron (Fe) are strongly positively correlated. The Fe content of soil is high; a high Fe value in a sample is a presumptive evidence for contamination with soil. Monti et al (2008) did a correlation analysis between (hand harvested) plant components and found no correlation between ash and Fe.

Notable is the relative strong (negative) correlation between de chlorine and zinc content. This should mean that grass with a high content of zinc, probably have a low content of chlorine. Chlorine and potassium are strongly positive correlated, both are negative for the combustion process. Advantage of this strong correlation is losing one element means losing both. There is hardly any correlation between ash and Cl or K content.

4.3.2   Statistical analysis

The experiment is unbalanced. Therefore a REML (Restricted Maximum Likelihood) analysis is used instead of ANOVA. The fixed effects were:

- Location (nature grass or road bank grass)
    - Within location
    - Mow/harvesting method
    - Interaction of field period with mow/harvesting method

The random effects are field (plot; the mowed strokes) and within plot the replicate's (sub-plot). The analysis showed if the fixed effects will influent the content of ash, K, Cl and Zn significant.

Ash content
Tests for fixed effects

Sequentially adding terms to fixed model

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
Location	6.90	1	6.90	4.0	0.059
Location.Mowing method	1.17	2	0.58	62.2	0.560
Location.Harvesting method	7.41	2	3.70	62.4	0.030
Location.Field period	1.93	3	0.64	66.8	0.591
Location.Harvesting method.Field period					
	0.02	1	0.02	61.6	0.896

There is a light indication (P=0.059) of a location effect. Based on the data, the ash content of the biomass from the nature conservation area seems to be a little lower, but the difference is not significant, nor relevant.
The harvesting method has a (location-dependent) significant influence on the ash content. The ash content is significantly (p=0.03) higher when a mechanic rake and load wagon is used at the road bank site. The absolute effect was a 1% higher ash content.

K content
Tests for fixed effects

Sequentially adding terms to fixed model

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
Location	0.44	1	0.44	3.9	0.544
Location.Mowing method	1.12	2	0.56	21.1	0.578
Location.Harvesting method	1.20	2	0.60	21.1	0.557
Location.Field period	5.27	3	1.73	22.1	0.190
Location.Harvesting method.Field period					
	0.92	1	0.92	21.1	0.348

None of the factors (location, mowing method, harvesting method, field period and the interaction) had a significant effect on the K content of the biomass.

Cl content
Tests for fixed effects

Sequentially adding terms to fixed model

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
Location	0.53	1	0.53	3.8	0.508
Location.Mowing method	0.62	2	0.31	21.3	0.736
Location.Harvesting method	1.50	2	0.75	21.3	0.485
Location.Field period	5.20	3	1.70	21.1	0.198
Location.Harvesting method.Field period	0.16	1	0.16	21.3	0.692

The statistical analyses on the Cl content showed the same outcome as the K content. None of the factors had a significant effect on the Cl content, so mowing and harvesting methods cannot reduce the content of K or Cl in the biomass.

Because according the correlation matrix, there is a strong negative effect between zinc and chlorine, also the effect on the zinc content is analysed.

Zinc analysis
Tests for fixed effects
Sequentially adding terms to fixed model

Fixed term	Wald statistic	n.d.f.	F statistic	d.d.f.	F pr
Location	1.15	1	1.15	3.9	0.345
Location.Mowing method	3.27	2	1.63	21.3	0.219
Location.Harvesting method	2.54	2	1.27	21.3	0.301
Location.Field period	7.56	3	2.48	22.4	0.087
Location.Harvesting method.Field period	1.55	1	1.55	21.3	0.226

As expected none of the treatments had any effect on the zinc content of the biomass.

4.3.3   Ultimate, Proximate and ash melting analysis

In Table 13 the proximate, ultimate and ash composition, and ash melting points, for two hand mowed verge grass samples and two natural area samples are presented. The ash content varies between 5.4% and 9.0%. The Deformation temperature is clearly higher for the natural area samples (5 and 6) compared to the verge grass samples (5, 6). It is not immediately clear how this can be explained, though the CaO and MgO contents are higher for the natural area samples. Ca and Mg are known to increase ash melting temperature.

Table 13. Selected characteristics of grass harvested from road verge (sample 4 and 7) or natural areas (sample 5 and 6 in June 2014).

		Sample 4, A6 verge grass	Sample 5, Natural area, Kooilaan	Sample 6, Natural area, Gement weg	Sample 7, A6 verge grass
Ash content (550°C)	% DM	9.01	5.71	5.36	7.17
Sulphur	% DM	0.150	0.140	0.170	0.120
Chlorine	% DM	0.480	0.280	0.310	0.470
Carbon	% DM	44.9	46.2	46.6	46.4
Hydrogen	% DM	5.72	5.84	4.10	5.89
Nitrogen	% DM	1.49	1.02	1.24	1.44
Oxygen	% DM	39.3	41.4	42.7	39.5
HHV (dry)	GJ/ton	17.93	18.58	18.74	18.73
HHV (daf)	GJ/ton	19.47	19.57	19.71	19.97
Shrinkage start temperature SST	°C	800	630	790	670
Deformation temperature DT	°C	830	1100	1030	860
Ash composition	**Mass% (ash)**				
SiO_2	Mass%	17.4	20.4	18.9	29
Al_2O_3	Mass%	< 0,1	0.53	0.25	< 0,1
TiO_2	Mass%	< 0,1	0.11	< 0,1	< 0,1
P_2O_5	Mass%	10.8	4.46	8.53	7.87
SO_3	Mass%	6.84	4.28	4.26	5.55
Fe_2O_3	Mass%	0.34	0.44	0.28	0.16
CaO	Mass%	8.03	20.2	15.4	8.43
MgO	Mass%	11.9	11	14.6	9.28
Na_2O	Mass%	21.5	12.2	16.4	16.1
K_2O	Mass%	19.8	19.9	16.3	19.1
Mn_3O_4	Mass%	0.56	0.12	0.17	0.99

4.4 Discussion & conclusions

In general grass harvested from natural areas and road verges contains high ash contents up to 40% which can mainly be attributed to soil contamination. The physiological ash content should on average be approximately 8% with a maximum of 12.5 % (see chapter 3). In this experiment the objective was to examine if it is possible to harvest verge grass and grass form natural areas with low or no soil contamination.

We can confirm that careful and clean work will not significantly increase ash content of harvested grass compared to grass harvested by hand. There was however an indication that using a loader wagon to collect the grass did increase soil contamination by approximately 1%.

Ash contents in this experiment did not differ much from ash contents found in the regular dairy farming, when grass is mown and harvested for silage. The different mowing and harvesting methods did not give variation in ash content. Ash (and sand) content of the fresh mown and harvested material was low comparable to the expected physiological ash content. Mowing and harvesting methods also did not lead to more leaching of minerals (K, Cl or Zn). During the longest field period (2 days lag before raking and harvesting), there was 12 mm rainfall, but this was not sufficient to lower the mineral content of the biomass significantly.

By observing some simple measures, the operators were apparently able to harvest grass with hardly any contamination. The measures included lowering the mowing speed, setting the mowing height slightly higher, avoiding sites with mole heaps and setting the collection height of the loader wagon slightly higher.

The extra cost of mowing and harvesting with low contamination was not quantified. The main concern for soil contamination appears to be the loader wagon. The risk of soil contamination appears to be especially relevant when biomass yields (ton per hectare) are low.

5. Field leaching tests

5.1 Introduction

Biomass harvested from road sides and natural areas is low in cost and might be an attractive feedstock for thermal conversion. The quality of the material is generally low making it a problematic feedstock. The main concerns are high content of minerals, especially K and Cl. Simple and low cost options to reduce the content of K and Cl are needed. Here we test the option of leaving mowed verge grass out in the field to allow the minerals to leach out naturally over a period of several weeks.

5.2 Materials & methods

In September 2014 grass from a road bank (A6, field 1) was collected by mowing several strips with a disc mower with and without a hay conditioner (to crush the grass). After collecting, the (fresh) material was divided over several permeable bags (net material). The bags were placed in a grass paddock (mown short) to expose the material to weather influences during a period of five weeks (Figure 15). The hypothesis is that rain and dew will leach out the highly soluble K and Cl.

Figure 15. Mesh bags containing grass in the field. Wageningen September 2014.

Experimental setup

The collected material which was mowed with and without conditioning (treatment: conditioning and no conditioning), was placed in mesh bags containing approximately 500 g fresh material (thick layer) or 160 g fresh material (thin layer). The DM content of the grass was 35,96% for mowed grass and 40,45% for mowed and conditioned grass.

The mesh bag measured 40 x 30 cm approximately. The thick layer was supposed to represent putting the grass on ridges while the thin layer represented the grass being spread out. The permeable bags were exposed to the prevailing weather conditions for one to five weeks. The bags were placed at random (in 4 repetitions, 4 rows) on a recently mowed lawn at a site in Wageningen. Every 7 days a bag of each object was taken from the field. Weight and dry matter content was determined. In addition, the mineral content in the sample was analysed at the start, after 2 weeks and after 4 weeks. Complete biomass thermal quality analysis (SGS Institut Fresenius GmbH) was performed on:

1. Mowed biomass samples at the start of the experiment
2. Mowed biomass after 1 week of field leaching[1]
3. Mowed biomass after 3 weeks of field leaching
4. Mowed and conditioned biomass after 3 weeks of field leaching

Before the start of the test (Day 0), the initial DM content was calculated per sample. The experiment layout had four replicates. In addition, an object with reference crop (commercially available hay, harvested in 2013) was added to the design. This bag contained 140 g hay (thick layer) and 57 g hay (thin layer). The initial DM content of the hay was 90%. The total experiment therefore consisted of 120 mesh bags: 4 replicates x 3 crop types (grass conditioned, grass mowed, and hay) x 2 layer thicknesses x 5 trial weeks. The amount of weekly rainfall and cumulated rainfall during the experiment is given in Table 14.

Table 14. Precipitation per week and cumulated (mm) over 5 weeks starting in September 2015

Week	Cum. Rainfall	Rainfall per week
1	10.3	12.3
2	22.6	10.5
3	69.6	47.0
4	93.6	24.0
5	104.1	10.5

The statistical analysis was done by a general ANOVA (using Genstat). Differences in amount of DM, content of K and Cl, and K and Cl yield during the leaching period of 5 weeks were tested. The main variables tested included: Week number (time effect), Material (crop type), Amount of material: thickness of layer, Interactions between these 3 variables.

---

[1] *The 4 replications of the thick and thin samples were combined to obtain sufficient material for analysis in all 4 cases.*

5.3 Results

The results are presented in tables to show the significant effects, and in figures (especially the time lapse effects).

Once per week 24 bags were collected representing the 6 treatments in 4 replications. For all the sample bags the DM content and DM weight was determined and related to the DM weight at the start of the test (measure week 0). Both, the absolute DM weight as well as the percentage weight loss (as percentage from the weight in week 0) were measured or calculated. The decrease in nutrient content was calculated based on nutrient analysis in week 2 and 4. For the DM content, a correlation with the measured amount of rainfall was made.

5.3.1 Dry matter development and ash content over time

The dry matter development is shown in Figure 16. As expected the DM is reduced over time. After 5 weeks the DM was reduced to between approximately 70% and 53%, the conditioned grass having the largest and the mowed grass and hay having the lowest DM decline. Overall there was a highly significant difference in dry matter between conditioned and mowed grass in DM loss over time (significant: $p < 0.001$). The apparent steep DM decline after one week and increase again in week 2 cannot be explained.
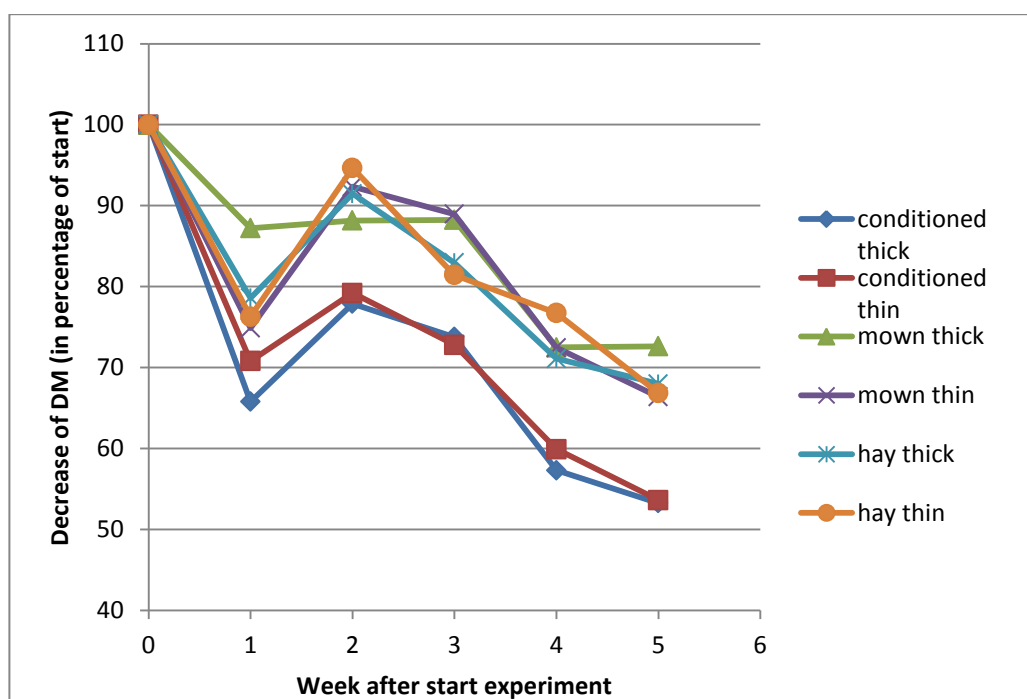

Figure 16. Absolute decrease of DM weight in time at 3 biomass types and two layer thicknesses

From this data one could conclude that mowing without conditioning is best as this will lead to the lowest loss of DM and more biomass to be used for thermal conversion.

Table 15. Dry matter remaining (as % of initial dry weight) after 0 to 5 weeks of weathering in the field

	Conditioned		Mowed		Hay	
	Thick layer	**Thin layer**	**Thick layer**	**Thin layer**	**Thick layer**	**Thin layer**
0	100.0	100.0	100.0	100.0	100.0	100.0
1	65.8	70.8	87.2	74.9	78.6	76.3
2	77.9	79.2	88.2	92.3	91.5	94.7
3	73.8	72.8	88.3	89.0	83.0	81.4
4	57.3	59.9	72.5	72.4	71.1	76.7
5	53.3	53.6	72.6	66.4	68.0	66.9
	lsd =7.62					

5.3.2 Ash and Iron (Fe)

Sand may play a role in the disruption of the measured values. The percentage of sand was not measured, but ash and iron (Fe) content data have been measured. Iron is an indicator of soil contamination.

The ash content absolute and as % of the initial ash content is presented in Figure 17. We see that the ash content of the mowed and the conditioned grass is approximately 20%. This is indeed very high, when compared to the ash content measured previously, when an effort was made to avoid soil contamination (see Chapter 4). At least 10% of the ash should be soil contamination. Over time (after 2 and 4 weeks in the field), see Figure 15, we see that the ash is first decreased and then increases again for the grass (conditioned and mowed). The hay sample had a low ash content at the start (4.9%) and was not contaminated by soil. Over time the ash content of the hay samples is increased from 4.9 to more than 7%. We can assume that is mainly soil contamination due to rain splashing or soil dust. This is supported by the fact that the iron content is increased between week 0 and week 2 and 4.

Figure 18 shows the iron (Fe) content of the samples over time. The iron content is much higher in the grass samples than in the hay samples, presumably because there is less soil contamination in the hay samples. There is a decrease of the iron content in week 2 in the grass objects and an increase of Fe in hay. Given the increasing amount of DM at week 2, it was expected that this could be caused by splashing up sand from the soil or a product harvested with sand. However, the Fe levels in grass just become lower, which may be indicative of just rinsing off sand. Poorly explained is the continuous increase of the Fe content in hay, but later (week 4) also in mown grass objects.
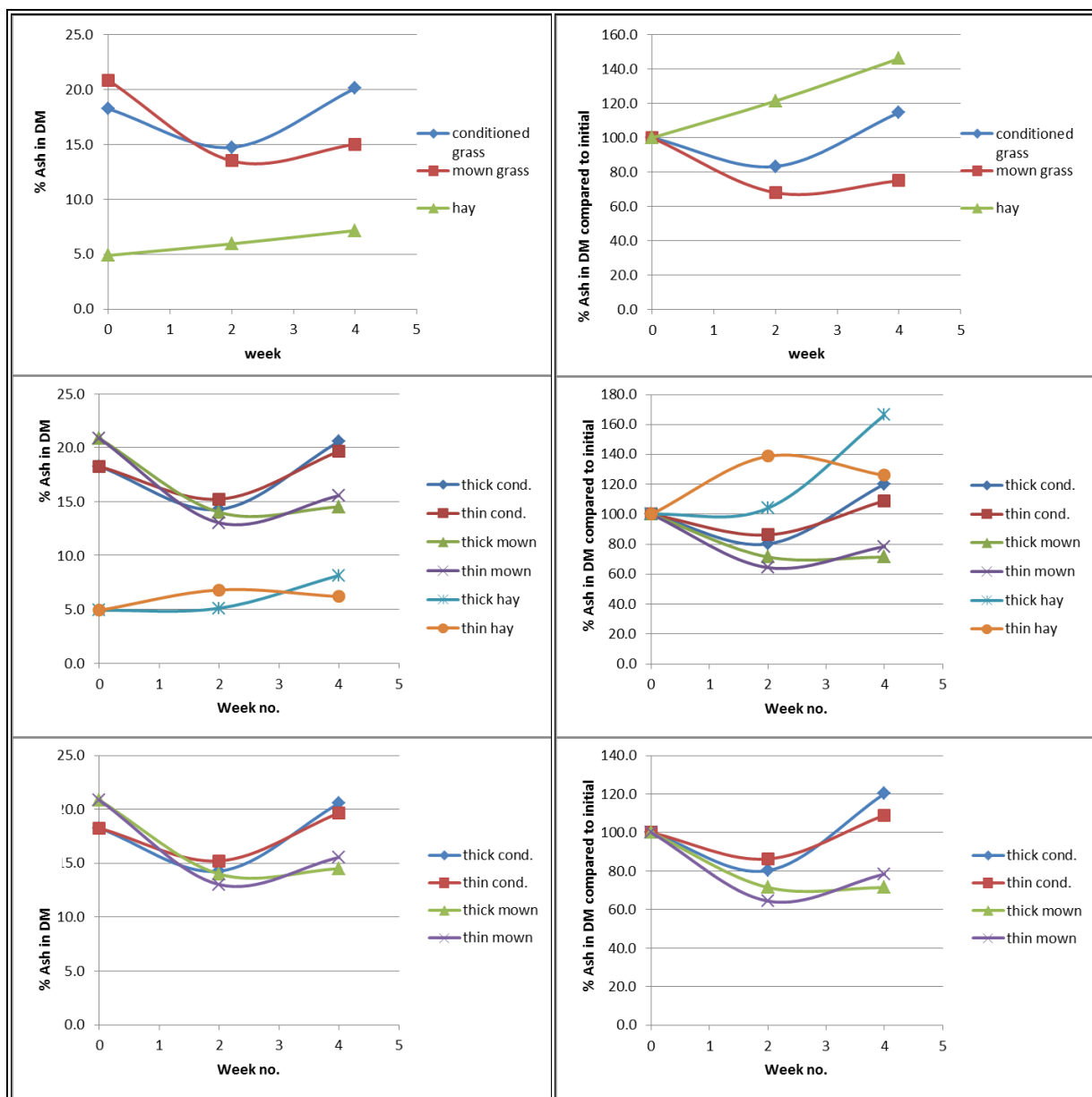
Figure 17. Ash content of grass and hay samples over time when left in the field to leach
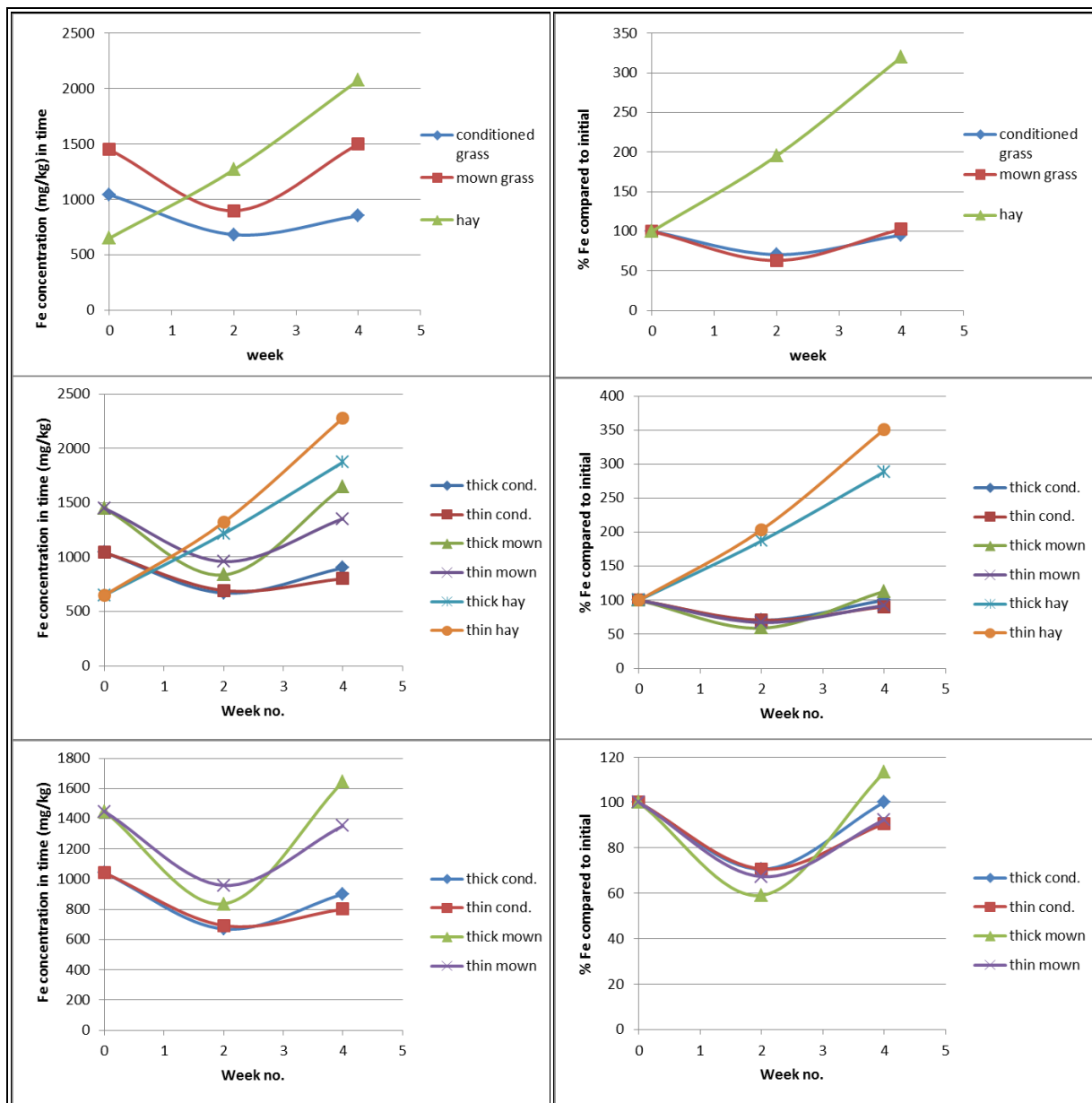
Figure 18. Iron (Fe) content of grass sample over time

5.3.3   Chlorine, potassium and sodium

As mentioned chlorine (Cl) and potassium (K) are the man biomass compounds that reduce quality for thermal conversion. In Figures 19 and 20, Cl and K content in grass and hay are shown over time.

We see that the chlorine content decreases rapidly with thin layers having lower Cl contents than think layers ($p < 0.001$). There was also an interaction between week and layer ($p < 0.001$) indicating that the reduction in Cl content was faster in thin than in thick layers.

This makes sense since both layers received the same amount of rain (22 mm over 2 weeks and 94 mm over 4 weeks). Therefore the thin layer had 3x less biomass (160 vs 500 g fresh biomass) for the same amount of precipitation. This explains why the thick layer had a slow reduction in Cl than the thin layer (more that 80% of Cl remaining). After 2 weeks (22 mm precipitation the thick layer had lost 50% of Cl. After 4 weeks (and another 62 mm of precipitation) the Cl was reduced to approximately 20% of initial for grass and almost 0 for the hay samples. The differences in layer thickness were reduced.
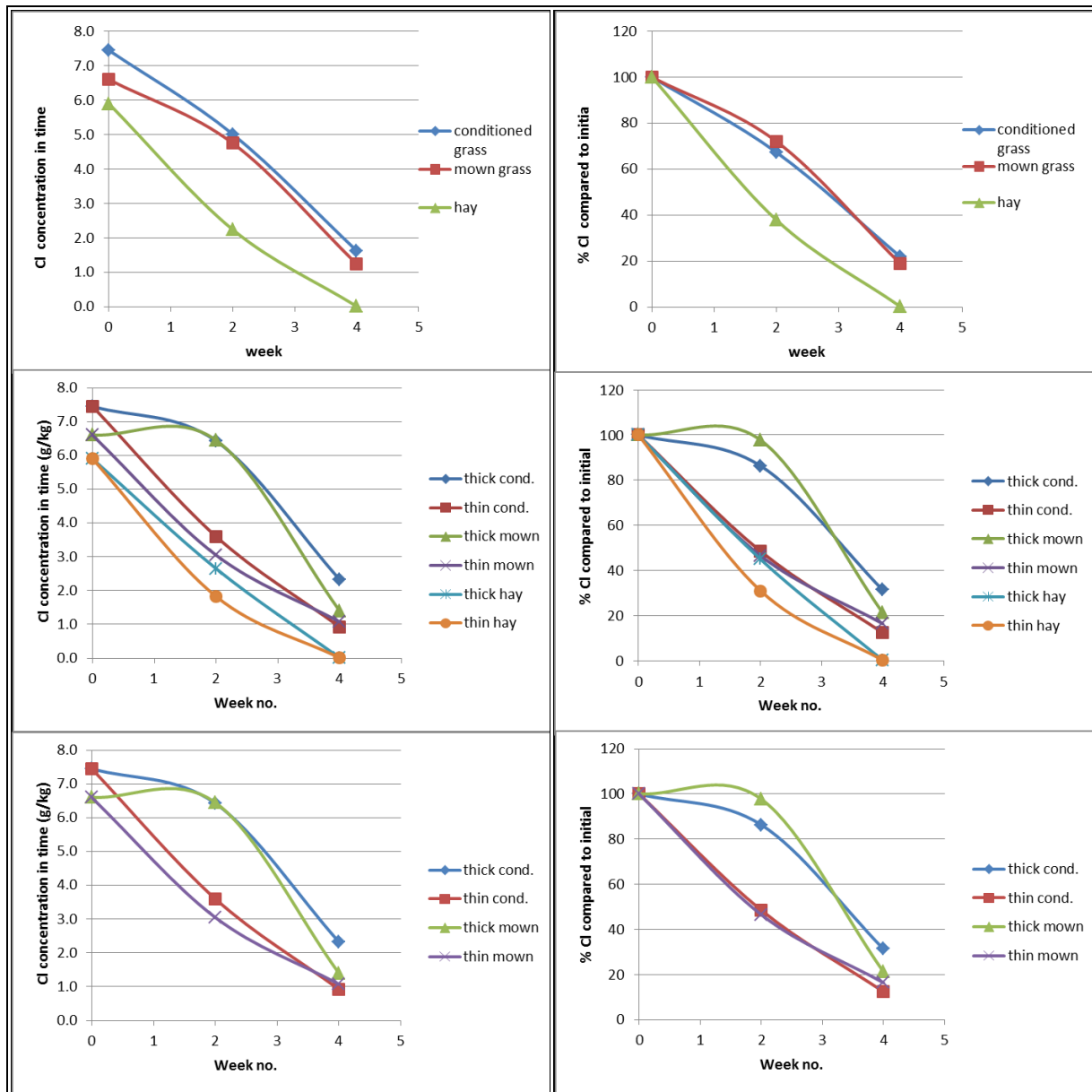

Figure 19. Chlorine (Cl) content of grass samples over time when left in the field to leach

The K content followed a similar trend as the Cl content though the reduction in K content was slightly slower than for Cl. This has also been shown in other studies. After 2 weeks (and 22 mm precipitation) 40% of the K was leached out of the thin grass layers and between 1% (mown grass) and 20% (conditioned grass) of K was leached out of the thick layers.

The initial K content in normal hay was much lower than in the road side samples (10 vs 19 g/kg). There was a significant effect ($p<0.001$) of the thickness of the layer. As with Cl, K leached out slower in a think than in a thin layer. As could be expected less K leached out of a thick layer, or better, it leached out slower.
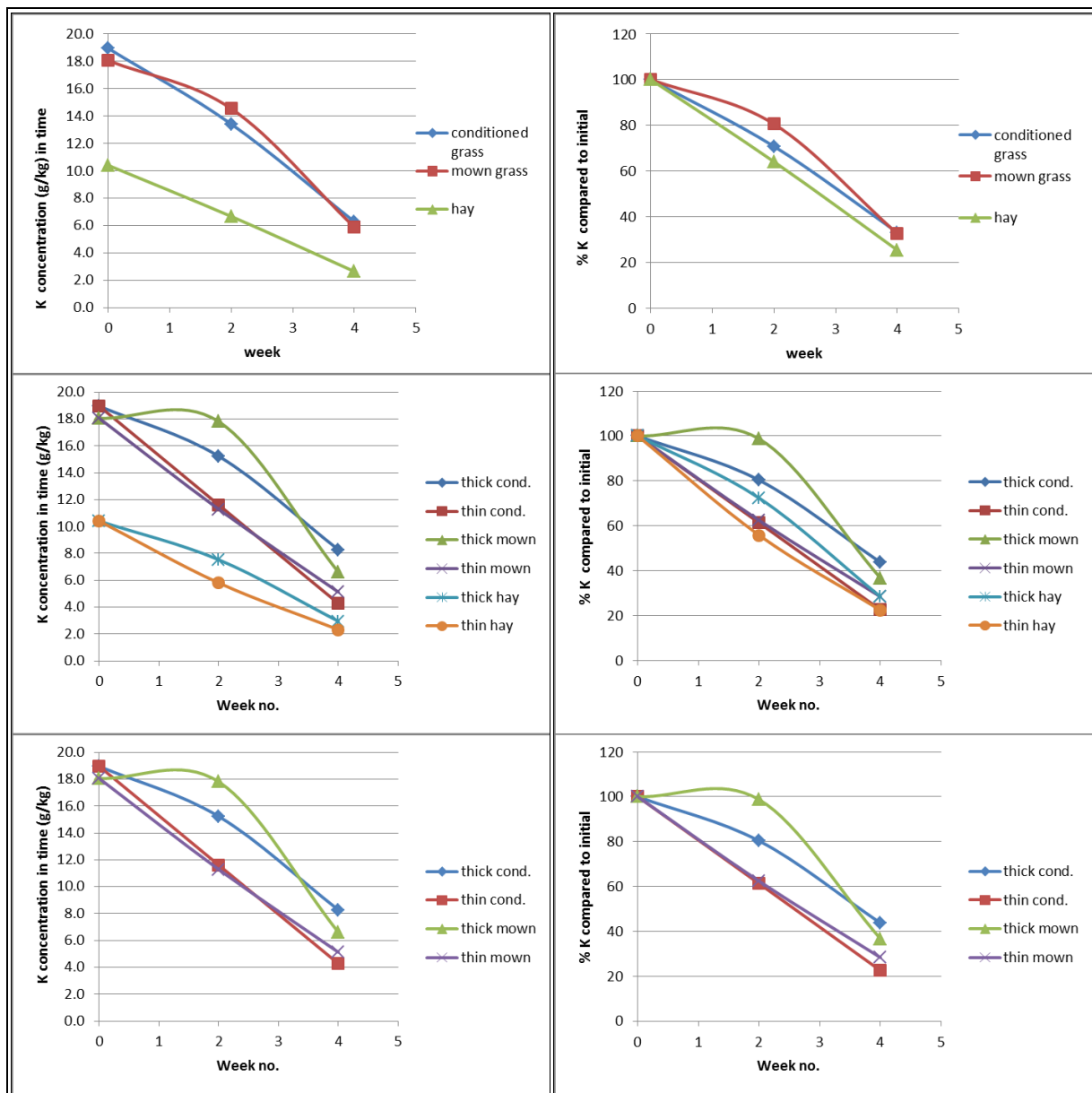

Figure 20. Potassium (K) content of grass and hay sample over time when left to leach in the field

There was no significant difference between conditioning or mowing though K leached out faster from the thick conditioned grass layer (20% reduction) than from the thick mown grass layer after 2 weeks (1% reduction). Sodium (Na) (Figure 19) showed similar results compared to K. Initial Na content of the samples was between 1.1 and 1.5 g/kg for the grass samples and 2.9 for the hay sample. This was 3 to 20 times lower than for K.
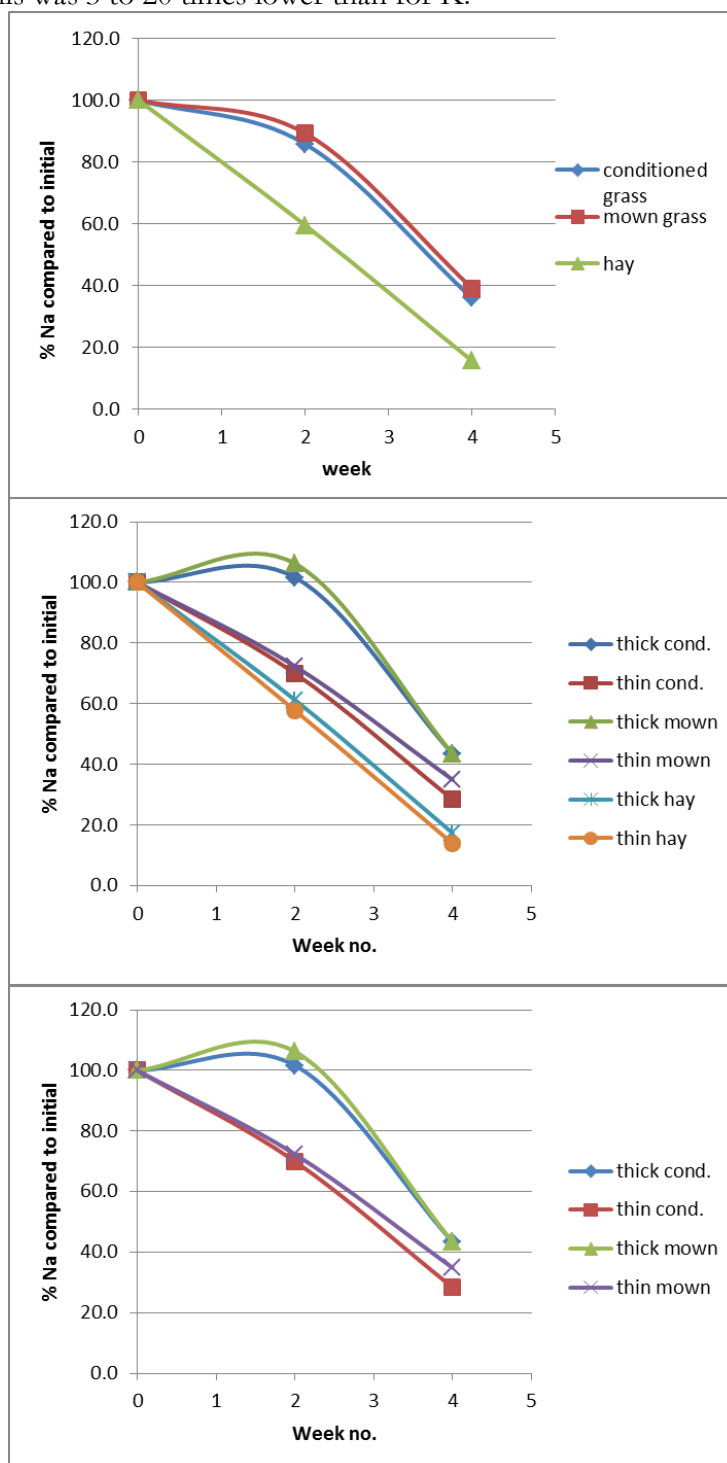

Figure 21. Sodium (Na) content of grass and hay sample over time when left to leach in the field

5.4 Proximate, ultimate and ash melting analysis

In Table 16 the proximate, ultimate and ash composition, and ash melting points, for the initial biomass sample and for the samples left to leach out for 1 or 3 weeks are presented. The thick and thin layer samples had to be combined to get enough sample material. We see that the ash values are in line with the measurements at 2 and 4 weeks (see above); they are high and variable.

Table 16. Selected characteristics of biomass leached in the field over 0, 1 and 3 weeks

		Week 0	Mowed week 1	Conditioned week 1	Mowed week 3	Conditioned week 3
Ash content (550C)	% DM	18.3	14.4	14.6	16.8	25.70
Sulphur	% DM	0.23	0.150	0.180	0.160	0.220
Chlorine	% DM	0.6	0.230	0.290	0.240	0.350
Carbon	% DM	40.0	44.2	44.2	42.7	45.0
Hydrogen	% DM	5.23	5.54	5.62	5.46	5.68
Nitrogen	% DM	1.56	1.90	1.61	1.72	1.71
Oxygen	% DM	34.8	34.4	34.2	33.7	37.2
HHV (dry)	GJ/ton	16.40	17.28	17.99	16.99	18.22
HHV (daf)	GJ/ton	19.90	20.00	20.89	20.23	20.20
Shrinkage start temperature SST	°C	950	800	1000	900	850
Deformation temperature DT	°C	1140	1160	1180	1210	1130
Ash composition	**Mass% (ash)**					
SiO_2	Mass%	46.5	44.8	44.5	49.8	36.9
Al_2O_3	Mass%	2.32	1.22	1.99	2.31	1.04
TiO_2	Mass%	0.23	0.1	0.23	0.28	0.12
P_2O_5	Mass%	7.22	8.2	7.49	7.36	8.83
SO_3	Mass%	3.02	2.8	3.55	2.5	3.85
Fe_2O_3	Mass%	1.56	0.75	1.41	1.76	0.95
CaO	Mass%	15.6	15.5	15.1	13.2	18.5
MgO	Mass%	7.81	9.97	8.84	7.48	9.24
Na_2O	Mass%	6.85	9.46	7.43	6.24	8.73
K_2O	Mass%	7.21	6.01	7.71	7.58	9.69
Mn_3O_4	Mass%	0.13	0.15	0.14	0.16	0.19

The chlorine values at week 0 are also in line with the values from other measurements (Figure 17). In Table 16 we see a decline from 0.6 to between 0.24 to 0.35% Cl. In week 3. This is seems to be in line with the values found after 4 weeks in Figure 17.

The potassium content of the ash appears not to change between week 0, 1, and 3. Still the K measurements on whole samples (see above) indicate a decline of 1 to 20% after 2 weeks (mown and conditioned respectively), and 60% by week 4. We cannot explain this inconsistency.

The ash melting point is also difficult to explain. The ash melting temperatures are relatively high.

The Deformation temperatures (DT) range between 1130 and 1210°C, which is positive. There does not seem to be an effect of leaching over 1 neither over 3 weeks. This may be mostly explained by the (very) high soil contamination from the outset and probably also from splashing of raindrops over the course of the field period.

5.5   Discussion & conclusions

Overall we see that the mowed and the conditioned road side biomass was highly contaminated with soil as indicated by the high ash (approximately 20%) and Fe levels. This contamination was highly variable across the samples.

Leaving the biomass out in the field did generally not reduce the contamination. The clean hay sample was actually also contaminated with soil as it weathered in the field.

During the 4 week experiment there was an above average amount of precipitation (94 mm over 4 weeks). This did help to leach out Cl and K by 70 to 80 %.

The weathering/leaching did both reduce the DM of the samples and reduce the K and Cl content. Cl was reduced by 85 to 90% over 4 weeks, with thin grass layers having a significantly better or faster result.

Conditioning the biomass, did over time, not lead to lower Cl and K contents but did lead to a higher DM reduction. 53% for conditioned grass vs approximately 70% for mowed grass and for hay (compared to initial samples).

The lower K content did not appear to translate in lower K in the ash nor in lower ash melting points. This may be partially due to the high levels of soil contamination at harvest and soil contamination in the field due to splashing of soil.

Conclusions

- Soil contamination at harvesting should be avoided, and can be, as the results of Chapter 4 show.
- Hay gave the best (Cl and K) leaching result.
- A thin biomass layer is best, leading to the fastest Cl and K leaching.
- Conditioning may lead to slightly faster leaching but also leads to much more DM loss.
- Almost 90% of Cl and 80% of K can be leached out.
- It is important to consider that leaving the biomass in the field to weather does not give a certain process. Precipitation is uncertain, potentially resulting in a longer necessary leaching/field time.

Overall we can conclude that the best result was obtained with a thin grass layer that had not been conditioned (crushed) over a period of approximately 3 to 4 weeks in which 94 mm of precipitation was recorded. In this period the amount of dry matter was reduced by approximately 30%.

6. Soaking tests

6.1 Introduction

This chapter describes the tests performed in the laboratory. Goal of the tests is to understand the leaching of grass as a result of the environmental conditions. Two different set-ups have been used to study the leaching. Primarily the leaching of grasses in a surplus of water (soaking). Secondly, the leaching of grass in simulated rain. Trials have been performed using different grasses, including hay and straw. The composition of the used water is varied to obtain different pH and mineral content.

6.2 Methodology

6.2.1 Leaching with a surplus of water

The raw material (about 5 grams of dry matter) is transferred into a container with 500 ml of water (Figure 22). The conductivity of the water is recorded at different times. After 2 hours the raw material is removed from the water.
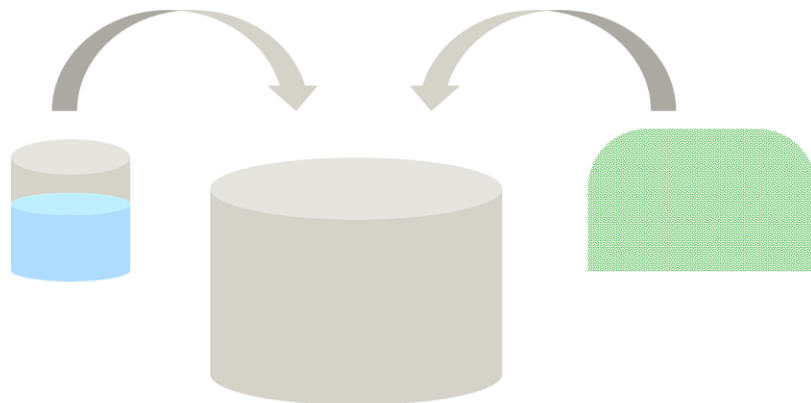

Figure 22. Leaching with a surplus of water

During these tests the leaching of the raw material is determined by determining the increase in conductivity of the water. The increase in conductivity is influenced by the actual amount of raw material used in the tests. For fresh material this amount had to be estimated, because dry matter content could not be measured before the start of the experiments. The results of the experiments are therefore standardised.

$$L = (C-Cw)/M*V$$

L =   Leaching   [μS/cm/g/L]
C =   Conductivity of the water after immersion of grass   [μS/cm]
Cw = Conductivity of the used water before immersion of grass   [μS/cm]
M = dry mass of the grass   [gr]
V = Volume of water   [L]

Larger scale soaking tests using the same dry matter to water ratio have been performed to produce samples to be tested on composition. The assumption that the increase of conductivity of the used water is related to the decrease in a.o. the chlorine and potassium content of the treated grass was tested by measuring both parameters in these larger scale soaking tests. These tests were performed using rain water, tap water and percolate water from Den Ouden.

6.2.2   Leaching with simulated rain
Rain on a layer of grass was simulated using a lab-scale process (Figure 23).
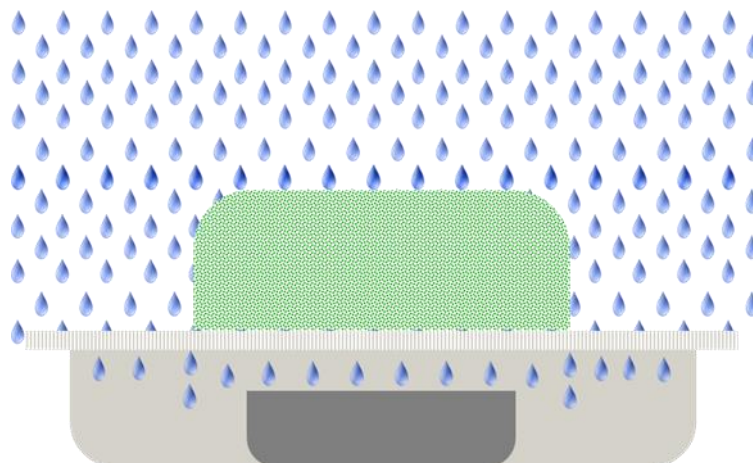

Figure 23. Lab-scale rain setup rain setup

Figure 24. Schematic representation of lab scale rain setup

The leaching was calculated based on the conductivity increase of the water passing through the layer of grass. In Figure 24 the green grass layer can be seen laying on a sieve, the water passing through the grass is collected in a plastic container underneath. The amount [g] and conductivity [μs/cm]of the water in the container related to the amount of rainfall [mm] was measured. Three different layer thickness and three different raw materials were tested.

6.3 Results

6.3.1 Leaching with a surplus of water

<u>Leaching as a function of time and raw material</u>
In all tests the raw material has been immersed for 2 hours. Conductivity of the water was measured at different times. For all materials the conductivity increased in time. Within the two hours there was no maximum reached. As can be seen in Figure 25, the leaching increased from straw to hay to cut grass to conditioned (bruised) grass.
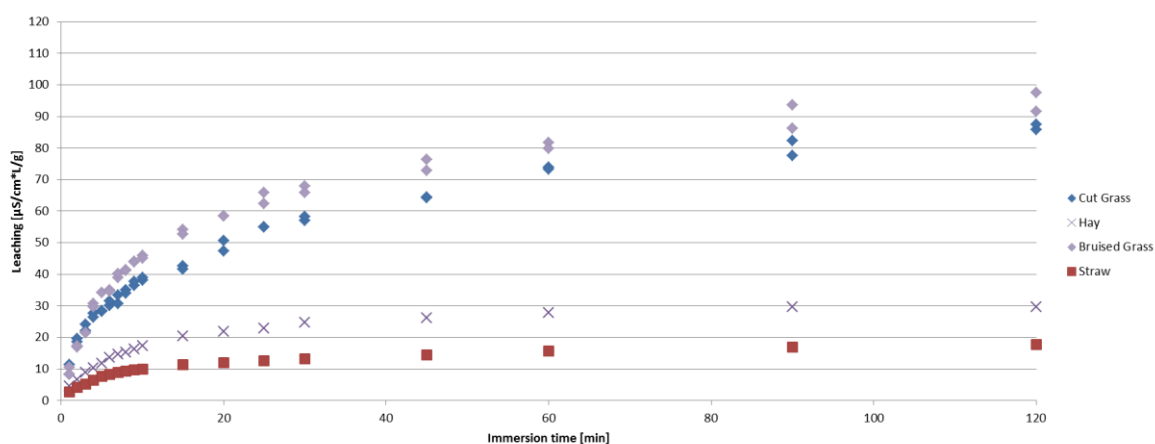

Figure 25. Leaching as a function of immersion time

<u>Leaching as a function of the conductivity of the used water</u>
The test have been performed with distilled water, tap water and water with increased conductivity (by adding KCl). Figure 26 shows that only at very high conductivity of the used water, the leaching of the raw materials is decreased. The results of the freshly cut grass (from a field near the laboratory) show a different effect, this grass seems to bind some of the KCl.
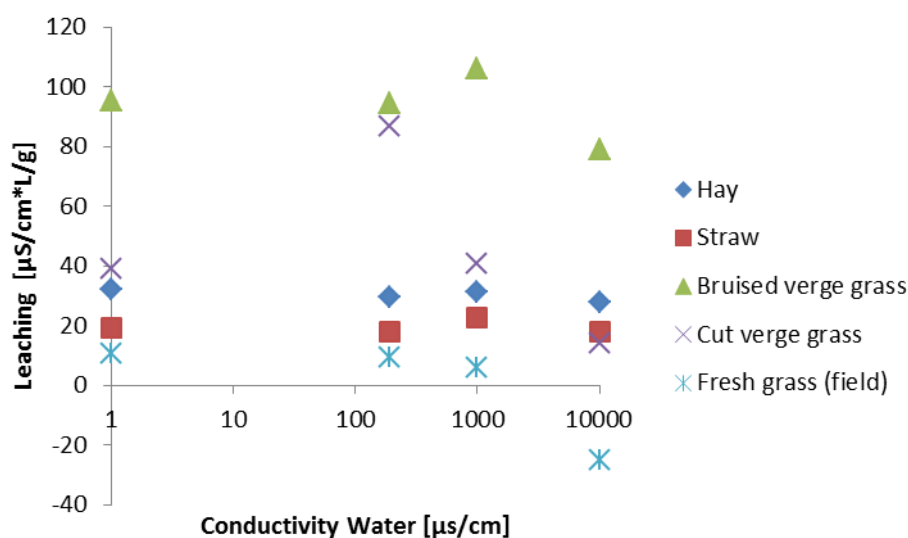
Figure 26. Leaching in water with different conductivities (2 hours immersion)

The percolate water from Den Ouden has a conductivity of about 190000 μS/cm. This would be located at the far right of the logarithmic scale of the graph.

Leaching as a function of the pH of the used water

The effect of the pH of the used water on the leaching was also tested. Leaching is slightly higher at higher pH of the water (Figure 27). During the immersion the pH of the water moved towards neutral. Measurement of pH and conductivity in the same test was not possible because of the influence of the pH-probe on the conductivity of the water.
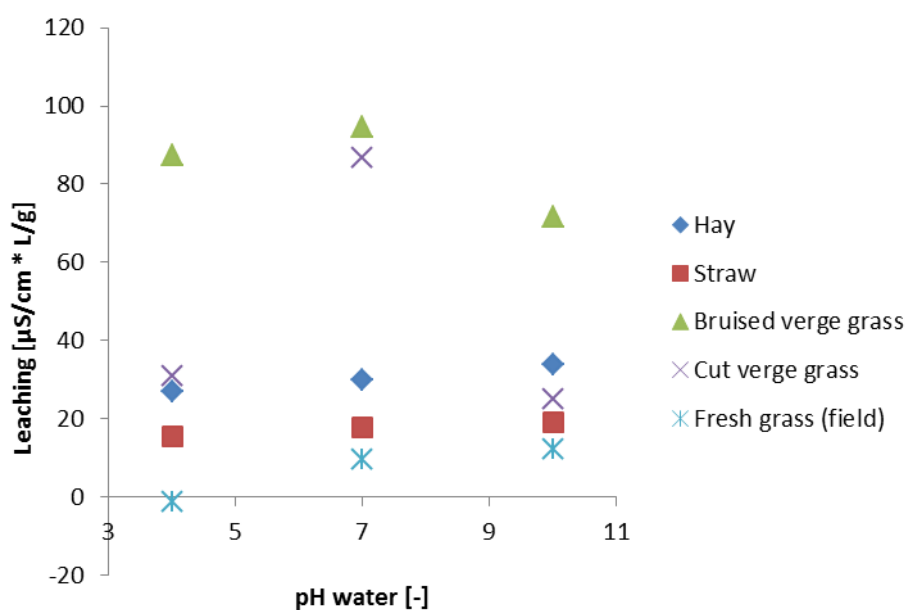

Figure 27. Effect of starting pH of the water on the leaching

Two stage leaching

Test were performed to see whether the leaching stopped after 2 hours immersion. This was done by performing the test two times with the same raw material. After two hours the raw material was removed from the water and placed in fresh water for another two hours. Figure 28 shows that also during the second immersion some leaching was measured. However, the leaching decreased for all raw materials, only for the freshly cut grass leaching in the second immersion was comparable to the first immersion.
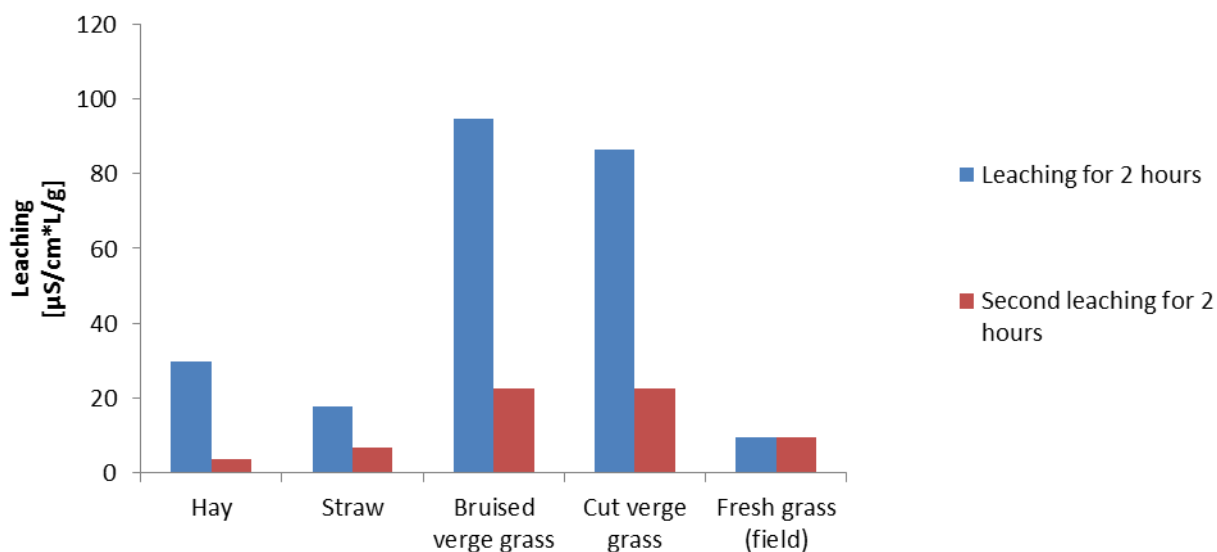

Figure 28. Two times immersion

Conductivity increase versus composition of the treated grass

Road side grass (A6) was harvested with and without bruising. The grass was soaked using rainwater, tap water and percolate water from Den Ouden. Hay and straw were also tested. Figures 29 and 30 show the Chlorine and Potassium content of the treated materials after soaking. There was no significant difference between cut and conditioned/bruised grass, therefore the data was combined. In the first minutes of soaking the largest decrease in content was observed.
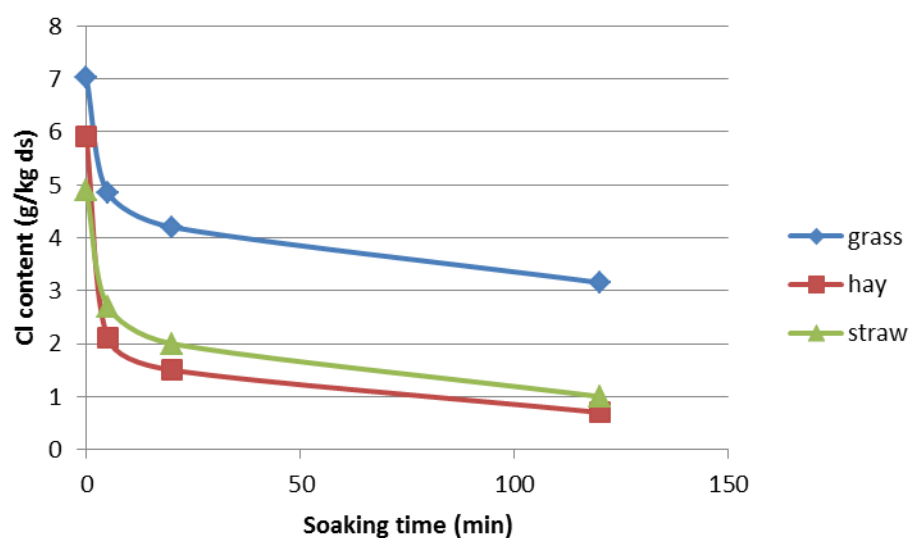
Figure 29. Chlorine content of the treated material as a function of soaking time
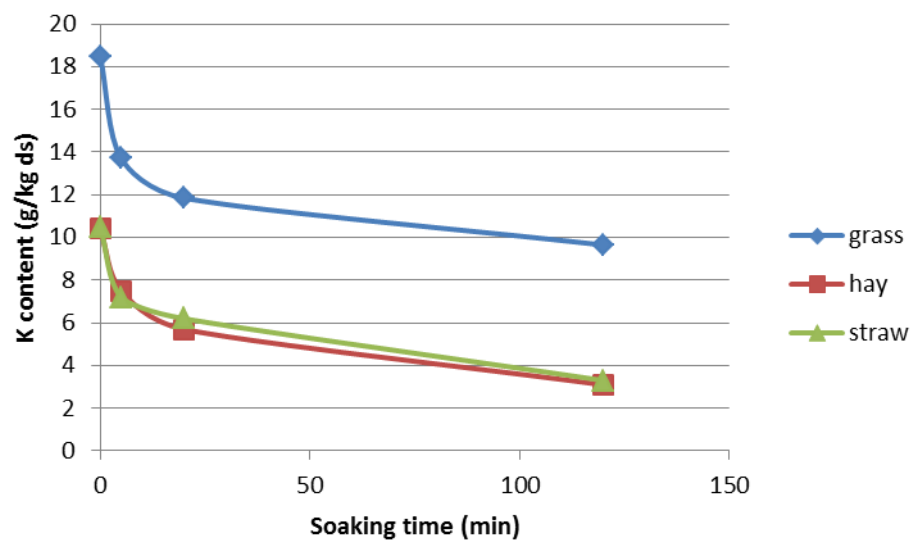

Figure 30. Potassium content of the treated material as a function of soaking time

In Figure 29 the conductivity increase of the soaking water is presented, leaching increases from straw to hay to grass. This corresponds with the results found on smaller scale (Figure 28).

Figure 31. Leaching as a function of soaking time

In Figure 32 the leaching after two hours is presented, using different waters and raw materials. It is clear that the high conductivity of the percolate reduces the leaching.

Figure 32. Leaching after two hours soaking for different raw materials and waters

In Figure 33 the reduction of potassium content in the treated materials after soaking for two hours is presented. The increase in potassium content of the materials treated with percolate corresponds to the results from Figure 32. Although leaching is observed using percolate, the potassium content of the treated material is increased because of the water uptake during the treatment. Reduction of this water uptake by pressing the material after the treatment would increase the effect of the soaking treatment.

Figure 33. Reduction of potassium content after soaking for two hours

Combined soaking and pressing

A large batch of conditioned/bruised grass was soaked for two hours and afterwards pressed out using a screw press. 28 kg of conditioned/bruised grass (10.4 kg dry matter) was soaked in 968 kg of tap water. Initial conductivity of the water was 190 µS/cm, after two hours the conductivity was 535 µS/cm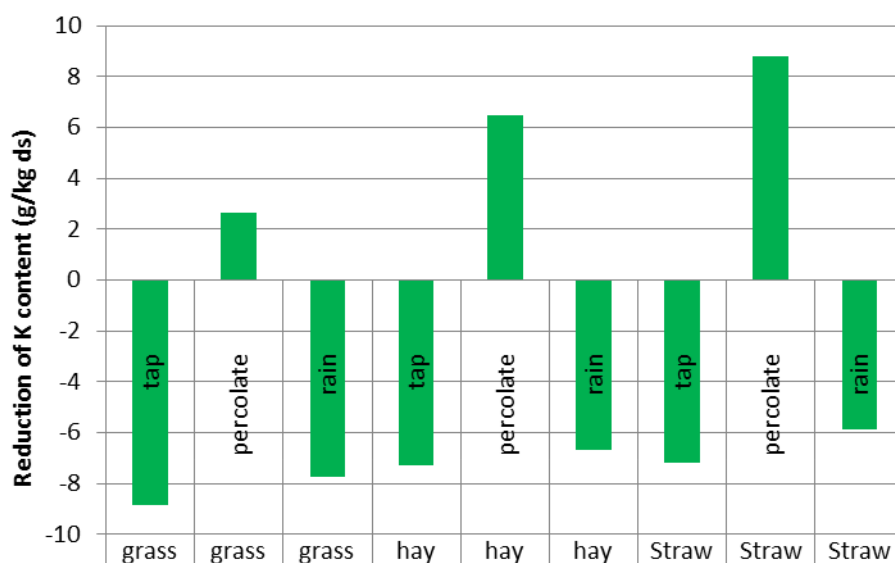. All wet grass (55 kg) was removed from the water and pressed using a screw press. After pressing the weight of the grass was 22.8 kg, with a dry matter content of 40.7 wt% (9.3 kg dry matter). The overall yield of the soaking and pressing stage was 89.6%.

6.3.2   Leaching with simulated rain

The experiments to test the effect of rain on lab scale showed that only a small amount of the raw material is actually getting wet. Although the rain covers the whole surface of the grass layers, canals are formed through which the rainwater is flowing. This canal forming was random and resulted in non-reproducible leaching (Figure 34). Most likely the exact canal formation is very dependent on the formation of the layer. In general the formation of the canals resulted in less leaching compared to the leaching by immersion.
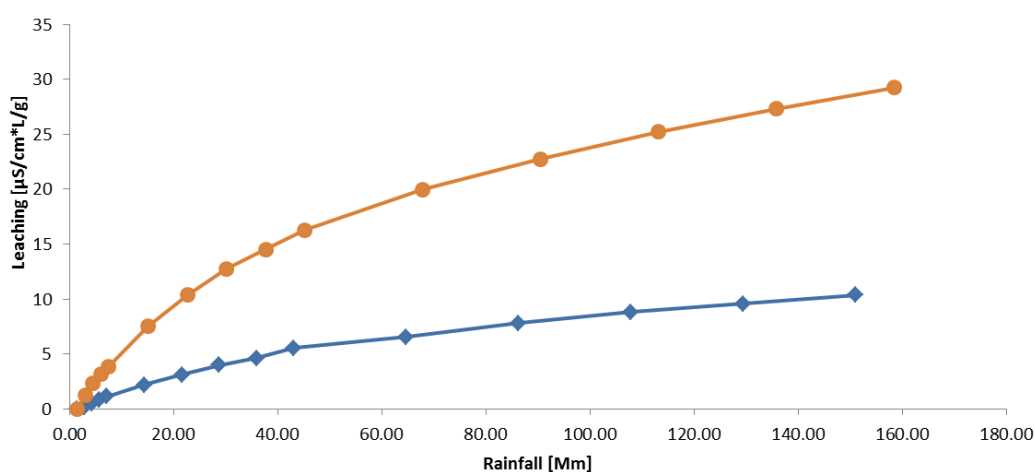
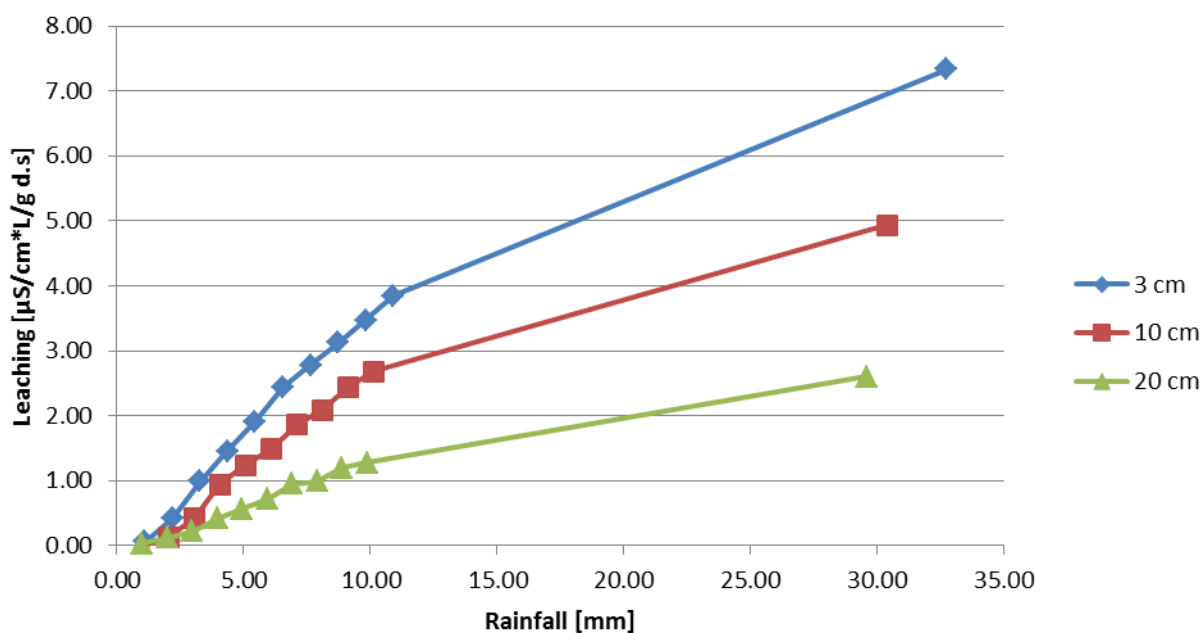*Figure 34. Duplicate measurement on a layer of 5 cm of cut grass*

Figure 35. Rain on hay

The effect of the thickness of the layer is presented in Figures 35. and 36. For the same amount of rain, most leaching is found in thinner layers.
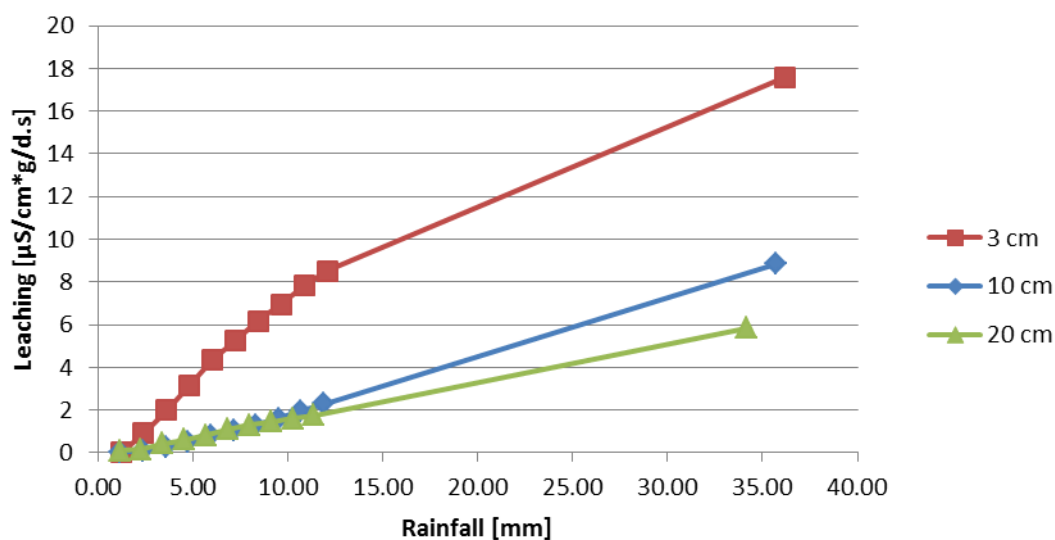
Figure 36. Rain on straw

6.4 Discussion & conclusions

Leaching with a surplus of water
The leaching results show that a large amount of contaminants can be removed within 2 hours. The conductivity of the used water has little effect on the leaching, unless the conductivity of the water is very high. pH only has a limited effect on the leaching. Leaching increases slightly with increasing pH. Even after two hours some leaching is still occurring. The reduction of the potassium and chlorine content after soaking corresponds with the leaching determined by measuring the conductivity in the used water.

In an actual process where the raw material would be immersed in water and then removed from it, some of the contaminants that were leached out of the material are collected together with the treated material. This is caused by the water uptake of the material during immersion. Therefore, after immersion the material should be pressed to remove as much water containing contaminants as possible.

Comparison of different treatments
Conditioned/Bruised and cut road side grass (A6) was treated on lab-scale by soaking for two hours in tap water. The composition of these grasses after treatment can be compared with the results from the field trails after 1 and 3 weeks. In Figures 37A-E the results are shown. The results are not complete clear towards soaking or leaching on the field. Ash content is of course influenced by the amount of sand in the sample. For cut grass soaking is the best option, for conditioned/bruised grass no conclusion can be made. Chlorine and Sulphur content also shows mixed results, soaking seems less beneficial as leaching on the field. The effect of the soaking on the melting behaviour of the ash is better than for the leaching on the field.

Most likely the results of the soaking would have been improved significantly when the soaked materials would have been pressed after the treatment.

Figure 37A. Ash content of conditioned/bruised grass after different treatments

Figure 37B. Ash content of cut grass after different treatments

Figure 37C. Chlorine and Sulphur content of conditioned/bruised grass after different treatments

Figure 37D. Chlorine and Sulphur content of cut grass after different treatments

Figure 37E. Ash melting of conditioned/bruised grass after different treatments

Figure 37F. Ash melting of cut grass after different treatments

Conclusions

- Leaching of grass, hay and straw was tested by soaking the materials in a surplus of water. The effect of time, pH and mineral content of the water was established. Leaching increased from Straw < Hay < Cut grass < Conditioned/Bruised grass. Leaching increased with time, even after two hours some leaching is observed. Only a minor effect of pH on the leaching was found. Higher pH improves leaching.
- Freshly cut grass shows diminished leaching compared to grass that was cut and treated after several hours. This could be a result of the waxy layer of grass that decays with time.

- Water with high conductivity e.g. percolate water reduces the leaching of the raw materials. Actual chlorine and potassium content of the raw material can increase by leaching with these waters, as the material takes up water. Pressing of the treated materials will reduce this uptake.
- Lab-scale tests to simulate rainfall did not represent the conditions in real life. Apparently the effect of dew, decay, sun etc. on the treatment of the grass during rainfall highly influences the test results.
- Using conditioned/bruised grass and a surplus of water a yield of 90% was observed for a process consisting of a soaking stage for two hours followed by a pressing stage to remove additional water and contaminants.

7. Sustainability analysis & assessment non-technical bottle-necks, incl. potential longer-term valorisation opportunities

7.1 Introduction

Within this chapter a quantitative assessment of both the CO_2-emission reduction potential [kg CO_2/ha.year] and the economic profitability [delta € (grass market value – grass costs delivered)] of some selected chains for the valorisation of road side grass and nature grass is made. Other chain related sustainability criteria are discussed on a more qualitative level. Also a very short description of potential longer-term valorisation options is presented.

7.2 Chain selection

The following chains are defined for the assessments:

1.1) Composting of road side grass producing compost

1.2) Composting of nature grass producing compost

2.1) Digestion of road side grass producing power and heat

2.2) Digestion of nature grass power and heat

3.1) Field leaching of roadside grass with combustion producing power and heat

3.2) Field leaching of nature grass with combustion producing power and heat

4.1) Artificial soaking of roadside grass with combustion producing power and heat

4.2) Artificial soaking of nature grass with combustion producing power and heat

7.3 Chain assessments – assumptions and results

Main assumptions

- Maintaining 1 ha of road verges with a picture quality demand B for a period of 1 year [Krinkels]
- Harvesting of 7 tons grass/ha as is, 2 times a year, delivering 14 tons grass as is/ha per year
- Nature grass 4 tonnes grass/ha as is, 2 times a year, delivering 8 tons grass as is/ha per year

7.3.1 Full chain greenhouse gas reduction potential [annual avoided CO_2-equivalents/ha]

1.1) Composting of road side grass producing compost

The composting case consists of harvesting, transport to processor, processing, and use of compost in agriculture.

Harvesting [based on Krinkels 2014]

Transport of the harvesters to the harvesting site by a tractor

- Maintaining 4 ha
- 1 load: 1 hour retour
- 2 loads a year

- Diesel use: 10 l/hour
- Specific CO_2-emmision diesel: 3.135 kg CO_2eq/l

Harvesting
- Harvesting 7 ha of grass per hours
- Collecting in rows, and collecting to central spot: 2 ha/hour
- 30% motor capacity: diesel use: 25 l/hour
- Specific CO_2-emmision diesel: 3.135 kg CO_2eq/l
- Harvesting frequency: 2 times a year

Transport to processer [based partly on Krinkels 2014]
Grass loading to truck
- 1 ha delivers 7 tonnes of grass as is (50% moisture) or 3.5 tonnes grass dry basis
- Transporter needs 30 minutes for loading 21 tons of grass
- Frequency: 2 times a year
- Diesel use: 5 l/hour
- Specific CO_2-emmision diesel: 3.135 kg CO_2eq/l

Transport to processer
- 1 transport is 21 tons of grass
- 1 ha: 7 tons grass as is
- Frequency: 2 times a year
- Distance assumed: 100 km
- Speed assumed: 80 km/hour, fuel use
- Diesel use: 28 l/hour

Processing: composting
- Aerobic conversion to compost and methane
- CO_2eq-emission reduction: 521.3 ton/10,000 ton verge grass, exclusive transport of compost [WUR-Alterra report 2064, 2010]

Annual CO_2eq-emmision reduction/ha: ((7 ton/ha * 2 times/year) / 10,000) * 521.3
= 0.730 ton CO_2eq/ha = 730 kg CO_2eq/ha.year

Use of compost in agriculture
Return of compost (or digestate) to agriculture does result in a reduction of CO_2, because it is assumed that part of this returned C remains in the ground for 100 years (6.2% of the carbon present in grass).

1.2) Composting of nature grass producing compost

For this composting chain the same methodology is used as described for roadside grass above. The distinguishing assumptions are:

- Harvesting 2 ha of grass per hour
- Nature grass 4 tonnes grass/ha as is, 2 times a year, delivering 8 tons grass as is/ha per year

2.1) Digestion of road side grass producing power and heat

The upstream part of the chain is considered to be the same as for composting; the only thing that differs is the processing (digestion instead of composting) part.

Processing: digestion

- Anaerobic conversion with biogas to CHP and digestate as C-binder
- CO_2eq-emission reduction: 1482.1 ton/10,000 ton verge grass, exclusive transport of digestate [WUR-Alterra report 2064, 2010]

Use of digestate in agriculture

Return of digestate (or compost) to agriculture does result in a reduction of CO_2, because it is assumed that part of this returned C remains in the ground for 100 years (6.2% of the carbon present in grass).

2.2) Digestion of nature grass power and heat

For this composting chain the same methodology used as described for roadside grass above. The distinguishing assumptions are:

- Harvesting 1 ha of grass requires 2 hours
- Nature grass 4 tonnes grass/ha as is, 2 times a year, delivering 8 tons grass as is/ha per year

3.1) Field leaching of roadside grass with combustion producing power and heat

This field leaching/combustion case consists of harvesting, field leaching, transport to processor and processing.

Harvesting [based on Krinkels 2014]

Field leaching

From the experiments described in chapter 5. resulted that field leaching, except for clean-up of the raw material, resulted in a biomass loss of 30%. This means that the amount of biomass to be transported per harvest is 4.9 tonnes as is, or 9.8 tonnes/ha.year (2 harvesting periods a year).

- Spreading of the grass at 4 ha/hour
- Diesel use: 30 l/hour

Transport to processer [based partly on Krinkels 2014]

Grass loading to truck

- 1 ha delivers 4.9 tonnes of grass as is (50% moisture) or 2.5 tonnes grass dry basis
- Transporter needs 30 minutes for loading 21 tons of grass
- Frequency: 2 times a year
- Diesel use: 5 l/hour
- Specific CO_2-emmision diesel: 3.135 kg CO_2eq/l

Transport to processer

- 1 transport is 21 tons of grass
- 1 ha: 4.9 tons grass as is
- Frequency: 2 times a year
- Distance assumed: 200 km
- Speed assumed: 80 km/hour, fuel use
- Diesel use: 28 l/hour

Processing: combustion

- Annual amount of biomass delivered per ha per year: 7 ton as is * 2 times a year = 14 ton as is * 0.7 (30% loss due to leaching) = 9.8 ton as is per ha per year
- Moisture content: 50%
- Energy content grass compared to wood chips (due to less lignin and more ash): 90%
- Energy content wood chips at 50% moisture: 8 MJ/kg
- Energy content grass at 50% moisture: 7.2 MJ/kg
- Energy in leached biomass delivered: 70.6 GJ/ha.year
- Electrical efficiency Cuijk plant: 30% (replacing NL mixture of fossil fuels)
- Specific CO_2eq-emission Dutch fossil fuel mix for power production [CE Delft]: 447 g CO_2eq/kWh$_e$
- 1kWh = 3.6 MJ
- Specific CO_2eq-emission per MJ$_e$: 124 g CO_2eq/MJ$_e$
- Heat efficiency Cuijk: 50% (replacing natural gas)
- LHV natural gas: 31.7 MJ/Nm^3
- Fossil electricity substituted: 70.6 * 0.3 = 21.1 GJ/ha.year
- Natural gas heat substituted: 70.6 * 0.5 = 35.3 GJ/ha.year
- Avoided CO_2-emission electricity production: 2620 kg CO_2eq/ha.yr
- Avoided natural gas use: 1114 Nm^3/ha.year
- Specific CO_2-emission natural gas: 1.8 kg CO_2/Nm^3
- Avoided CO_2-emission heat production: 2004 kg CO_2eq/ha.yr

Annual CO_2eq-emmision/ha: 2620 + 2004 = 4624 kg CO_2eq/ha.year

3.2) Field leaching of nature grass with combustion producing power and heat

This case is calculated based on the same assumptions given for roadside grass, with the following exception: 4 tonnes grass per ha harvested 2 times a year.

In spite of the fact that this case shows a significant CO_2-reduction potential, however less than in the case of roadside grass mainly due to the lower productivity (4 vs. 7 tonnes grass as is per ha per harvesting period), this option is not a realistic option for Natuurmonumenten. At their sides the grass has to be removed shortly after harvesting; i.e. natural leaching is not an option.

4.1) Artificial soaking of roadside grass with combustion producing power and heat

This field artificial soaking/combustion case consists of harvesting, transport to pre-processer artificial soaking, transport to processor and processing.

Harvesting [based on Krinkels 2014]
Transport of the harvesters to the harvesting site by a tractor and harvesting
Annual specific CO_2-emmision per ha: 62.7 + 658.35 = 721 kg CO_2eq/ha.year (same as composting case).

Transport to pre-processer
Sum annual specific CO_2-emmision per ha grass loading and transport (see composting case)

Artificial soaking
- 7 ton grass as is/ha * 2 times harvesting a year = 14 ton grass/ha.year
- 10% biomass loss to waste water = 1.4 ton grass
- C is 40% = 0.56 ton
- 1 g C = 1.47 g CO_2
- 0.56 ton C = 0.823 ton CO2 = 823 kg CO_2/ha.jr
- Energy-related CO_2-emission: based on composting – 15.1 ton CO_2/10000 ton grass

Transport to processer
See former cases, modified for 6.3 ton grass/ha or 12.6 ton grass/ha.year (2 harvests).

Processing: combustion
See natural leaching case, however, modified for combustion of 12.6 ton road side grass/ha.year (10% upstream loss due to artificial soaking) instead of 9.8 ton road side grass/ha.year (30% upstream loss due to natural leaching).

4.2) Artificial soaking of nature grass with combustion producing power and heat

This field artificial soaking/combustion case consists of harvesting, transport to pre-processer artificial soaking, transport to processor and processing.

Harvesting [based on Krinkels 2014]

Transport to pre-processer

Artificial soaking

See former road side grass artificial soaking case with:

- 4 ton grass as is/ha * 2 times harvesting a year = 8 ton grass/ha.year
- 10% biomass loss to waste water = 0.8 ton grass
- C is 40% = 0.32 ton
- 1 g C = 1.47 g CO_2
- 0.32 ton C = 0.470 ton CO2 = 470 kg CO_2/ha.jr
- Energy-related CO_2-emission: based on composting – 15.1 ton CO_2/10000 ton grass
- 8/10000 * 15.1 = 0.01208 ton CO_2 = 12 kg CO_2/ha.year

Transport to processer

See former cases, modified for 3.6 ton grass/ha or 7.2 ton grass/ha.year (2 harvests).

Processing: combustion

See natural leaching case, however, modified for combustion of 7.2 ton natural grass/ha.year (10% upstream loss due to artificial soaking) instead of 5.6 ton natural grass/ha.year (30% upstream loss due to natural leaching).

Avoided annual CO_2eq-emmision/ha: 7.2/5.6 * 2645 = 3401 kg CO_2eq/ha.year

7.3.1.1 Overview

In Table 17 the annual CO_2eq-emmisions per ha and the avoided emissions are given

Table 17. Overview annual CO_2eq-emmisions per ha and the avoided emissions

kg CO_2 eq/ha/year	Composting		Digesting		Field leaching and combustion		Artificial soaking and combustion	
	road	nature	road	nature	road	nature	road	nature
CO_2 emission								
Transport of harvesters	125	125	125	125	125	125	125	125
Harvesting	101	157	101	157	179	329	132	282
Truck loading	5	3	5	3	4	2	5	3
Transport to processor	73	42	73	42	102	59	146	84
processing							21	12
waste water							412	235
Transport to processor							66	38
Total	**305**	**327**	**305**	**327**	**410**	**515**	**907**	**779**
CO_2 reduction								
Composting	730	417						
Digestion			2075	1186				
Cuijk					4635	2648	6621	3784
Total	730	417	2075	1186	4635	2648	6621	3784
Balance CO_2 reduction	**425**	**90**	**1770**	**859**	**4225**	**2133**	**5714**	**3004**
Balance CO_2 reduction kg CO_2 eq/ton d.m. to final processor	**61**	**23**	**253**	**215**	**862**	**762**	**907**	**835**

7.3.2   Full chain economics: €/tonne grass delivered vs €/tonne grass market value

7.3.2.1   Grass delivered: Full chain economics

The economics of the eight different chains (1.1.-4.2) as described in paragraph 7.3 were calculated. Additional to the assumptions made in paragraph 7.3 the economic assumptions are:

- Cost of diesel 1.2 €/l (excluding vat)
- Personal costs 30 €/hour
- Additional costs transport harvester to site 37.5 €/hour
- Additional costs spreading of grass 20 €/ha
- Additional costs collecting on field and collecting to central spot 45 €/ha
- Personal costs transport by truck, truck included 85 €/hour
- Investment for soaking 85 k€, pressing at 10 ton d.m/hour
- Use of press 3000 hours/year, 5 years
- Electricity use press 50 kWh/ton d.m.
- Electricity: 0.1 €/kWh

In Table 18 the economics of the different chains are shown in Euro/ha/year. In Table 19 the economics of the different chains are shown in Euro/ton of product (50% water content).

Table 18. Full chain economics (per ha per year) of grass delivered

€/ha/year	Composting		Digesting		Field leaching and combustion		Artificial soaking and combustion	
	road	nature	road	nature	road	nature	road	nature
Transport of harvesters	159	159	159	159	159	219	159	40
Harvesting	107	150	107	150	156	262	116	222
Truck loading	30	17	30	17	21	12	30	17
Transport to processor	99	56	99	56	138	79	198	113
Processing							54	31
waste water							p.m.	p.m.
Transport to processor							44	25
Total	395	383	395	383	475	572	602	448

Table 19. Full chain economics (per ton product) of grass delivered

€/ton product	Composting		Digesting		Field leaching and combustion		Artificial soaking and combustion	
	road	nature	road	nature	road	nature	road	nature
transport of harvesters	11.4	19.9	11.4	19.9	16.2	39.1	12.6	5.5
Harvesting	7.7	18.8	7.7	18.8	16.0	46.8	9.2	30.8
Truck loading	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.4
Transport to processor	7.1	7.1	7.1	7.1	14.1	14.1	15.7	15.7
processing							4.3	4.3
waste water							p.m.	p.m.
Transport to processor							3.5	3.5
Total	28.2	47.9	28.2	47.9	48.5	102.2	47.8	62.3

7.3.2.2   Grass market value

Essent is interested in adding new biobased raw materials to their fuel mix because of several reasons, i.e. : making use of lower value residue streams (such as herbaceous biomass) that won't have a higher value application, lowering dependency on woodchips, and decreasing the price of the fuel mix.

The disadvantage of using other lower value biobased raw materials in the mix is that the facility in Cuijk is designed for using a 100% wood mix, which among others, requires a moisture content of between 40-60% and specific particle sizes. Adding other components than wood to the fuel mix, might cause process complication such as:

- Logistical complexity: When using a single fuel (e.g. woodchips) the logistical chain is easy to manage. Containers received can be immediately loaded in the process. Therefore, there is no mixing facility created at Cuijk. When various streams (wood, grass, paper sludge, etc.) are received from various suppliers, mixing at a separate location, should be included, which will create additional costs.
- Agglomeration and fouling: When other fuels are used, also other chemical compositions will be created. A common technological challenge is the so called fouling and agglomeration. These aspects potentially will cause an additional maintenance programme (reduction in revenues and additional costs). Another solution to overcome such problems are to add additives to the fuel mix, which also create additional costs.
- Higher Ash content: When lower value biomass streams have a higher ash percentage then wood chips, ash is ending at the end of the process, and needs to be sold off (at a negative cost of approximately €100 per ton). More ash means higher costs. Besides that, 100% wood ash has another composition than ash of a fuel mix. It depends on the composition if more or less needs to be paid for the same volume of ash.

For all these challenges, solutions might be created but the exact additional costs can only be calculated when first experimental tests can be done with herbaceous biomass.

Therefore, Essent indicates that grass should have a price of less than 2.5 €/GJ to be an attractive alternative compared to woodchips. Assuming that delivered grass (at 50% moisture content) has an energy content of 7 to 9 GJ/ton (LHV) this would value the grass at € 17.5 to €22.5 per ton delivered.

7.3.3   *Qualitative assessment other chain related sustainability criteria*

For natural areas and road verges the removal of biomass is often necessary to fulfil ecological goals generally related to lowering fertility or maintaining open areas. The option of having another outlet can be attractive and may reduce the cost of maintenance of natural areas and road verges. At the same time we have shown that it is necessary (and possible) to deliver biomass of a certain quality in order to be of value for thermal conversion (and also other added value applications).

Optimizing quality demands from biomass buyers, and management goals may lead to management adaptation of verges and natural areas. The first goal should be to deliver biomass with very little contamination (soil, etc.). Avoiding moles should be necessary for instance.

If delivering biomass of a certain quality incurs less cost or even a profit, it should become attractive to also increase production (per hectare). This may lead to new management practices.

7.4   Longer-term valorisation options

Longer-term valorisation options of road side grass and nature grass are aimed at valorisation of the different components present in the grass. In contrast to the low tech processes producing energy pellets, compost, biogas or feed, longer-term processes are relatively high tech. Biorefinery setups are developed to harvest, store and process grasses into valuable products. Most grass biorefineries use a two stage process as presented in Figure 38.

Figure 38. Biorefinery setup

The main product groups that can be produced from nature and road side grass are:
- Fibres: Cellulose containing materials that can be used in e.g paper and board, building materials, insulation and fibre reinforced plastic composites.
- Sugars: Raw material for fermentation processes to produce e.g. Biohydrogen, Bioethanol or poly lactic acid
- Amino Acids: The protein inside the grass is used as source of peptides and amino acids to be uses as chemical of feed.
- Minerals: Minerals removed from the grass can be reused as fertiliser
- Organic Acids: During e.g. silage the sugars and part of the (hemi-) cellulose is converted into organic acids, these products can be used as chemical or feed additive.
- Lignin: a minor amount of lignin is present which can be used e.g. as binder or chemical additive.

Currently in the Netherlands several initiatives are working on the development of biorefineries from road side and nature grass. At the moment none of these initiatives are economically feasible. Large differences in expected time to market of these technologies exist. An overview of several initiatives is presented below.

Newfoss B.V. develops a process to produce fibres, amino acids and minerals from silage nature grass. The fibres are currently sold as raw material for moulded fibre products (Egg- trays). A demo-plant is under construction, this demo plant will show the quality of the mineral and amino-acid products.

Solid Pack Loenen has developed a process to produce fibres from silage nature grass to be used in cardboard boxes. The cardboard boxes have been sold for several years, but are currently not produced. The status of the research towards valorisation of the other products is unknown.

Indugras is developing a process for nature grass based on the superheated steam process from TNO. Goals is to produce feed from nature grass. Status of the research towards valorisation of the other products is unknown.

A European consortium (**Hytime**) is developing the production of biohydrogen by fermentation from nature and road side grass. Time to market is estimated at at least 5-10 years.

ECN is developing a Torwash process that produces torrified energy pellets from e.g. nature and road side grass. Valorisation of the by-products has to be developed to obtain an economically feasible process.

Other initiatives to use grass as raw material for a biorefinery (e.g. **Grassa, Harvestagg**) use culture grass. The higher protein content of this grass compared to verge grass and road side grass is the main driver for these biorefineries. It is not expected that nature or road side grass will be an economically feasible option for these initiatives.

7.5 Discussion & conclusions

The main results of the chain assessments are shown in Table 20.

Table 20. Results overall chain assessments

Items	Case 1.1 Roadside grass Composting	Case 1.2 Nature grass Composting	Case 2.1 Roadside grass Digestion	Case 2.2 Nature grass Digestion	Case 3.1 Roadside grass Natural leaching & combustion	Case 3.2 Nature grass Natural leaching & combustion	Case 4.1 Roadside grass Artificial soaking & combustion	Case 4.2 Nature grass Artificial soaking & combustion
CO_2-emission reduction [kg CO_2eq/ha.year]								
Harvesting	-231	-285	-231	-285	-308	-457	-262	-411
Transport to pre-processer							-146	-84
Artificial soaking							-433	-247
Natural leaching					0	0		
Transport to final processer	-73	-42	-73	-42	-102	-59	-66	-38
Final processing	730	417	2075	1186	4635	2648	6621	3784
Total	425	90	1770	859	4225	2133	5714	3004
Estimated production costs								
Euro/ton as is	28	48	28	48	49	102	48[*]	62[*]
Estimated market value grass (wood chips: 30 Euro/ton as is)								
Euro/ton as is					17.5-22.5 (info Essent)			

Table 20 shows that:

- The full chain CO_2eq-reduction potential for roadside grass (7 ton as is per harvest), considering 2 harvests a year, varies between 425 (composting) till 5714 (combustion with upstream artificial soaking) kg CO_2eq/ha.year.
- The full chain CO_2eq-reduction potential for nature grass (4 ton as is per harvest), considering 2 harvests a year, varies between 90 (composting) till 3004 (combustion with upstream artificial soaking) kg CO_2eq/ha.year.
- Artificial soaking seems to be a better grass pre-treatment option upstream thermal conversion than natural leaching based on a CO_2eq-reduction potential point of view. For natural grass this is the only option to receive pre-treated grass of the right quality at the gate for thermal conversion, because natural leaching is not a practical option for natural areas (info Natuurmonumenten).
- The value of clean grass for (Cuijk) thermal combustion is estimated at €2.5/GJ to have an attractive alternative compared to woodchips. At 50% moisture content this is equivalent to 17.5 to €22.5 per ton delivered.

Main conclusions are:

1. All cases will result in a net reduction of specific full chain CO_2eq-emission (CO_2eq-emission/ha.year].
2. The CO_2eq-reduction potential of thermal conversion (combustion) is about 3 times that of digestion; which on itself is much better than composting.
3. For thermal conversion, upstream artificial soaking will result in an about 10% higher CO_2eq-reduction potential than natural leaching, mainly caused by the lower biomass loss (10 compared to 30%) in the pre-treatment process.
4. The CO_2eq-reduction potential of roadside grass in in all cases higher (about 30%) than that of natural grass, caused by the higher annual harvested amount (14 tonnes vs. 8 tonnes as is, two harvests per year).
5. The current best estimate of the value of grass for Cuijk is 17.5 to 22.5 € per ton delivered (50% moisture).
6. Reduction of cost of biomass delivery may make management less costly and thus supports management goals. At the same time there are quality demands that will require adaptation of the management system.

8. Discussion & conclusions

The main goal of this project was to analyse if it is technically possible, environmentally favourable and economically profitable to use herbaceous biomass from verges (roadsides) and natural areas as raw material for combustion in the Cuijk facility of Essent for the production of CHP.

<u>Technical constraints</u>

Potential technical constraints are both a) the contamination of herbaceous biomass streams with soil and other debris, and b) the quality of these steams (high ash, potassium, chlorine contents) potentially causing slagging, fouling and corrosion during thermal conversion.

Contamination

Current mowing and collection methods, flail and rotary mowing, experimentally monitored (chapter 2.), indeed resulted in biomass heavily polluted by sand and (roadside) garbage, making this biomass unusable for direct use as raw material, unless the pollutants are removed at additional costs.

To estimate the effect of the harvesting method on contamination with soil/sand harvesting experiments have been performed within this project at two locations in the Netherlands (chapter 4.). Biomass was mown and collected by respectively Krinkels and Natuurmonumenten (both in cooperation with Wageningen UR) from 1) a light marine clay A6 highway roadside in Flevoland and 2) a sandy low-nutrient nature conservation area in Noord Brabant, and transferred to Wageningen UR for further analysis and experimental work.. Both conventional and optimised harvesting tests were performed. Results confirmed the expectation, viz. that **harvester operators are able to produce grass with hardly any soil contamination**. In case they are aware of the fact that they have to come-up with clean product they are able to simply optimise their harvesting method by lowering the mowing speed, setting the mowing height slightly higher, levelling the surface with a "grass roller" and controlling moles and other rodents, and setting the collection height of the loader wagon slightly higher. The main concern for soil contamination appears to be the loader wagon. The risk of soil contamination appears to be especially relevant when biomass yields are low. The additional costs of mowing and harvesting with low contamination were not quantified.

Quality and slagging/fouling and corrosion behaviour

Nature grass sampled throughout the Netherlands contains significant amounts of potassium and chlorine, and very low sulphur amounts (chapter 3.). In combination with other elements, including silica, ash fouling/slagging and corrosion is expected to occur during biomass combustion.

The ash concentration of the grass samples – that were taken by hand, so contamination with soil is unlikely, was within the 5 to 8 weight percent range (with several samples showing concentrations higher than 10 weigh percent).

Both late harvesting (September) and grass from clay soils generally resulted in higher ash contents compared to harvesting in June and grass from sandy soils. The higher heating value (HHV) is 18.7 MJ/kg on average, which is representative for lignocellulosic biomass.

Application of thermal conversion quality indicators (Chapter 3.), that are based on mineral composition, show that most of the analysed nature grass samples do not meet compliance thresholds for ash fouling and slagging, which means that fouling and slagging (agglomeration) is most likely if not certainly to occur when these samples are used for combustion. However, a few samples could be used in a fuel blend with more benign fuels (wood). Based on calculating chlorine concentration-based indicators, almost all natural grass samples would have tendency to lead to corrosion during combustion. **Fouling and corrosion indicators showed that reducing potassium and chlorine by 70% would lead to grassy materials that are above or very near to the fouling and corrosion thresholds.**

Experimental work on both natural field leaching (chapter 5.) and artificial soaking (chapter 6.) showed that the 70% reduction goal of both potassium and chlorine can be met by both types of pre-treatment. Disadvantages of natural leaching are a 30% biomass loss and an uncontrolled process (natural precipitation is uncertain potentially resulting in longer required field times). Advantages of artificial soaking are a biomass loss of "only" 10% and a controlled process producing a fixed amount of processed biomass within a fixed timeframe. A disadvantage will be that the pre-treatment costs per tonne grass will be higher (additional investment and operational costs (a.o. processing water). If both the additional investments and operational costs of artificial soaking compared to natural leaching can be compensated for by a relatively low biomass loss (10 instead of 30%) and if a profitable business case based on artificial soaking can be developed has to be analysed in more detail.

Environmental aspects

Concerning the environmental aspects both for roadside grass and nature grass 4 valorisation cases have been assessed, viz.: composting (reference-case), digestion for CHP, combustion (Cuijk) with upstream natural leaching for CHP, combustion (Cuijk) with upstream artificial soaking for CHP.

CO_2eq-reduction potential [kg CO_2eq/ha.year]

All grass valorisation cases will result in a (significant) CO_2eq-reduction replacing their fossil alternatives for CHP production. The specific CO_2eq-reduction potential of thermal conversion with upstream biomass pre-treatment will be about 3 times the amount of that of digestion. Considering the pre-treatment options for thermal conversion, artificial soaking will result in an approximately 35-40% higher CO_2eq-reduction potential than natural leaching, mainly caused by the lower biomass loss (10 vs. 30%) during pre-treatment. The CO_2eq-reduction potential of roadside grass is in all cases significantly (> 50%) higher than that of natural grass, mainly caused by the higher annually harvested amount (14 vs. 8 tonnes as is, two harvests a year).

Other sustainability issues

Reduction of cost of biomass delivery may make management less costly and thus will support management goals. At the same time there are quality demands that will require adaptation of the management system.

Economics

The potential delivery costs of pre-treated (leaching/soaking) roadside grass have been estimated as 48-49 €/ton as is; those of pre-treated nature grass at 62-102 €/ton as is. The market value of these streams for combustion in the Cuijk power plant is € 17.5-22.5 €/ton as is (info Essent).

Conclusions

It can be concluded that:

1. It is technically possible to h1arvest roadside/nature grass with hardly any soil contamination.
2. Reducing potassium and chlorine by 70% - which could be met by both natural leaching and artificial soaking – will lead to grassy materials that are in the fouling and corrosion thresholds for thermal conversion.
3. Artificial soaking potentially is the most promising pre-treatment option for grassy materials to meet the technical thermal conversion quality constraints due to both the relatively low (10%) biomass loss during pre-treatment and the controlled process producing a fixed amount of processed biomass within a fixed timeframe.
4. All grass valorisation cases will result in a (significant) CO_2eq-reduction replacing their fossil alternatives for CHP production. The specific CO_2eq-reduction potential of thermal conversion with upstream biomass pre-treatment will be about 3 times the amount of that of digestion. Considering the pre-treatment options for thermal conversion, artificial soaking will result in an approximately 35-40% higher CO_2eq-reduction potential than natural leaching, mainly caused by the lower biomass loss (10 vs. 30%) during pre-treatment.
5. The current best estimate of the value of grass is for Cuijk is €17.5 to 22.5 per ton delivered (50% moisture). Compare to more than €30 per ton for wood chips (50% moisture). Projected delivery costs of pre-treated grassy materials of minimally 50 € per ton delivered show that significant further chain optimisation and/or a take-away fee will be necessary to result in a potential attractive business case.
6. Reduction of cost of biomass delivery may make management less costly and thus supports management goals. At the same time there are quality demands that will require adaptation / rethinking of the management and handling system.

Contractors Krinkels and Den Ouden, and nature conservancy Natuurmonumenten, have indicated that based on the results presented they may not be able to deliver pre-treated roadside and natural grass at such a price level that the further exploitation of a profitable business case based on CHP production could be possible for all stakeholders involved.

Den Ouden currently has developed and available a production process to clean grass from a variety of contaminants by means of an integrated pre-treatment process. These pellets can be used for both combustion (co-firing) processes and the production of cardboard, and can be produced at 125 €/tonne, including: raw material costs, washing, pressing, wastewater treatment, drying and pelletising. These production costs, together with the ash-content, are not competitive with wood pellets. These pellets, therefore, will be used outside of the energy sector for the production of cardboard.   .

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Annex: Average proximate and ultimate analysis of 25 herbaceous biomass samples from natural areas in The Netherlands collected late summer and early fall

Macro-elementen in samples						
% in DM or mg/kg DM		Samples	Average	STD	Min	Max
Al	%	25	0.02	0.02	0.01	0.06
Ca	%	25	0.74	0.33	0.29	1.52
Cl	%	25	0.72	0.32	0.15	1.90
Fe	%	25	0.03	0.02	0.01	0.10
K	%	25	1.30	0.67	0.33	2.53
Mg	%	25	0.25	0.10	0.13	0.59
Na	%	25	0.26	0.22	0.02	0.80
P	%	25	0.24	0.09	0.09	0.42
Si	%	25	1.30	0.72	0.22	2.64
Ti	%	25	0.00	0.01	0.00	0.03
Other elements						
As	mg/kg	22	0.68	0.48	0.30	2.20
B	mg/kg	0	0.00	0.00	0.00	0.00
Ba	mg/kg	0	0.00	0.00	0.00	0.00
Be	mg/kg	0	0.00	0.00	0.00	0.00
Br	mg/kg	0	0.00	0.00	0.00	0.00
Cd	mg/kg	6	0.42	0.15	0.30	0.70
Ce	mg/kg	0	0.00	0.00	0.00	0.00
Co	mg/kg	15	0.59	0.28	0.30	1.20
Cr	mg/kg	25	3.14	1.73	1.60	9.50
Cs	mg/kg	0	0.00	0.00	0.00	0.00
Cu	mg/kg	25	6.57	1.91	3.50	11.00
Eu	mg/kg	0	0.00	0.00	0.00	0.00
F	mg/kg	22	7.25	3.49	1.20	14.00
Ge	mg/kg	0	0.00	0.00	0.00	0.00
Hf	mg/kg	0	0.00	0.00	0.00	0.00
Hg	mg/kg	25	0.01	0.01	0.00	0.03
I	mg/kg	0	0.00	0.00	0.00	0.00
La	mg/kg	0	0.00	0.00	0.00	0.00
Mn	mg/kg	25	253.64	247.31	18.00	1034.00
Mo	mg/kg	25	2.30	1.80	0.50	8.00
Ni	mg/kg	25	1.34	0.48	0.70	2.40
Pb	mg/kg	25	3.74	9.59	0.50	50.00
Rb	mg/kg	0	0.00	0.00	0.00	0.00
Sb	mg/kg	12	0.32	0.12	0.20	0.60
Sc	mg/kg	0	0.00	0.00	0.00	0.00
Se	mg/kg	10	1.47	2.12	0.30	7.70
Sm	mg/kg	0	0.00	0.00	0.00	0.00
Sn	mg/kg	3	0.83	0.12	0.70	1.00

Sr	mg/kg	0	0.00	0.00	0.00	0.00
Te	mg/kg	0	0.00	0.00	0.00	0.00
Th	mg/kg	0	0.00	0.00	0.00	0.00
Tl	mg/kg	0	0.00	0.00	0.00	0.00
U	mg/kg	0	0.00	0.00	0.00	0.00
V	mg/kg	25	0.71	0.50	0.20	2.10
W	mg/kg	0	0.00	0.00	0.00	0.00
Zn	mg/kg	25	40.96	19.16	13.00	79.00
Main elements - in sample DM						
C	%	25	46.32	1.38	43.84	49.53
H	%	25	5.83	0.25	5.14	6.22
N	%	25	1.67	0.54	1.02	3.24
S	%	25	0.28	0.11	0.11	0.56
O (calculated)	%	25	38.03	1.48	34.46	40.05
Total water, ar	%	25	68.97	7.73	53.54	78.56
Ash content	%	25	8.05	2.10	5.12	12.47
Vluchtig	%	25	73.86	1.69	69.80	76.88
Energie-inhoud						
HHV, ds	MJ/kg	25	18.70	0.64	17.49	20.06
LHV, ds	MJ/kg	0	0.00	0.00	0.00	0.00
LHV, ar	MJ/kg	25	3.67	1.59	1.80	6.79
In Sample – calculated						
SiO_2	mg/kg	25	27857	15471	4658	56569
Al_2O_3	mg/kg	25	411	301	115	1148
Fe_2O_3	mg/kg	25	595	417	162	1912
CaO	mg/kg	25	10393	4634	4082	21211
MgO	mg/kg	25	4215	1714	2091	9806
Na_2O	mg/kg	25	3540	2982	272	10807
K_2O	mg/kg	25	15607	8059	4029	30522
TiO_2	mg/kg	25	51	93	10	484
P_2O_5	mg/kg	25	5424	2007	2144	9521
SO_3	mg/kg	25	7057	2857	2745	13974
Sum	mg/kg	25	75149	22062	35919	119210
Sum/ as percentage	%	25	93.3	11.0	44.6	103.2
Ash composition - Calculated						
SiO_2	%	25	33.2	15.0	7.8	57.7
Al_2O_3	%	25	0.5	0.4	0.2	2.0
Fe_2O_3	%	25	0.8	0.5	0.2	2.2
CaO	%	25	13.2	5.7	5.3	29.3
MgO	%	25	5.5	2.4	2.3	12.9
Na_2O	%	25	4.8	4.3	0.3	17.5
K_2O	%	25	19.3	9.1	6.2	44.6

TiO2	%	25	0.1	0.2	0.0	0.9
P2O5	%	25	7.2	3.1	1.9	13.4
SO3	%	25	8.8	2.9	4.3	18.4
Sum	%	25	93.3	11.0	44.6	103.2