Programme Area: Bioenergy

Project: Characterisation of Feedstocks

Title: D13 Synthesis Report of Phase 1 and Phase 2

Abstract:

The primary objective of this 2015/16/17 Project was to provide an understanding of UK produced biomass properties, how these vary and what causes this variability.

This document contains the Appendices to the Final Report from the second Phase (2016/17) of the Characterisation of Feedstocks (CofF) project, Deliverable D12. This deliverable (D12) is one of three to be provided under the second phase (2016/17) of the Characterisation of Feedstocks Project. It is supported by the Excel dataset (D11). A synthesis and summary of the findings from the whole project, Phases 1 plus 2, is provided separately (Deliverable D13).

The purpose of this deliverable D12 is to report the findings from the 2016/17 investigations into the impact of harvest time on the properties of UK produced Short Rotation Coppice (SRC) willow and Miscanthus; the impact of variety on UK produced SRC willow properties, and; the impact of four different types of commonly used storage types over time on UK produced Miscanthus properties.

Context:

The Characterisation of Feedstocks project provides an understanding of UK produced 2nd generation energy biomass properties, how these vary and what causes this variability. In this project, several types of UK-grown biomass, produced under varying conditions, were sampled. The biomass sampled included Miscanthus, Short Rotation Forestry (SRF) and Short Rotation Coppice (SRC) Willow. The samples were tested to an agreed schedule in an accredited laboratory. The results were analysed against the planting, growing, harvesting and storage conditions (i.e. the provenance) to understand what impacts different production and storage methods have on the biomass properties. The main outcome of this project is a better understanding of the key characteristics of UK biomass feedstocks (focusing on second generation) relevant in downstream energy conversion applications, and how these characteristics vary by provenance.

ETI Project Code: **BI2010**

Project Title: **Characterisation of Biomass Feedstocks**

Deliverable title: **Synthesis report of Phase 1 and Phase 2**

Reference: **D13**

Participant lead: **Forest Research**

Other participant: **Uniper Technologies Ltd**

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Executive Summary

Within the UK, the installation of dedicated biomass power plants and the conversion of existing coal plants to use biomass, either in dedicated plants or co-fired with coal, has dramatically increased the demand for biomass feedstocks. At present home-grown output is significantly less than the demand, creating the opportunity for UK land-owners to supply this new market. Despite this, the level of understanding of biomass crops in the UK is still rather general. In particular, there is limited understanding of the variability in feedstock properties and a lack of recognition that differences in various properties can have a significant effect on the subsequent conversion to power and/or heat. Across all scales of use, feedstock quality is critically important in order to optimise plant performance, safeguard the environment, and maximise the financial benefits of the project.

The overall purpose of the project (Characterisation of Biomass Feedstocks) is to inform the ETI on the variability in feedstock properties of UK-produced energy biomass types. Four main feedstocks were investigated: *Miscanthus*, willow short rotation coppice, poplar short rotation forest, spruce short rotation forest which are referred to respectively as *Miscanthus*, willow SRC, poplar SRF and conifer SRF. Sites with poplar short rotation coppice were limited in number so although data are presented in the database, no analysis was possible. The specific objective of this Deliverable D(Deliverable D13) is to provide a succinct and concise summary of the key findings of the entire project and in addition draw out the practical implications for both growers and operators of conversion plants.

In Phase 1 there were four related studies. Field work took place from spring through to autumn 2015. The largest was designed to investigate the reasons behind any observed variation in feedstock characteristics within the UK. Potential sources of variation included were climate zone, soil type, harvest time, storage, and plant part. Three smaller studies in Phase 1 explored specific supplementary points which were of practical value to the grower and buyer: feedstock variability within a site (*Miscanthus* and one variety of willow SRC only); leaf properties (poplar SRF and willow SRC) for comparison to the feedstocks containing little or no leaf material; and pellet properties since the process of pelletising may alter the composition compared to the raw feedstock. The findings are described in detail in Deliverable D6 and associated appendices.

In Phase 2 there were four studies designed to follow up on points of particular interest in Phase 1: the impact of harvest time on *Miscanthus* properties; the impact of harvest time on willow SRC properties; the impact of variety on willow SRC characteristics; and the possible effects of four different, but commonly used methods for storing *Miscanthus* bales, to understand the changes in fuel quality during 6 months of storage. Field work ran from November 2015 to November 2016. The findings are described in detail in Deliverable D12 and associated appendices. All data are contained in Deliverable D11.

For each of the main feedstock characteristics, the effects of all the sources of variation studied during the project have been summarised for all four feedstocks in a table followed by a composite set of figures, one for each species. This allows a visual assessment of the relative impact of each of the studied factors and the variability across factors and feedstocks for each of the main feedstock characteristics. In view of the

differences in both the species-specific responses demonstrated in this project and in feedstock specifications for conversion plant, a single ranking would be misleading and under value the findings of this project.

In response to the project's hypotheses, which are shown in italics, the findings can be summarised as:

1. *The feedstocks examined range from Miscanthus, through woody deciduous plants grown for only a few years and regenerated by coppicing (willow and poplar), to small deciduous and evergreen trees (poplar and Sitka spruce respectively), therefore we hypothesise that the feedstocks will differ in their fuel properties and/or composition.* Significant variation was seen between the different feedstocks in terms of their fuel properties and composition in terms of both the mean values and the range of the data. For example, the *Miscanthus* showed higher levels of chlorine than the conifer SRF. Of the ETI samples, only the conifer SRF stem wood met the strictest criteria for current relevant standards of industrial wood pellets. The importance of this variability will differ depending on the chemical parameter and the conversion system being considered.

2. *The feedstocks are differentiated into plant parts that have different functions, e.g. mechanical support versus photosynthesis; therefore we hypothesise that these plant parts will differ in their fuel properties and/or composition.* This hypothesis was investigated for willow SRC, poplar SRF and conifer SRF but not *Miscanthus* for which separation into leaf and stem is not commercially feasible at an operational scale. Plant part did have a significant impact. Levels of chemical elements were highest in the leaves when they were sampled in late July/early August (poplar SRF) and September (willow SRC). In willow SRC, concentrations where lower in the stems than the leaves. In poplar SRF, the general pattern was for lower concentrations in the tops followed by the stems but the differences between these parts were smaller in the spring than the summer. In conifer SRF, concentrations were generally higher in the tops than the stem wood with bark intermediate and the differences between plan parts were smaller in spring than summer. The lowest concentrations were found in the stem wood. A similar pattern was found in gross calorific value across plant parts. By contrast net calorific value tended to be lowest in the leaf samples of willow SRC and poplar SRF, while in poplar SRF and conifer SRF, the tops had a higher net calorific value than the stems.
   Biological material when in active growth has cells containing high levels of genetic material and all the compounds necessary for cell division, maintenance and growth as well as photosynthesis. The distribution of many elements within the plant changes seasonally according to the cellular activity. As winter approaches and active growth, photosynthesis, and cell maintenance decline, cell contents are moved to other locations within the plant, for example to the roots, for storage leaving the cell wall, which is essentially inert, to fulfil a support function. These relationships are also relevant to the impact of time of harvesting addressed in point 5 below.

3. *Feedstock properties will differ depending on the climate the crop is exposed to.* Within the range of average climate zones covered in this UK-based project, climate zone (as defined by average temperature and precipitation) had little influence on fuel composition.

4. *Feedstock properties will differ depending on the soil composition and characteristics of the site.* Within the range of soil types (defined in terms of texture for mineral soils and texture plus organic matter for peaty soils) examined in the project, soil type had very little influence on fuel properties and/or composition. Similarly, the analysed soil parameters showed few correlations with the corresponding feedstock composition. Both findings were unusual, and it is probable that the lack of significant relationships between both soil type and soil composition and feedstock properties is due to the very low levels of most nutrients and metals in these typical rural soils.

5. *Feedstock properties will differ according to the time of year that the biomass is harvested (see also hypothesis 9).* In Phase 1 this question focussed on poplar and conifer SRF. Feedstock properties of both did differ when harvested in the spring compared to summer harvests, with an impact on the poplar SRF particularly apparent. In the tops of poplar SRF, there were increases from spring to summer in moisture, zinc, potassium, and the Alkali Index as well as the oxides K_2O and SiO_2. Conifer SRF stem wood increased in levels of MgO but decreased in calcium, potassium, sodium, and silicon as well as the oxides Na_2O and SiO_2. Conifer SRF bark decreased in nitrogen, phosphorus and P_2O_5. Conifer SRF tops increased in P_2O_5, SiO_2 but decreased in levels of lead, sodium and the oxides of $CaCO_3$, MgO, Na_2O. These differences were more pronounced for the tops than the lower part of the stem; for the poplar SRF this may be due to the inclusion of leaves in the second tops harvest that are essentially absent from the first harvest.

6. *Feedstock properties will change with storage.* Storage had a strong influence on most feedstocks, particularly for moisture content and related properties for *Miscanthus,* which was stored for up to six months, and poplar SRF and conifer SRF which were both stored for three months. In this instance storage of willow SRC had no operationally important impacts but this finding should not be assumed to be a generalisation as the storage time was only one month.

7. *Within a given field, feedstock properties will be relatively uniform.* This hypothesis was investigated for *Miscanthus* and willow SRC. For some feedstock characteristics (for example gross calorific value, chromium, copper, nickel, arsenic, mercury, lead, iron, and sodium), the variation within fields was much greater than that between different sites. It was generally the case that if for a particular feedstock property within-field variation was greater than between field variation for *Miscanthus* it was also true for willow SRC, i.e. similar behaviour between the two feedstocks was seen for a number of individual fuel quality parameters.

8. *The process of pelletisation will influence the fuel properties and/or composition*. This hypothesis was investigated for *Miscanthus* only. There was a marked change in physical and chemical properties of *Miscanthus* following pelletisation. The results indicated that there was a relatively high risk of product contamination, either from deliberate use of additives, from other materials or wear products from the grinding process or the pellet mill itself. However due to the limited number of samples available from the pelletisation process no clear conclusions could be made on changes to the chemical compositional aspects which were not directly related to the additives used by the pellet producer.

9. *Harvest time will affect the fuel properties and/or composition of Miscanthus and willow SRC (Phase 2).* In *Miscanthus* a general decrease through late autumn, winter and early spring was observed in moisture content, ash, carbon, nitrogen, chlorine, molybdenum, zinc, bromine, phosphorus, silicon, and calcium accompanied by an increase over the same period in net calorific value, volatile matter, and sodium. Only a few characteristics of willow SRC grown at six sites from north west to southern England showed statistically significant differences across three simulated harvesting times (mid-November, mid-January and mid-March) – gross calorific value, chromium, and calcium carbonate, potassium oxide and phosphorus - with the majority showing no difference. For the characteristics that did change, a variety of patterns was evident: gross calorific value decreased from November to January and then increased to March; chromium increased across the three sampling times; $CaCO_3$ was similar in November and January but increased to March; K_2O decreased across the three sampling times.

10. *The feedstock characteristics of Miscanthus and willow SRC will differ from one year to the next at a given site.* The levels of many feedstock characteristics were broadly similar from one year to another but this was not the case for all parameters and some important properties, e.g. gross calorific value, magnesium and phosphorus, differed. Looking at seasonal changes where they were shown to be significant in the Phase 2 study of seasonal trends, some parameters had broadly similar dynamics, e.g. moisture content, net calorific value, ash, and chlorine (even though the absolute levels were slightly different). On the other hand, although the general seasonal patterns of nitrogen levels were broadly similar in the two years, the direction of change was not always the same on a particular date in the spring. No direct comparisons were possible in willow SRC because the crops sampled in the first year were harvested that spring and were therefore not at a stage for sampling in the following year.

11. *The feedstock characteristics of willow SRC varieties will differ from one variety to another in a consistent manner from one location to another.* There was a certain degree of consistency in willow variety properties across sites from Northern Ireland to Southern England, with approximately 40% of the parameters analysed showing statistically consistent rankings for the varieties tested (Endurance, Nimrod, Resolution, Sven, Terra Nova, and Tora) but no variety combined the best ranking in all parameters and for the majority of parameters there was not a consistent ranking.

12. *The fuel properties and/or composition of Miscanthus are influenced by the storage method and duration.* In 14% of analysed feedstock characteristics, which included ash, nitrogen, sulphur, zinc, bromine and calcium, storage treatments did have a significant influence; 43% were affected by storage but there was no influence in type of storage treatment; and another ca 43% of the feedstock characteristics tested were not significantly affected by storage. These results suggest that no single type of storage is likely to minimise the deterioration in all aspects of feedstock quality with storage.

These findings have the following implications for the growers of biomass as bioenergy feedstocks.

Although different feedstocks clearly varied in key fuel quality parameters that can have a significant impact on conversion technologies, species choice is likely to be determined by the farm's capability, expected yields and personal preferences rather than a consideration of fuel characteristics. Species differences are however highly relevant to anyone sourcing feedstocks.

Climate zone was only occasionally a decisive factor but the clear seasonal effects demonstrated in the project suggest that local environmental effects, e.g. temperature, rainfall and day length, influence feedstock characteristics. Harvesting and baling of *Miscanthus* in particular is very weather dependent and this can influence harvest time. Growers' experience of local weather may therefore be a useful guide to likely feedstock properties but the long term average seems to be of limited value in predicting feedstock quality.

Soil type was rarely important in determining the composition of the feedstock during this project. Initially this was a surprising finding, but on further examination it became clear from soil analyses and provenance information that sites were typical of rural soils and were neither derived from reclaimed or contaminated sites or treated recently with sewage sludge. The soil analysis data revealed that the sites were very 'clean', with below average or very low levels of soil metals and metalloids, which probably explains the absence of any impact of soil type and the very small number of strong correlations found between feedstock ash characteristics and soil properties. Furthermore soil type was defined in terms of texture for mineral soils and texture plus organic matter for peaty soils therefore our findings do not exclude the possibility that aspects of soil chemistry and structure may have an influence on feedstock characteristics.

For *Miscanthus* and willow SRC, the variation in some feedstock characteristics between the sites was greater than that seen within samples taken from across the same field, whilst for others the variation within-field was much greater than that between different sites. This suggests that for critical quality characteristics e.g. ash, silicon, potassium, sodium and chlorine, it could be useful to understand if there are appreciable differences between fields in soil chemistry and/or structure. If so, fields could be chosen to benefit crop quality. If there is much greater variation within fields than between fields, it is difficult to see what, if any, practical steps could be taken to improve crop quality though in extreme cases it might be possible to restrict the bioenergy crops to particular sections of a field or ensure blending of feedstock to even out inconsistencies.

Plant part for willow SRC, poplar SRF and conifer SRF was a key determinant of feedstock properties. For willow growers, the results emphasise that leaves should generally be excluded by harvesting in the dormant season if soil conditions allow. Poplar growers may improve the quality of harvested tops by harvesting in the dormant season or if other factors dictate that the crop is harvested in the summer, tops could be stored until the leaves have been shed. Although conifer SRF tops usually had higher concentrations of most elements than the stem wood and bark, the levels tended to be so low that even tops could be harvested without exceeding quality thresholds although growers of conifer SRF may improve the quality of harvested tops by storing them until as many needles as possible have fallen off.

Despite the perception that bark is a poor quality fuel, this was generally not the case. From the perspective of bioenergy supply, the cost of separating bark from stem wood would not be justified but if other processing steps have generated material with a high proportion of bark, this is likely to be an acceptable bioenergy feedstock. The caveat is that the good quality observed here may be due to the careful sampling methodology, which was designed to minimise contamination, and commercial harvesting operations may cause a reduction in quality, typically caused by soil contamination. If this concern is justified, potential bioenergy suppliers may be able to modify their harvesting techniques assuming it is economically viable.

Willow varieties showed a moderate degree of consistency across six sites, with approximately 40% of the parameters analysed showing statistically consistent rankings. At first glance this suggests that growers could select varieties to improve the feedstock quality. Considering the results as a whole however, three important points emerged - firstly that no variety combined the best ranking in all parameters of importance for commercial conversion technologies; secondly, that no variety is problematic; and thirdly, for the majority of parameters, there was not a consistent ranking.

The choice of *Miscanthus* harvesting time needs to weigh up several trends. A general decrease through late autumn, winter and early spring was observed in moisture content, ash, carbon, nitrogen, chlorine, molybdenum, zinc, bromine, phosphorus, silicon, and calcium accompanied by an increase over the same period in net calorific value, volatile matter, and sodium. Considered as a whole these results suggest that to maximise *Miscanthus* quality, harvesting should be delayed until at least the beginning of March, with chlorine and ash a particular concern if harvesting is earlier in the year which also risks losing the advantages of low moisture content and higher NCV.

Harvesting willow with leaves increased the GCV but this risks raising the moisture content, and ash, nitrogen, sulphur and chlorine levels considerably. Considering the dormant season, few differences were detected in the willow SRC from autumn, through winter to spring, especially when compared to the *Miscanthus* results. Even if changes during the dormant season are under-represented, our results suggest that willow growers have considerable flexibility over harvesting times and that the window should be limited to after leaf fall through to bud burst.

Storage for six months proved to be an important determinant of many *Miscanthus* characteristics - in 14% of the characteristics, which included ash, nitrogen, sulphur, zinc, bromine and calcium, storage treatments did have a significant influence and a further 43% were affected by storage although there was no influence in type of storage treatment. The majority of significant changes represented a deterioration in fuel quality. About 43% of the feedstock characteristics tested were not significantly affected by storage. From a practical point of view, some period of on-farm storage is likely to be needed so the question becomes: what can be done to minimise the deterioration? These results suggest that no single type of storage is likely to minimise the deterioration in all aspects of feedstock quality and the choice of storage type is more likely to be dictated by what type of storage is available and perhaps the contamination risk on the farm, especially in the absence of any price differential linked to quality.

Although we have limited evidence of the pattern of change over time, the results imply that storage should be minimised. These findings, however interesting, should be treated with caution since it was just one site in the south west England in one year. Although the 6-month storage duration represented a typical operational situation, the questionnaire of commercial growers showed that both much shorter and longer periods may be used to fit with work patterns on the farm and market demands. Since this project demonstrated major changes in many aspects of *Miscanthus* quality during storage and also that the storage method and duration could be influential, these findings should be considered carefully by the sector and a wider range of sites and storage duration may be worthy of further investigation.

Three months' storage of SRF stems and tops was also associated with many changes on feedstock characteristics which indicates that growers are able to influence many aspects of crop quality through their choice of harvest time and storage duration.

Only limited statistical analysis of crop management practices was possible in Study 1, but this identified possible relationships between year of planting and both cadmium in *Miscanthus* (cadmium concentrations in the feedstock with earlier planting years being associated with lower levels in the sampled biomass) and sodium in willow SRC (sodium and Na_2O were negatively related with planting year). The age of sampled material appeared to influence several characteristics in both willow SRC (nitrogen, K_2O in the ash, elemental Fe, K, Mg, P, and the Alkali Index all tended to decrease whereas $CaCO_3$ in the ash increased with crop age) and conifer SRF bark, whilst planting density had impacts on levels of barium in conifer SRF wood as well as the volatile matter, nitrogen, copper and cadmium in conifer SRF tops. Although these are interesting insights, the evidence is not sufficiently robust to make recommendations to growers and further investigation would be necessary if these feedstock properties were thought to be important.

In general terms, the largest differences in production costs between the feedstock types was in the initial establishment and management costs, with conifer SRF and poplar SRF incurring higher costs in the early years. It is unlikely that many land owners will have land that offers a choice of growing more than one biomass type however if that situation does arise, productions costs, potential yields, and personal preference will be likely to sway the choice rather than considerations of feedstock quality which does not benefit from a price premium in the current biomass feedstock market other than a specification for a maximum moisture content.

A qualitative ranking of factors affecting the important characteristics extracted from the analysis of the individual feedstocks indicates that feedstock characteristics are not affected in a consistent way by the site properties and crop management. Nevertheless, the following general observations can be made:

- The implications for growers of *Miscanthus,* poplar SRF and conifer SRF are that the most important factors affecting moisture and NCV (season and storage) can be manipulated by their choice of harvesting time and storage practice.
- In the case of *Miscanthus,* some of the chemical properties might be modified by the selection of fields

- With a better understanding of the impact of environment on the growth of *Miscanthus*, sections of the farm could be chosen that would optimise the feedstock properties (and yield).
- Willow SRC growers have a reasonable degree of control over some of the important feedstock characteristics by their choice of variety, harvesting time – as a means of controlling leaf content– the age of the root stock and the length of the cutting cycle.
- For poplar SRF and conifer SRF, many of the other properties can be adjusted by the choice of the plant part to market and harvest time. Feedstock properties were relatively insensitive to the way conifer SRF was grown.

In spite of the consistent high-level findings summarised above, it was not possible to derive simple guidance for biomass growers because of the differences in the behaviour of the individual feedstock characteristics. For any one year and site, the net effect of these changes is difficult to predict. If there was sufficient premium for crop quality, a monitoring programme, which could focus on the most important parameters for the end-use in mind, could be considered.

Finally, feedstock quality must be considered in tandem with biomass yields. Although the seasonal changes in quality we observed from autumn, through winter and spring would generally be beneficial we did not collect yield information in either fresh or dry weight terms, therefore it is not possible to estimate the overall impact of crop quality and quantity from our project. Compared to *Miscanthus,* this is likely to be less of an issue for willow SRC, poplar SRF and conifer SRF growers because seasonal changes in biomass yield are less pronounced. If there is a price advantage for feedstock quality, the woody crops could be managed to optimise quality with little counter impact on quantity.

For all conversion technologies, correct matching of the fuel and equipment is important. Failure to understand the probable impacts of the feedstock on the system is likely to result in reduced efficiency, lower availability, increased OPEX and increased emissions. Different conversion technologies will have different acceptable levels for each feedstock parameter. These limits will depend on a number of factors, such as steam parameters and technology type and will tend to be more restrictive for those technologies offering the highest quality outputs (e.g. highest efficiency or specific conversion products). For all feedstocks, the implications for buyers are that consideration must be given to the feedstock characteristics of prime importance in a particular end use application.

These findings have the following implications for end-users of biomass as bioenergy feedstocks.

Levels of sulphur and nitrogen in the studied feedstocks were low when compared to typical UK coal values, although nitrogen in particular was elevated in the leaves of both willow SRC and poplar SRF. These elements have a direct impact on gaseous emissions of the respective oxides, which are both considered primary pollutants and hence regulated for many applications. Chlorine contents were heavily dependent on the feedstock, with *Miscanthus* containing some of the highest levels, together with the poplar and willow leaves. As well as contributing to acid gas emissions, chlorine is considered to be one of the highest risk elements contributing to boiler corrosion in biomass combustion systems, although these impacts can sometimes be mitigated by the presence of sulphur and upstream removal of the chlorine. Acid gases (such as SO_2 and HCl) will also lead to degradation of the amine used in post-combustion carbon capture and storage (CCS) systems and hence high levels of control will be necessary in bioCCS applications. Buyers should therefore check the levels of leaf material in willow and poplar and consider specifying a harvesting window or, in the case of poplar tops harvested during the growing season, the use of a storage period to ensure that leaf material is shed.

Compared to most coals, the ash levels seen in the project feedstocks were low, with the SRF trunks showing the lowest levels. While coal ash is primarily alumino-silicate based, the biomass ash compositions were very different. For most of the feedstocks, the ash was primarily composed of calcium and potassium compounds (the exception was *Miscanthus*, which contained significant levels of silica). This has important practical implications because potassium (and sodium) are linked to a number of detrimental effects within boilers, including slagging, fouling, agglomeration of fluidised beds, corrosion, deactivation of $deNO_x$ catalysts and formation of fine particulate matter. As a result, equipment suppliers will often impose limits on inputs of these elements to the conversion system, which may in turn restrict feedstock choice. Calcium can have positive and negative impacts, the former including capture of acidic gases into the ash (allowing easier removal). The impact on e.g. slagging can vary depending on the presence of other species.

The importance of the trace metals such as mercury and cadmium contained in fuel for conversion plant is primarily due to environmental concerns (i.e. air and water emissions), but the feedstocks used in this project were generally so low in these elements for this not to be an issue. Lead and zinc have been identified as presenting a corrosion risk in boilers (particularly in combination with chlorine) and lead in ash may also raise occupational health concerns, but only at higher levels than seen in this project (for example in waste wood combustion).

The levels of ash, chlorine content and calculated alkali index for the *Miscanthus* samples were interesting to compare against the other data in light of the general industry perception of this feedstock as being ‘problematic’ - they were actually similar to the SRF conifer and poplar tops for these parameters. By contrast, some of the *Miscanthus* pellets had elevated sodium levels (caused by addition of caustic soda to improve pellet throughput) which would have severe consequences for conversion plans in terms of corrosion and fouling. This illustrates that common commercial practice can have a significant impact on fuel quality and that good communication between supplier and end-user is necessary to maintain fuel quality requirements.

A number of wood pellet standards have been agreed internationally, with fuel quality limits set for different grades depending on the market. At present, most coal plant that have been converted to biomass use primarily wood pellet as a “clean” biomass to minimise risk, but for other conversion technologies a wider basket of fuel qualities may be acceptable. On a dry basis, only conifer SRF stem wood met the most stringent wood pellet standards, with cadmium an issue in poplar SRF, nitrogen, chlorine, cadmium and zinc exceeding the limits in some or all of the willow SRC samples and high levels of chlorine and nitrogen in *Miscanthus*. In light of the potential advantages of these biomass feedstocks for conversion (especially relative to coal), there is scope to use them for co-firing in coal-fired plant or other conversion plants set up to take account of the high nitrogen and chlorine levels in leaves, needles and grasses, such as *Miscanthus*. In addition there is scope to make use of the individual strengths and weaknesses of these biomass feedstocks by mixing them to achieve a bio-blend that matches the requirements of the biomass conversion plant. The most realistic approach would be to blend these feedstocks at the point of use or at an intermediate re-processing plant (for example by producing mixed pellets).

1 Contents

1 Introduction

1.1 Background and context

At a global scale, the use of biomass as a source of energy has transformed in the last two decades, from widespread utilisation within a local geographic area for cooking and heating, to use for power generation at a large scale and combined heat and power generation at a medium scale. This change is largely in response to policy and financial drivers to limit CO_2 emissions from fossil fuels, with biomass combustion generally considered to be low carbon, or even CO_2 neutral (although account must be taken of the sustainability of the supply and upstream emissions from production and transport). As a result of the biomass tonnages required for large-scale industrial operations, global trading of biomass feedstocks is now well established. The more traditional use for heat persists and has even grown in some developed countries, due to a variety of reasons, including environmental, financial and aesthetic reasons, as well as a lack of alternative sources of heating in some locations.

Across all scales of use, feedstock quality and properties are critically important in order to optimise plant performance, safeguard the environment and maximise the financial returns of the project.

1.2 Objectives

The overall purpose of the project (Characterisation of Biomass Feedstocks) is to inform the ETI on the variability in feedstock properties of UK-produced energy biomass types. The specific objective of this Deliverable D(Deliverable D13) is to provide a succinct and concise summary of the key findings of the entire project and in addition draw out the practical implications for both growers and operators of conversion plants.

1.3 Initial hypotheses

The hypotheses were:

1. The feedstocks examined range from *Miscanthus*, through woody deciduous plants grown for only a few years and regenerated by coppicing (willow and poplar), to small deciduous and evergreen trees (poplar and Sitka spruce respectively). It is therefore hypothesised that the feedstocks will differ in their fuel properties and/or composition.
2. The feedstocks are differentiated into plant parts that have different functions, e.g. mechanical support versus photosynthesis; therefore we hypothesise that these plant parts will differ in their fuel properties and/or composition.
3. Feedstock properties will differ depending on the climate the crop is exposed to.
4. Feedstock properties will differ depending on the soil composition and characteristics of the site.

5. Feedstock properties will differ according to the time of year that the biomass is harvested.
6. Feedstock properties will change with storage.
7. Within a given field, feedstock properties will be relatively uniform.
8. The process of pelletisation will influence the fuel properties and/or composition.
9. Harvest time will affect the fuel properties and/or composition of *Miscanthus* and willow SRC.
10. The feedstock characteristics of *Miscanthus* and willow SRC will differ from one year to the next at a given site.
11. The feedstock characteristics of willow SRC varieties will differ from one variety to another in a consistent manner from one location to another.
12. The fuel properties and/or composition of *Miscanthus* are influenced by the storage method and duration.

2 Methodology

2.1 Study overview

In Phase 1 there were four related but different studies with an overview of the primary variables examined in each study shown in Table 2-2 and the sites in Figure 9-1**Error! Reference source not found.**, **Error! Reference source not found.**, Figure 9-3, and Figure 9-4**Error! Reference source not found.** for *Miscanthus,* willow SRC, poplar SRF and conifer SRF respectively (only three operational poplar SRC sites were located which was insufficient to analyse statistically). Field work took place from spring through to autumn 2015. The largest (Study 1) was designed to investigate the reasons behind any observed variation in feedstock characteristics. Potential sources of variation included within Study 1 were climate; soil type, harvest time, storage, and plant part.

Three smaller ancillary studies in Phase 1 explored specific supplementary points which were of practical value to the grower and buyer:

- Study 2 investigated feedstock variability within a site (*Miscanthus* and one variety of willow SRC only) addressing hypothesis 7.
- Study 3 investigated leaf properties (poplar SRF and willow SRC) for comparison to the feedstocks containing little or no leaf material (as obtained in Study 1). This addresses in part hypothesis 2. While it would be usual practice to harvest without leaves, there could be situations when crops are harvested when leaves are present.
- Study 4 investigated pellet properties. The process of pelletising may alter the composition compared to the raw feedstock, which was formalised as hypothesis 8. Furthermore, significant quantities of biomass are imported in pellet form, especially wood pellets, and Uniper have contributed data from the routine sampling of imported wood pellets which allows comparison with the characteristics of the woody biomass sampled within the project.

In Phase 2, there were four studies designed to follow up on points of particular interest in Phase 1. Field work ran from November 2015 to November 2016 and summary details are provided in Table 2-2.

- Study 5 investigated the impact of harvest time on *Miscanthus* properties. On three occasions covering the autumn and winter, samples were collected from standing crops at six commercial *Miscanthus* sites (see Figure 9-1 to simulate commercial harvesting. At each site samples were collected on two further occasions linked to normal commercial practice – immediately after the crop was cut as part of Study 8.
- Study 6 investigated the impact of harvest time on willow SRC properties. On three occasions covering the autumn and winter, samples were collected from six willow SRC sites to simulate commercial harvesting of the mix of varieties on the site.

- Study 7 investigated the impact of plant variety on the feedstock characteristics of willow SRC. Five sites were selected (Aberystwyth, Rothamsted, Long Ashton, Loughall, Brook Hall; see Figure 9-2**Error! Reference source not found.**). These sites spanned a wide range of environmental conditions to provide a robust test of the consistency of willow SRC feedstock characteristics across a range of varieties. In total six varieties (Endurance, Tora, Terra Nova, Resolution, Sven, and Nimrod) were identified that were found at all five sites with the exception of Sven and Nimrod which were absent at Aberystwyth. Information about the lineage of the varieties is listed in Table 2-1(Lindegaard, 2013). . Sampling at all sites was done within one week (end February/beginning of March 2016) to minimise the impact of sampling time on feedstock characteristics.

- Study 8 evaluated the possible effects of four different, but commonly used commercial *Miscanthus* storage systems, to understand the changes in fuel quality during 6 months of storage (May 2016 at the start and at the final sample timing in November 2016). The four different storage methods evaluated (see Figure 2-1) were:

  - Storage outside with no cover
  - Storage outside with waterproof sheeting protecting the top of the stack of bales and the sides of the upper two/three bale layers only
  - Storage inside in a building with open sides providing roof cover only
  - Storage inside in a fully enclosed building

  The site selected for the trial was in Taunton, Somerset at the farm of a *Miscanthus* grower, Richard Gothard of Miscanthus Nurseries Ltd; the location is shown in Figure 9-1. The *Miscanthus* bales used for the trial were harvested in the field next to the yard at the end of April 2016. The *Miscanthus* was left to dry in the field for almost three weeks prior to being baled and brought in to the farm yard and placed in to the four different storage systems.

Table 2-1: Varieties of willow included in Study 7 and their parentage

Blocks shaded in green are varieties from the Swedish Svalöf Weibull breeding programme; Blocks shaded in yellow are varieties from the UK Long Ashton breeding programme.

Male	**Female**	**Male**	**Female**
Male		**Female**	
L78101 (*S. viminalis*)	L78195 (*S. viminalis*)	Unknown	Unknown
Orm (*S. viminalis*)		L79069 (*S.schwerinii*)	
Tora (Female)			
Orm (*S. viminalis*)	L79069 (*S.schwerinii*)	L830201 (*S. viminalis*)	N81102 (*S. viminalis*)
Björn (*S. schwerinii x S. viminalis*)		Jorunn (*S. viminalis*)	
Sven (Male)			
Unknown	Unknown	Unknown	Unknown
77056 (*S.dasyclados*)		(*S. redheriana*)	
Endurance (Female)			
Björn (*S. schwerinii x S. viminalis*)	Pavainen (*S. viminalis*)	Björn (*S. schwerinii x S. viminalis*)	Jorunn (*S. viminalis*)
Quest		SW930812	
Resolution (Female)			
Unknown	Unknown	Dark Newkind (*S. triandra*)	Bowles Hybrid (*S. viminalis*)
Shrubby willow (*S. miyabeana*)		LA940140	
Terra Nova (Female)			
Unknown	Unknown	Orm (*S. viminalis*)	L79069 (*S.schwerinii*)
Shrubby willow (*S. miyabeana*)		Tora (*S. schwerinii x S. viminalis*)	
Nimrod (Female)			

Figure 2-1: Study 8 storage types

Top left – Storage outside with no cover; top right - Storage outside with waterproof sheeting protecting the top of the stack of bales and the sides of the upper two/three bale layers only; bottom left - Storage inside in a building with open sides providing roof cover only; bottom right - Storage inside in a fully enclosed building.

Table 2-2: Overview of sampling undertaken in the four studies in Phase 1 (n= the number of samples)

Feedstock	Climatic zone	Soil types	Harvest Time (all 2015)	Plant part	Time of Sample
Study 1: Variability and its determinants					
Miscanthus	Warm/dry (n=10) Warm/moist (n=2)	Light (n=8) Medium (n=4)	February to April	whole	at harvest in-field prior to baling 1 month stored as bales
Willow SRC	Warm/dry (n=5) Warm/moist (n=1)	Light (n=3) Medium (n=3)	February to May	whole	at harvest 1 month stored as chips
Poplar SRC	Warm/dry (n=3)	Light Medium	June	whole	at harvest
Poplar SRF	Warm/dry (n=8) Warm/moist (n=3)	Light (n=6) Medium (n=5)	April July/August	trunk tops	at harvest 3 months stored
Conifer SRF	Warm/moist (n=6) Cold/wet (n=6)	Light mineral (n=2) Light organic (n=3) Light peat (n=7)	March June	trunk tops	at harvest 3 months stored
				bark	at harvest
Study 2: Within-field variation					
Miscanthus	Warm/dry (n=60)	Light (n=60)	March/April	whole	at harvest
Willow SRC	Warm/dry (n=60)	Light Medium	March	whole	at harvest
Study 3: Leaves					
Poplar SRF	Warm/dry (n=8) Warm/moist (n=3)	Light (n=6) Medium (n=5)	July/August	leaves only	In full leaf
Willow SRC	Warm/dry (n=9)	Light (n=6) Medium (n=3)	September	leaves only	In full leaf
Study 4: Pelleting					
Miscanthus	n/a	n/a	n/a	whole	before and after pelleting

Table 2-3: Overview of sampling undertaken in the four studies in Phase 2 (n= the number of samples)

Feedstock	Climatic zone	Soil types	Harvest Time	Varieties	Time of Sample
Study 5: The impact of harvest time on the feedstock characteristics of *Miscanthus*					
Miscanthus	Warm/dry (n=6)	Light (n=3) Medium (n=3)	4 to 9.11.2015 4 to 12.01.2016 7 to16.03.2016 22.03 to 10.05.2016 27.04 to 26.05.2016	*Miscanthus x giganteus*	3 simulated harvests 1 sampling at commercial harvest 1 sampling pre-baling
Study 6: The impact of harvest time on the feedstock characteristics of willow SRC					
Willow SRC	Warm/dry (n=5) Warm/moist (n=1)	Light (n=5) Medium (n=1)	9 to 24.11.2015 8 to 25.01.2016 14 to 23.03.2016	Representative mix of commercial varieties	3 simulated harvests
Study 7: The impact of variety on the feedstock characteristics of willow SRC					
Willow SRC	Various (n=5)	Various (n=5)	29.02 to 3.03.2016	Endurance Tora Terra Nova Resolution Sven Nimrod	1 simulated harvest
Study 8: The impact of storage system and duration on the feedstock characteristics of *Miscanthus*					
Miscanthus	Warm/moist (n=1)	Medium (n=1)	18.4.2016	*Miscanthus x giganteus*	4 different storage systems – bales were sampled monthly from May – November 2016

2.2 Fuel parameters

For the purpose of this study, the analysis options were:

A Proximate and ultimate analyses (moisture, ash, volatile matter, net calorific value, gross calorific value, sulphur, chlorine, carbon, hydrogen, nitrogen)

B Ash composition (SiO_2, Al_2O_3, Fe_2O_3, TiO_2, $CaCO_3$, MgO, Na_2O, K_2O, Mn_3O_4, P_2O_5, BaO) plus trace metals (Ba, Be, Cr, Co, Cu, Mo, Ni, V, Zn)

C Extended trace metals (Hg, Pb, Cd, As, Se, Sb)

D Halides (bromine and fluorine)

E Ash fusion temperatures.

The parameters were prioritised if they are key fuel quality parameters, affect boiler performance (for example through impacts on slagging and fouling, corrosion and bed agglomeration) or are of environmental concern (see Table 2-4). Those deemed of high priority were subjected to statistical analysis with the exception of those flagged in Table 2-4 which were omitted as too many of the measured values were at or below the limit of detection to all meaningful statistical analysis.

2.3 Soil and site parameters

A (composite) soil sample was collected for each site with the exception of Study 8. The rationale for the selection of soil properties is shown in Table 2-5. Results of all soil analysis can be found in the Deliverable D11 database.

Table 2-4: Analysed fuel parameters and their prioritisation for statistical review

Analysis Group	Parameter basis	Parameter	Priority for statistical analysis	Justification/impact on conversion systems	Included in results
A - Proximate and Ultimate analysis	As Received fuel basis	Moisture content wt %	High	High moisture content will reduce combustion plant efficiency. Potential impact on fuel handling/ dustiness/ degradation in storage	Yes
		Fixed carbon wt %	Low	Calculated from other parameters – limited value	No
		NCV kJ/kg	High	Direct impact on size and efficiency of plant and fuel logistics	Yes
	Dry Fuel Basis	Ash wt %*	High	Impacts calorific value, plant efficiency, slagging and fouling tendencies, erosion. Ash handling systems need to be designed to deal with the expected ash quantities of ash produced. With high ash levels, fluidised bed materials may need more regular replacement.	Yes
	Dry, Ash-free basis	Volatile matter wt %	High	Volatile matter will impact on flame stability, combustion burnout performance and NOx emissions.	Yes
		GCV kJ/kg	High	Measure of fuel consistency across different feedstock samples - allows comparison without being affected by moisture and ash	Yes
		Carbon wt %*	Medium	Measure of fuel consistency across different feedstock samples - limited direct impact on plant although will affect CO_2 emissions per unit output; slight impact on CV	No
		Hydrogen wt %*	Medium	Measure of fuel consistency across different feedstock samples – used in NCV calculations	No
		Nitrogen wt %*	High	Direct impact on NO_x emissions	Yes
		Sulphur wt %*	High	Direct impact on SO_x emissions and can be corrosive in high temperature systems, but in lower temperature systems can mitigate against chloride corrosion. Acid gases also cause amine degradation in carbon capture processes.	Yes
		Chlorine wt %*	High	Implicated in corrosion mechanisms and acid gas emissions. Acid gases also cause amine degradation in carbon capture processes.	Yes

Analysis Group	Parameter basis	Parameter	Priority for statistical analysis	Justification/impact on conversion systems	Included in results
		Oxygen wt %* (by difference)	Low	Calculated from other parameters – limited value; impact on CV	No
Category B - Trace elements	mg/kg dry fuel	Barium	Medium	Limited environmental/plant impact	No
		Beryllium	High	Emissions are of environmental concern	No[1]
		Chromium	High	Emissions are of environmental concern	Yes
		Cobalt	Medium	Limited environmental/plant impact	No
		Copper	High	Emissions are of environmental concern	Yes
		Molybdenum	Medium	Limited environmental/plant impact	No
		Nickel	High	Emissions are of environmental concern	No[1]
		Vanadium	Medium	Limited environmental/plant impact	No
		Zinc	High	Emissions are of environmental concern. Implicated in corrosion mechanisms. Metallic zinc can melt in combustion systems and block air nozzles (not expected to be an issue for clean feedstocks)	Yes
Category C - Trace elements	mg/kg dry fuel	Antimony	High	Emissions are of environmental concern	No[1]
		Arsenic	High	Emissions are of environmental concern. Poison for NO_x reduction catalysts.	No[1]
		Mercury	High	Emissions are of environmental concern.	No[1]
		Selenium	High	Emissions are of environmental concern	No[1]
		Cadmium	High	Emissions are of environmental concern	Yes
		Lead	High	Emissions are of environmental concern. Can have an impact on plant integrity. Elevated levels in the ash and boiler deposits may also be of occupational health concern to plant workers	Yes
Category D - Halides	mg/kg dry fuel	Bromine	High	Forms acidic gases which are of environmental concern and may be involved in corrosion mechanisms. Also believed to damage bag-house filters but may aid in mercury capture mechanisms. Acid gases also cause amine degradation in carbon capture processes.	No[1]

Analysis Group	Parameter basis	Parameter	Priority for statistical analysis	Justification/impact on conversion systems	Included in results
		Fluorine	High	Forms acidic gases which are of environmental concern may be involved in corrosion mechanisms. Acid gases also cause amine degradation in carbon capture processes.	No[1]
Category B - Ash forming elements in fuel	mg/kg dry fuel - back-calculated from measured concentration of the oxide in ash	Aluminium	High	Alumino-silicate in the ash may mitigate alkali-metal mediated corrosion/ slagging/fouling	Yes
		Calcium	High	Principal biomass ash component - impacts on slagging. May help acid gas abatement	Yes
		Iron	High	High levels of iron in ash can cause slagging, but it is normally present at low concentrations in biomass	Yes
		Potassium	High	Key concern for plant corrosion and slagging. Alkali metals may also result in formation of fine particulate matter which is an issue for emissions and for amine-based carbon capture processes. Poison for NO_x reduction catalysts.	Yes
		Magnesium	High	Magnesium in the ash may mitigate alkali-metal mediated corrosion/ slagging/fouling	Yes
		Manganese	Medium	Manganese levels are normally so low in biomass ash as to have no significance	Yes[2]
		Sodium	High	Key concern for plant corrosion and slagging. Alkali metals may also result in formation of fine particulate matter which is an issue for emissions and for amine-based carbon capture processes.	Yes
		Phosphorous	High	Poison for NO_x reduction catalyst. Phosphorous may also be implicated in corrosion.	Yes
		Silicon	High	Alumino-silicate in the ash may mitigate alkali-metal mediated corrosion/ slagging/fouling. Silica (quartz) may cause abrasion and erosion.	Yes
		Titanium	Medium	Titanium levels are normally so low in biomass ash as to have no significance	Yes[2]
Category E - Ash fusion temperatures	Reducing Atmosphere, °C	Initial deformation	Low	Data unsuitable for statistical analysis. Ash fusion temperatures provide an indication of the likelihood of ash slagging and bed agglomeration	No
		Softening	Low		
		Hemisphere	Low		
		Flow	Low		

Analysis Group	Parameter basis	Parameter	Priority for statistical analysis	Justification/impact on conversion systems	Included in results
	Oxidising atmosphere, °C	Initial deformation	Low		
		Softening	Low		
		Hemisphere	Low		
		Flow	Low		
Category B - Ash Oxides	Normalised ash oxides, %wt in ash (calculated from measured ash oxides to normalise for SO_3 and express Ca as $CaCO_3$)	Al_2O_3*	High	Alumino-silicate in the ash may mitigate alkali-metal mediated corrosion/ slagging/fouling.	Yes
		BaO*	Medium	Barium levels are normally so low in biomass ash as to have no significance	No
		$CaCO_3$*	High	Calcium is often the most dominant macroelement in biomass ash and can be implicated in slagging and fouling. May help acid gas abatement	Yes
		Fe_2O_3*	High	High levels of iron in ash can cause slagging, but it is normally at low concentrations in biomass	Yes
		K_2O*	High	Key concern for plant corrosion and slagging. Alkali metals may also result in formation of fine particulate matter which is an issue for emissions and for amine-based carbon capture processes. Poison for NO_x reduction catalysts.	Yes
		MgO*	High	Magnesium in the ash may mitigate alkali-metal mediated corrosion/ slagging/fouling	Yes
		Mn_3O_4*	Medium	Manganese levels are normally so low in biomass ash as to have no significance	No
		Na_2O*	High	Key concern for plant corrosion and slagging. Alkali metals may also result in formation of fine particulate matter which is an issue for emissions and for amine-based carbon capture processes.	Yes
		P_2O_5*	High	Poison for NO_x reduction catalysts. Phosphorous may also be implicated in corrosion.	Yes
		SiO_2	High	Principal ash component - Alumino-silicate in the ash may mitigate alkali-metal mediated corrosion/slagging/fouling. Silica (quartz) may cause abrasion and erosion.	Yes
		TiO_2*	Medium	Titanium levels are normally so low in biomass ash as to have no significance	No

Analysis Group	Parameter basis	Parameter	Priority for statistical analysis	Justification/impact on conversion systems	Included in results
Derived	Alkali Index	kg(Na_2O + K_2O)/GJ	High	Measure of slagging risk in combustion systems	Yes

*Also included in Deliverable D4 on other bases but these are considered to be lower priority for statistical review as they are less comparable

[1] These parameters were not subjected to statistical analysis as too many of the values were at or below the limit of detection for meaningful statistical analysis

[2] These parameters were subjected to statistical analysis despite being only medium priority as levels were found to be high enough to show differences

Table 2-5: Analysed soil parameters and their prioritisation for statistical analysis

Provenance Data Collected	Reasoning for provenance data collection
Clay, Silt, Sand and Organic Matter (OM) % in soil	Understanding the clay, silt, sand and organic matter (OM) content within a soil is important in helping to understand the potential capacity for achieving element exchange between the plant and the soil.
Soil Classification – including higher classification of (Light, Medium and Heavy)	Soil classification is based on the ratios of clay, silt, sand and organic matter within a soil. The soil classification chart used is shown in Deliverable D6, which identifies eleven textural classes and three organic classes. The textural classes are grouped further into Light, Medium and Heavy soils based on their mineral and/or organic soil classifications.
pH	The soil pH is required to understand any potential limitations or lock up of certain elements in the soil.
Elements analysed	The elements analysed for the project were the most common for plant health status, and those elements which are linked to both desirable and undesirable elements seen within biomass composition when being combusted. The main soil elements were analysed were; P, K, Mg, Ca, Na, Fe, Zn, Mn, Cl, S, N, plus Cu, B, Mo, Co, Se, Pb, As, Ni, Cd, Hg, Cr. All elements that were present above the Limit Of Detection (LOD) have been statistically analysed for correlations between feedstock characteristics and soil properties.
CEC (Cation Exchange Capacity)	The CEC of a soil helps to determine a soil's capability to hold and offer elements to a plant. The higher a CEC of a soil the more readily elements are able to be transferred within the soil and between the soil and the plant.

2.4 Sampling and analysis

The aims of the field sampling and laboratory analyses were to maximise consistency and repeatability while minimising contamination, such that the variability of the data was a true reflection of the variability of the feedstock. Sampling of both soil and feedstocks has been previously described in Deliverable D2 (Appendices 5 to 12); flow charts in Deliverable D2 (Appendix 13) described the process for sample collection and dispatch. Standard operating procedures (SOPs) for sampling were developed and are presented in Table 3 of Deliverable D2. Fuel analysis was primarily undertaken in the ISO17025-accredited internal laboratories of Uniper Technologies, following standard procedures as listed in Table 2 of Deliverable D2, although ash fusion temperatures were sub-contracted to external ISO17025 accredited laboratories, as were soil analyses. Flow charts in Deliverable D2 Appendix 14 described the laboratory process for sample preparation and testing. Methods specific to Phase 2 were described in Deliverable D12.

2.5 Data analysis and evaluation

In view of the large dataset generated by the project, the project team developed a process to focus on the most important findings. In essence, the data were evaluated using statistical analysis in combination with the project team's understanding of the energy and heat sector and conversion technologies to focus on those parameters which are most influential. Studies 1 to 7 were analysed statistically using Genstat and Study 8 using R. These were described in Deliverable D6 and Deliverable D12.

The ash fusion temperatures (AFTs) were not considered suitable for statistical analysis, as the use of e.g. average values can hide potential issues with low melting point supplies. Also reliability of the AFT estimates is affected by a number of factors; the repeatability given in the standards is quite wide, the measurement can be dependent on operator interpretation and it can be affected by the ash preparation method.

Quality assurance of data was identical to the approach described in Section 2.3.2 of Deliverable D6, which gave a very objective systematic assessment of all outliers. Many of the values identified as statistical outliers were retained as they were considered to be within the normal variation of the biomass feedstock. These are indicated by green shaded cells within the Deliverable D11 database; those flagged values which were deemed to be "true" outliers are shaded red in Deliverable D11.

2.6 Data synthesis

Each of the studies in Phase 1 and 2 was reviewed and the impact of the various factors on each of the key feedstock characteristics summarised in a consistent way. The factors and characteristics were tabulated in the same order as they were reported in Deliverable D6 and Deliverable D12, followed by a group of four figures with *Miscanthus* in the top left, willow SRC top right, poplar SRF bottom left and conifer SRF bottom right. Each of the figures has the same x-axis covering 2015 to the beginning of December 2016 whereas the y-axis has been scaled automatically so that the detail is shown equally in each figure. Care must be taken when scanning across the group to avoid being misled by the difference in scales. For this reason, each table starts with a section of general information which includes the range of values for each feedstock. Note that the qualitative ranking of factors provided in Deliverable D6 is superseded in this synthesis of both Phase 1 and Phase 2 findings.

2.7 Reference standards

The standards available for wood pellets are provided in Table 2-6 to allow a comparison with the levels found in the various feedstocks during this project. The ENplus quality certification scheme classifies pellets into three categories A1, A2 and B, which are aimed at the commercial and residential market. A1 is the premium pellet with the most stringent limits for trace elements and other species together with the most restrictions on feedstock types. Category B has higher limits for trace elements and other species and a wider variety of feedstocks are accepted including used wood (chemically untreated). A parallel scheme was developed by major wood pellet consumers (Initiative of Wood Pellet Buyers (IWPB)) for industrial wood pellets, again with three categories I1, I2 and I3. Both the ENplus standards and the IWPB standards were combined under a single standard ISO 17225-2 in 2014. Table 2-6 includes appropriate extracts from the ISO 17225-2:2014 for parameters relevant to those determined during this project.

Table 2-6: Non-industrial (A/B) and Industrial (I) Pellet classes as defined in BS EN ISO 17725-2:2014

Property Class	Reference standard	A1	A2	B	I1	I2	I3
Origin/source (permitted feedstocks)	ISO 17225-1	Stemwood Chemically untreated wood residues	Whole trees without roots Stemwood Logging residues Chemically untreated wood residues	Forest, plantation, virgin wood By-products and residues from wood processing industry Chemically untreated wood residues	Forest, plantation, virgin wood Chemically untreated wood residues	Forest, plantation, virgin wood Chemically untreated wood residues	Forest, plantation, virgin wood By-products and residues from wood processing industry Chemically untreated wood residues
Moisture, %wt. (ar)	ISO 18134	≤10	≤10	≤10	≤10	≤10	≤10
Ash, %wt. (d)	ISO 18122	≤0.7	≤1.2	≤2.0	≤1.0	≤1.5	≤3.0
Net CV, kJ/kg (ar)	ISO 18125	≥16,500	≥16,500	≥16,500	≥16,500	≥16,500	≥16,500
Nitrogen %wt. (d)	ISO 16948	≤0.3	≤0.5	≤1.0	≤0.3	≤0.3	≤0.6
Sulphur %wt. (d)	ISO 16994	≤0.04	≤0.05	≤0.05	≤0.05	≤0.05	≤0.05
Chlorine %wt. (d)	ISO 16994	≤0.02	≤0.02	≤0.03	≤0.03	≤0.05	≤0.1
Arsenic mg/kg (d)	ISO 16968	≤1	≤1	≤1	≤2	≤2	≤2
Cadmium mg/kg (d)	ISO 16968	≤0.5	≤0.5	≤0.5	≤1	≤1	≤1
Chromium mg/kg (d)	ISO 16968	≤10	≤10	≤10	≤15	≤15	≤15
Copper mg/kg (d)	ISO 16968	≤10	≤10	≤10	≤20	≤20	≤20
Lead mg/kg (d)	ISO 16968	≤10	≤10	≤10	≤20	≤20	≤20
Mercury mg/kg (d)	ISO 16968	≤0.1	≤0.1	≤0.1	≤0.1	≤0.1	≤0.1
Nickel mg/kg (d)	ISO 16968	≤10	≤10	≤10	-	-	-
Zinc mg/kg (d)	ISO 16968	≤100	≤100	≤100	≤200	≤200	≤200

3 Results

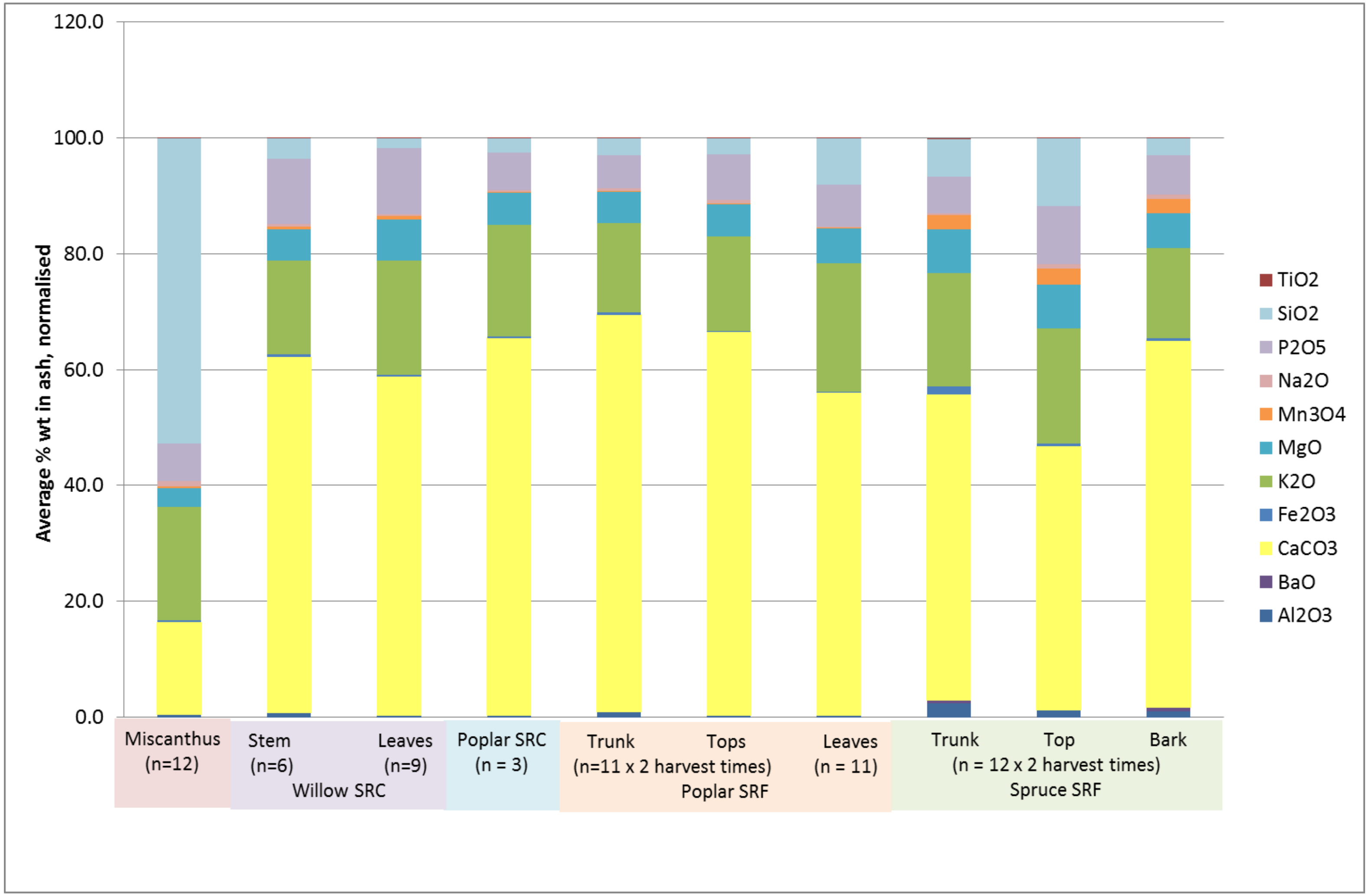
For each of the main feedstock characteristics, the effects of all the sources of variation studied during the project have been summarised for all four feedstocks in a table followed by a composite set of figures, one for each species. This allows a visual assessment of the relative impact of each of the studied factors and the variability across factors and feedstocks for each of the main feedstock characteristics. Note that:

- the horizontal axes use the same scale and duration which spans the entire duration of both phases
- in the case of poplar SRF, the date of the end of the storage period for the first harvest coincided with the date of the collection of fresh material for the second harvest so the data points of the latter have been artificially displaced by 10 days so that the symbols can be distinguished.
- The vertical axes have been chosen automatically according to the data values for each individual feedstock so care must be taken scanning from one figure to the next. We decided to take this approach rather than set all to a common scale in order to show as much detail as possible.
- The shaded columns represent the winter period from November to January.

The average ash composition for each feedstock is shown in These compositions exclude SO_3 and have been normalised to sum to 100%, with the majority of the elements expressed as oxides; the exception is calcium which is expressed as carbonate. It should be noted that these values reflect their proportions in the ash – actual levels of the ash forming elements in the fuels will depend on its ash content. The ash composition will influence a number of operational concerns within the plant, including slagging, fouling, corrosion, erosion, bed agglomeration in fluidised bed systems, emissions (particularly of acidic gases) and ash disposal/recovery options.

With the exception of the *Miscanthus*, all of the feedstock ashes were predominantly composed of calcium carbonate, with potassium oxide levels also high. High alkali input is linked to corrosion, slagging and bed agglomeration in combustion plant. Calcium can be beneficial in the reduction of acid gases, but depending on its concentration and the levels of other ash constituents it can have mixed impacts with regards to slagging and fouling. The *Miscanthus* also contained significant levels of silica. In some cases this may be due to contamination by soil, but as the silica was consistently high, it is also likely to be an inherent characteristic of the *Miscanthus*. Silica in combination with potassium can form low melting point (eutectic) mixtures which can lead to a higher probability of slagging/fouling/agglomeration issues.

Figure 3-1: Average normalised ash compositions for the feedstocks in Study 1 and 3



Generally, the results have revealed some interesting outcomes. Comparison of equivalent plant parts for the poplar and spruce SRF demonstrates that the spruce samples are nearly always lower in concentrations of most species, the spruce bark was also much lower in ash content, and hence a much better fuel than was expected. The levels of ash, chlorine content and calculated alkali index for the *Miscanthus* samples were also interesting to compare against the other data in light of the general industry perception of this feedstock as being 'problematic'. When *Miscanthus* is compared to the other feedstocks, although only the leaves approach the *Miscanthus* chlorine levels, the ash content and calculated alkali index for the *Miscanthus* are broadly similar to those of the poplar and spruce SRF tops, suggesting that some commonly held perceptions regarding *Miscanthus* are perhaps not always justified, see Table 3-1.

Table 3-1: Comparison of ash, chlorine and alkali index averages for all fresh feedstocks

Colour coding for ash and chlorine relates to the wood pellet standards given in Table 2-6; green denotes that the samples met the A1 standard; amber denotes that the samples met the A1 standard but not the I3 standard; and red denotes that the samples did not meet the I3 standard. For alkali index green denotes that there is a low risk of fouling/slagging; amber denotes that fouling/slagging is probable; and red denotes that fouling/slagging is certain.

Feedstock	Ash %wt (d)	Chlorine % (DAF)	Alkali index (kg(Na_2O+K_2O)/GJ)
Miscanthus	2.3	0.14	0.204
Willow SRC	1.8	0.02	0.147
Willow SRC – Leaves	8.0	0.16	0.706
Poplar SRC	3.0	0.01	0.171
Poplar SRF – Trunk	1.6	0.01	0.112
Poplar SRF – Tops	4.5	0.03	0.340
Poplar SRF – Leaves	9.1	0.09	0.871
Spruce SRF - Trunk	0.4	0.01	0.038
Spruce SRF – Tops	2.4	0.04	0.195
Spruce SRF - Bark	2.3	0.04	0.158

4 Discussion

4.1 Representativeness of soil type and climate zones

Although this project has provided an extensive body of information, the range of sites does not include contaminated sites and may not cover the full range of soil types or climates that could be used to grow bioenergy crops. Nevertheless the sites we sampled are generally representative of the soils and climate zones in which these crops are currently grown commercially in the UK. While the sampling design is appropriate for the project's objective there are some points to consider:

- any comparison of the impact of climate zone across feedstocks in the UK should be done with caution. For example, conifer SRF was sampled across a much wider geographical area than poplar SRF so it is reasonable to expect, on the basis of the project's results, that climate would have a greater effect in conifer than poplar SRF.
- climate zone was rarely influential in this UK project but this should not be used as a generalisation outside the range encompassed in the project. Considering the findings themselves, the limited impact of climate zone may be due to a lack of actual difference in growing conditions during the crop's development, to the expectation that differences would be indirect through the impact of growing conditions on growth rate and therefore limited in magnitude, and the comparatively limited sample size.
- the distinction between climate and weather should be made, with weather likely to have a more significant impact on annual crops and climate on those feedstocks with longer growth cycles.

4.2 Data quality assurance and interpretation

The data collected underwent several levels of review. A very small proportion of the data points were excluded as outliers from the statistical analysis, which indicates high standards of sampling and analytical procedures. Following statistical analysis, any statistically significant findings were also reviewed for operational relevance, and as a result many of the observed effect and/or relationships were excluded from further consideration. It should be noted that the review of operational relevance was based mainly on the use of biomass in a pulverised fuel combustion plant; some of the less critical chemical parameters may have greater significance for other conversion technologies.

4.3 Field sampling approach

It should be noted that a manual sampling approach was used throughout this project. This was necessary to avoid contamination with soil, litter or other detritus which had the potential to compromise the results. However, this does not reflect commercial operational practice, where contamination might typically occur. As a result, levels of for example ash may be lower in the project samples than could be expected from bulk harvesting.

Only limited statistical analysis of crop management practices was possible for three reasons: there were relatively small numbers of sites; practices were standardised for some crops; and the provenance data available from the growers was often found to be incomplete and fairly unreliable, especially where crops had been planted many years ago.

The decision was made to sample the conifer SRF trunk, tops and bark separately. The sampling approach was informed by our understanding of the most likely practice – spruce bark is sold separately in some circumstances whereas poplar is not debarked. Resource constraints prevented measurement of the proportions of each component so it was not possible to calculate the average composition for the whole tree (while values for wood and bark proportions for spruce are available from the literature, these are generally for much older trees).

The field sampling procedures were designed to give an insight into the feedstock characteristics of commercial *Miscanthus* over a range of potential harvesting times after the crop had ceased active growth. In two respects however the simulated harvests during autumn, winter and early spring differed from commercial practice – operational harvesting is likely to dislodge more leaf material and break off more of the finer stalk tops, also in commercial practice the harvested crop is left on top of the stubble. The possible effects are that the chemical composition of our samples from the simulated harvests differ slightly because of the higher proportion of fine material and absence of soil contamination.

Six varieties of willow SRC (Endurance, Tora, Terra Nova, Resolution, Sven, and Nimrod) were identified that were found at four sites while Endurance, Tora, Terra Nova, and Resolution were present at Aberystwyth. Newer varieties were available at some but not all sites, and since the main objective was to test the hypothesis that feedstock characteristics are consistent across sites we accepted older varieties that were found across a wider range of sites. Nevertheless Endurance, Tora, Terra Nova, and Resolution would still be considered for any new commercial plantings. Although the sites selected for this study were research trials rather than commercial sites, the results are valuable because they cover a wide geographical range and encompass a wide range of local site conditions. The selection of varieties included in this study is useful in providing a comparison across varieties with a wide range of lineages. The nearest comparator – the study of willow varieties in England (Gudka, 2012) - had a narrower set of lineages with only one *S. viminalis x S. Schwerinii.*

No significant differences were detected after six months in the condition of the *Miscanthus* bales stored in an undisturbed condition and those that had been repeatedly moved (to allow sampling). Although we had been concerned that repeated movement might make our samples unrepresentative of normal operational conditions, the results indicated that this concern was unfounded.

Although the 6-month storage duration represented a typical operational situation, the questionnaire showed that both much shorter and longer periods may be used to fit with work patterns on the farm and market demands. Since this project demonstrated major changes in many aspects of *Miscanthus* quality during storage and also that the storage method and duration could be influential, these findings should be considered carefully by the sector.

The changes in *Miscanthus* quality associated with differences in storage method – for example to ash, nitrogen, sulphur, zinc, bromine and calcium - are extremely interesting and commercially relevant findings but should be used with caution, bearing in mind that they relate to just one site and year. In addition, the storage treatments used elsewhere may differ in small but important ways even though they would be given the same general description as ones used here. For example, outdoor covered storage may use different types of tarpaulin or cover more/less of the stack sides.

4.4 Comparison with literature, available data and standards

Because of this project's scale, many quality parameters of bioenergy feedstock are reported for the first time and there are no published data for comparison. Where comparisons are possible, our findings were generally consistent with published literature.

The observed seasonal changes in *Miscanthus* characteristics were supported by the literature. For example the observed decrease in N and increase in sodium in *Miscanthus* between November and January is consistent with findings of Nsanganwimana *et al.* (2016) during autumn. Delaying harvesting from the autumn to the following spring improved the quality of the harvested biomass by a reduction in N, K and Cl as well as a reduction in moisture content through drying (Himken *et al.,* 1997; Heaton *et al.,* 2009; Di Nassi *et al.,* 2011) which is consistent with our observations on N, Cl and moisture content. It should be noted that although references are available for some aspects of this project, for example *Miscanthus* seasonal dynamics, others are poorly reported, for example the changes in *Miscanthus* quality during storage or the impact of storage method.

Varietal differences in willow SRC were stable across the six sites for a number of feedstock characteristics which is consistent with many reported studies. For example Brereton et al. (2014) found genotype-specific variation in all the traits they measured in an investigation of the N dynamics during growth and onset of winter dormancy in 14 willow genotypes; in our study Resolution had consistently low nitrogen concentrations whereas Nimrod, Terra Nova and Endurance had high concentrations. In a study of willow varieties in England, Gudka (2012) reported differences in cellulose, hemicellulose and lignin content, calorific value and both total ash content and the percentage of different oxides in the ash. Like Gudka (2012) we found that % CaO was negatively correlated with K_2O – Resolution had the lowest $CaCO_3$ while Endurance, Tora, Terra Nova and Nimrod tended to have the highest ranking whereas Resolution had the highest levels of K_2O with Endurance and Terra Nova having low levels.

Some views held by bioenergy growers and end-users have been confirmed by this project and are reported for the first time in peer-reviewed reports. For example, several of our *Miscanthus* sites, mainly those in south west England, showed a previously unreported pattern of increasing nitrogen in the late spring which may be associated with a resumption of growth in stems. In the case of nitrogen there is a view among *Miscanthus* growers in the UK (Steve Croxton, pers. comm.) that winters in some more southerly areas are not always reliably cold enough to complete the growth cycle of the stems. As a result, when conditions improve in the spring, nutrients and sugars are remobilised and translocated to the overwintered stem to support a continuation of last season's growth. Although Heaton *et al.* (2009) found that there was a major reduction in N concentration between June and December but then little additional change over the following months to February/March, we have not found reports of an increase in N around March/ April in the UK.

On the other hand, our findings have challenged some widely held views. For example, the chemical composition of *Miscanthus* after pelletisation differed from the *Miscanthus* sampled directly from the field; bark was better than expected in particular it was lower in ash; and the most protected storage conditions were not always associated with the best feedstock quality at the end of long-term *Miscanthus* storage.

The data gathered as part of this project were consistent with the Phyllis2 database for *Miscanthus* and only minor differences noted for willow SRC, with the exception of manganese which was much higher in the project samples. In some cases a direct comparison, e.g. of plant parts or times of year, was difficult because the associated provenance data is not available in Phyllis 2; this affected poplar and spruce comparisons in particular because Phyllis2 does not generally distinguish between different plant fractions or harvest cycle periods, making it unclear whether equivalent samples were being compared. A direct comparison of spruce bark was possible however and indicated that potassium, sodium and phosphorus were higher in the project feedstock, whereas calcium and cadmium were lower than Phyllis2.

The dataset from this project (Deliverable D11) is much more comprehensive in terms of number of samples, feedstocks, parameters and sources of variation than most other studies which has allowed a much wider range of comparisons to be made, e.g. the differences between storage of poplar stems and tops depending on whether they were harvested in spring or summer; the relative uniformity of some feedstock characteristics across a single site but the major changes in other characteristics.

Data provided on internationally traded wood pellets by Uniper showed them to be an extremely consistent and homogeneous fuel, with the analysis data tightly clustered when compared to the raw woody feedstocks analysed in this project.

A number of quality standards exist for wood pellets depending on the market application and these have been defined recently in ISO17225-2:2014. Depending on which pellet class limits are applied, some of the woody feedstocks from Study 1 would not meet the dry nitrogen and chlorine content, whilst for dry ash, the conifer SRF stem wood, which was bark-free, was the only plant part to consistently meet the strictest limit. In terms of trace elements, the limit for cadmium was the most challenging and was exceeded by a proportion of the poplar SRF dataset (both trunk and tops) and some willow SRC samples, although it is comfortably achieved for all the conifer SRF plant parts. In addition, a few poplar SRF tops and willow SRC samples exceeded some of the limits for copper and zinc. None of the other trace element limits proved to be an issue.

4.5 Implications for growers

At the outset of the project, the expectation was that the characteristics would differ with the plant species and for a given species would be most highly influenced by climate, soil type, harvest time and storage. For the woody species plant part was also expected to have an important influence.

Comparison of the different feedstocks clearly shows that they varied in key fuel quality parameters that can have a significant impact on conversion technologies. For example, the dry ash-free gross calorific value (GCV) was lowest for *Miscanthus.* For the grower, species choice is likely to be determined by the farm's capability, expected yields and personal preferences rather than a consideration of fuel characteristics. That said, it is possible that growers could use the project data to seek a competitive advantage by knowing how their product will deliver improved outcomes. Species differences are however highly relevant to anyone sourcing feedstocks (see 4.6).

The findings suggested that within the range of climates selected for commercial operations in the UK, climate zone was only occasionally a statistically significant factor. Yet for *Miscanthus* seasonal effects proved key determinants of many characteristics and some properties of willow SRC, poplar SRF and conifer SRF were affected by harvesting time. These seasonal effects suggest that there are more local environmental effects, e.g. temperature including frost, rainfall and day length that do indeed have an influence on the feedstock characteristics. Growers' experience of local weather may therefore be a useful guide to likely feedstock properties but the long term average seems to be of limited value in predicting crop quality. It is certainly true that local weather does have a direct impact on when a specific field and/or crop can be harvested and can, therefore, indirectly influence feedstock properties.

Soil type was rarely important in determining the composition of the feedstock. Initially this was a surprising finding, but on further examination it became clear from soil analyses and provenance information that sites were typical of rural soils and were neither derived from reclaimed or contaminated sites or treated recently with sewage sludge. The soil analysis data revealed that the sites were very 'clean', with below average or very low levels of soil metals and metalloids, which probably explains the absence of any impact of soil type and the very small number of strong correlations found between feedstock ash characteristics and soil properties. Furthermore soil type was defined in terms of texture for mineral soils and texture plus organic matter for peaty soils therefore our findings do not exclude the possibility that aspects of soil chemistry and structure may have an influence on feedstock characteristics.

For *Miscanthus* and willow SRC, the variation in some feedstock characteristics between the sites was greater than that seen within samples taken from across the same field, whilst for others the variation within-field was much greater than that between different sites. It was intriguing to find that the results were generally similar for both *Miscanthus* and willow SRC which suggests that there are characteristic spatial distribution patterns found with particular chemical elements possibly as a result of a combination of fertilisation applications, the soils' inherent availability and the mobility of each element within the soil. This suggests that for critical quality characteristics e.g. ash, silicon, potassium, sodium and chlorine, it could be useful to understand if there are appreciable differences between fields in soil chemistry and/or structure. If so, fields could be chosen to benefit crop quality. If there is much greater variation within fields than between fields, it is difficult to see what, if any, practical steps could be taken to improve crop quality though in extreme cases it might be possible to restrict the bioenergy crops to particular sections of a field.

By contrast the expected importance of plant part for willow SRC, poplar SRF and conifer SRF was borne out decisively. For example, the dry ash-free gross calorific value (GCV) increased in the order trunk wood < tops ≈ bark and was highest in the leaves. Ash on a dry basis was low in the poplar SRF trunks, conifer SRF stem wood, willow SRC and *Miscanthus* but was higher in the SRF tops and conifer SRF bark and was especially high in the poplar SRF and willow SRC leaves. Sulphur and nitrogen concentrations were generally very low in the SRF trunks, and increased in the order: willow SRC stems≈*Miscanthus*< tops≈bark and finally leaves. For willow growers, the results emphasise that leaves should generally be excluded by harvesting in the dormant season if soil conditions allow. Poplar growers may improve the quality of harvested tops by harvesting in the dormant season or if other factors dictate that the crop is harvested in the summer, tops could be stored until the leaves have been shed. Although conifer SRF tops usually had higher concentrations of most elements than the stem wood and bark, the levels tended to be so low that tops could be harvested without exceeding quality thresholds; growers of conifer SRF may improve the quality of harvested tops by storing them until as many needles as possible have fallen off.

Despite the perception that bark is a poor quality fuel, this was generally not the case – for almost all feedstock parameters it was intermediate between the conifer stem wood and the conifer tops. Conifer bark for example was low in ash content, and hence a much better fuel than was expected. From the perspective of bioenergy supply, the cost of separating bark from stem wood would not be justified but if other processing steps have generated material with a high proportion of bark, this is likely to be an acceptable bioenergy feedstock. The caveat is that the good quality observed here may be due to the careful sampling methodology, which was designed to minimise contamination, and commercial harvesting operations may cause a reduction in quality. If it is economically viable, potential bioenergy suppliers may be able to modify their harvesting techniques or investigate upstream washing technology to reduce surface contamination.

One important feature of the study of willow varieties is that it covered a very wide range of parameters of potential relevance to the commercial operation of large-scale power plants. The results suggest a certain degree of consistency across the sites, with approximately 40% of the parameters analysed showing statistically consistent rankings. For example, the most highly significant differences ($P<0.01$) in rankings were in moisture, net calorific value, carbon, nitrogen and $CaCO_3$. For example, Endurance was consistently the lowest in terms of moisture content, with Tora, Resolution and Sven in the mid-range, with Terra Nova and Nimrod generally having the highest moisture content. Resolution generally had low nitrogen concentrations whereas Nimrod, Terra Nova and Endurance generally had high nitrogen levels with Sven intermediate. At first glance, this suggests that growers could select varieties to improve the feedstock quality. Considering the results as a whole however, two important points emerged. Firstly, no variety combined the best ranking in all parameters of importance for commercial conversion technologies; secondly, that no variety is problematic; and thirdly, for the majority of parameters, there was not a consistent ranking. Volatile matter, sulphur and chlorine content for example did not show consistent rankings and neither did the alkali index. These results are based (quite deliberately) on a snapshot in time and, since the project also demonstrated that there were statistically significant differences during autumn, winter and spring, the impact of seasonality should be considered. Consequently the findings about the consistency of rankings should be applied to a wider time frame only with considerable caution. It should be noted that best practice is to plant a mix of varieties rather than a single variety as a means of reducing the risk of disease. Growers should consider the pros and cons of the available willow varieties when deciding on the varietal mix.

The choice of *Miscanthus* harvesting time needs to weigh up several trends. The low moisture content of spring harvested *Miscanthus* and consequent high NCV are a clear advantage over the other feedstocks which generally had moisture contents in the range of 50-70% hence NVCs of <8000 kJ/kg as received fuel. Having monitored *Miscanthus* through the autumn, winter and spring it is clear that moisture content at the end of the growing season is as high as that of other feedstocks and remains high during November through January before drying down. Earlier harvesting may risk higher moisture contents than desirable. Moreover the comparison of moisture contents at the same site over two successive years suggests that the optimum harvesting time with respect to moisture content and NCV varies from year to year. There is a somewhat similar situation with ash content - Phase 2 findings indicate that ash levels in November ranged from 3.5 - 5% before falling to 2- 3% over winter and spring. Early harvesting also risks undesirably high levels of chlorine and nitrogen levels. Considered as a whole, these results suggest that to maximise *Miscanthus* quality, harvesting should be delayed until at least the beginning of March.

Harvesting willow with leaves increases the GCV but this risks raising the moisture content, and ash, nitrogen, sulphur and chlorine levels considerably. Considering the dormant season, few differences were detected in the willow SRC from autumn, through winter to spring, especially when compared to the *Miscanthus* results. There are several possible reasons for the lack of seasonal differences in willow SRC. Firstly there was a wider geographical range of willow SRC sites which resulted in a wider range of climate zones and soil types. Secondly the sampling approach was designed to take a representative sample of commercial crops – this resulted in a single *Miscanthus* genotype at all sites but several different varieties within a willow SRC site and different varietal mixes at different sites. Finally there were fewer willow SRC sampling occasions. Even if changes during the dormant season are under-represented because of these factors, our results suggest that willow growers have considerable flexibility over harvesting times and that the window should be limited to after leaf fall through to bud burst.

Storage for six months proved to be an important determinant of many *Miscanthus* characteristics - ca 43% of the feedstock characteristics tested were not significantly affected by storage; another 43% were affected by storage but there was no influence of storage treatment; and in the remaining 14%, which included ash, nitrogen, sulphur, zinc, bromine and calcium, storage treatments did have a significant influence. Where changes were statistically significant, the majority decreased fuel quality. From a practical point of view, some period of on-farm storage is likely to be needed so the question becomes: what can be done to minimise the deterioration? Contrary to common advice to *Miscanthus* growers, our study indicated that sulphur and zinc increased more in both types of indoor storage compared to outdoor storage. Furthermore ash values were much higher in the covered storage in the samples after one month's storage. Nitrogen decreased (improved) more in the outdoor uncovered bales but this type of storage also increased calcium and bromine more than the other treatments. In contrast to many of the changes discussed above, potassium levels were significantly lower after storage than before; this translated into a significant decrease in alkali index to a level where fouling is unlikely.

We considered the effect of rainfall during spring and summer 2016 at the site on *Miscanthus* stored with different degrees of protection from the weather but there was not an obvious impact of rainfall on feedstock quality during storage.

Moisture content increased during storage, even in the treatments where the bales had protection, and there was no significant difference between storage methods; although these findings indicate that covered storage may not be necessary even in high-rainfall areas these findings must be validated at other sites.

One unexpected possibility suggested by the findings was that contamination by wind-blown lime or soil may explain the general increase in calcium levels during storage of *Miscanthus* bales. The increase was especially marked in the outdoor covered bales - perhaps the cover trapped more fine particulates including those with a high calcium content. Ash concentrations increased during storage as did many of the metals including aluminium and silicon, regardless of storage treatment. This too may be due to contamination, either from wind-blown soil particles, soil introduced during stacking of the bales, or during the sampling process. The pattern of ash levels hints that much of the increase may be due to dust being stirred up when the bales are being stacked at the start of the storage period. These possible influences should be checked at other sites before guidance is drawn up and growers should consider the possibility of contamination at their storage facilities.

These results suggest that no single type of storage is likely to minimise the deterioration in all aspects of feedstock quality and the choice of storage type is more likely to be dictated by what type of storage is available and perhaps the contamination risk on the farm, especially in the absence of any price differential linked to quality.

Although we have limited evidence of the pattern of change over time, the results imply that storage should be minimised. These findings, however interesting, should be treated with caution since it was just one site in the south west England in one year. Although the 6-month storage duration represented a typical operational situation, the questionnaire showed that both much shorter and longer periods may be used to fit with work patterns on the farm and market demands. Since this project demonstrated major changes in many aspects of *Miscanthus* quality during storage and also that the storage method and duration could be influential, these findings should be considered carefully by the sector and a wider range of sites and storage duration may be worthy of further investigation.

Three months' storage of SRF stems and tops was also associated with many changes in feedstock characteristics. For some characteristics, the effect of storage depended on whether it started in spring and occurred over summer or started in summer and occurred through to late autumn; the net effect may be the result of the plant's physiological condition at the start of storage or the physical conditions during storage. Although our study cannot disentangle these potential causes, our findings suggest that growers are able to influence many aspects of crop quality through their choice of harvest time and storage duration.

The general absence of a storage effect on willow SRC may be due to the relatively short storage period (one month) or the particular conditions for our selection of sites during the storage period, or the relatively small number of samples.

Storage of pellets was not studied in this project and the findings on storage of *Miscanthus* bales, willow SRC chips or lengths of SRF tops and stems should not be extrapolated to *Miscanthus* or wood pellets.

Only limited statistical analysis of crop management practices was possible in Study 1. Planting year of *Miscanthus*, which ranged from 2005 to 2011, affected only cadmium concentrations in the feedstock with earlier planting years being associated with lower levels in the sampled biomass. Sodium and Na_2O of the willow SRC were negatively related with planting year; nitrogen, K_2O in the ash, elemental Fe, K, Mg, P, and the Alkali Index all tended to decrease as the harvested willow increased in age whereas $CaCO_3$ in the ash increased with crop age. For this limited number of elements the age of the rhizome and stool may also influence the changes from one year to the next. Management factors, in this case planting density and the age of the sampled material, were not important determinants of the feedstock characteristics of poplar SRF trunks or tops. In the case of conifer SRF, planting density and the age of the sampled material were linked to a small number of feedstock properties. As planting density increased, the barium concentrations in the trunk wood fell, as did the volatile matter of the tops; nitrogen, copper and cadmium of the tops increased with planting density; and as the age of the sampled material increased, ash and nitrogen content of the tops increased. Although these are interesting insights, the evidence is not sufficiently robust to make recommendations to growers and further investigation would be necessary if any of these feedstock properties was thought to be important.

In general terms, the largest differences in production costs between the feedstock types was in the initial establishment and management costs, with conifer SRF and poplar SRF incurring higher costs in the early years. Willow SRC costs were typically higher than *Miscanthus*, largely due to the additional cut back operations at the end of year one, but the difference in costs across all feedstocks was marginal, with an average cost of establishment being less than £1,500/ha for all feedstocks. Harvesting costs were the largest management cost and were noticeably different between feedstocks, with the poplar and conifer SRF incurring the highest costs on a per year per oven dried tonne basis. It is unlikely that many land owners will have land that offers a choice of growing more than one biomass type. If that situation does arise productions costs, potential yields and personal preference will be likely to sway the choice rather than considerations of feedstock quality which does not benefit from a price premium other than a specification for a maximum moisture content.

A qualitative ranking of factors affecting the important characteristics extracted from the analysis of the individual feedstocks indicates that feedstock characteristics are not affected in a consistent way by the site properties and crop management. Nevertheless, the following general observations can be made. The implications for growers of *Miscanthus,* poplar SRF and conifer SRF are that the most important factors affecting moisture and NCV, season and storage, can be manipulated. In the case of *Miscanthus,* some of the chemical properties might be modified by the selection of fields. With a better understanding of the impact of environment on the growth of *Miscanthus*, sections of the farm could be chosen that would optimise the feedstock properties (and yield). Willow SRC growers have a reasonable degree of control over some of the important feedstock characteristics by their choice of variety, harvesting time – as a means of controlling leaf content– the age of the root stock and the length of the cutting cycle. For poplar SRF and conifer SRF, besides moisture content and NCV which are mentioned above, many of the other properties can be adjusted by the choice of the plant part to market and harvest time. Feedstock properties were relatively insensitive to the way conifer SRF was grown.

In spite of the consistent high-level findings summarised above, it was not possible to derive simple guidance for biomass growers because of the differences in the behaviour of the individual feedstock characteristics. For any one year and site, the net effect of these changes is difficult to predict. If there was sufficient premium for crop quality, a monitoring programme, which could focus on the most important parameters for the end-use in mind, could be considered.

Finally, feedstock quality must be considered in tandem with biomass yields. This is particularly relevant for *Miscanthus.* Lewandowski et al. (2003) reported that a significant decrease in water content and in the concentrations of ash, nitrogen, chloride and sulphur in the biomass concentrations between December and March was accompanied by a reduction in yield. Although the seasonal changes in quality we observed would generally be beneficial we did not collect yield information in either fresh or dry weight terms, therefore it is not possible to estimate the overall impact of crop quality and quantity from our project. Put succinctly: there is a trade-off to consider when harvesting perennial biomass crops: harvest too late and yield declines, harvest too early and risk higher mineral contents, particularly nitrogen (N) (Heaton *et al.* 2009). This is less of an issue for willow SRC, poplar SRF and conifer SRF growers because the biomass yield is much more stable. If there is a price advantage for feedstock quality, the woody crops could be managed to optimise quality.

4.6 Implications for conversion plant

For all conversion technologies, correct matching of the fuel and conversion equipment is important. Failure to understand the probable impacts of the feedstock on the system is likely to result in reduced efficiency, lower availability, increased OPEX and increased emissions. Different conversion technologies and individual system designs will have different acceptable levels for each feedstock parameter. These limits will depend on a number of factors, such as steam parameters, grate design and technology type and will tend to be more restrictive for those technologies offering the highest quality outputs (e.g. highest efficiency or specific conversion products). For all feedstocks, the implications for buyers are that consideration must be given to the feedstock characteristics of prime importance in a particular application.

In view of the differences in both the species-specific responses demonstrated in this project and in feedstock specifications for conversion plant, a single ranking would be misleading and under value the findings of this project.

As shown in Table 2-4, the different feedstock characteristics investigated in this project can have multiple impacts on conversion plant. For energy production, calorific value of the feedstock (as received at the plant gate) is of primary importance, and the project has demonstrated that this can vary significantly depending on the feedstock type, and in particular the moisture content. It should be noted however that moisture is one of the easiest parameters to change, as shown by the changes during storage.

Some end-use applications may be designed to use material with a moisture content of 40-50 % but where lower moisture contents are needed, forced drying may be used at an intermediate collection site or at the point of use, albeit at a cost. Drying may also improve other characteristics such as handling and resistance to biological degradation but the benefits must be weighed against the costs of drying and the increased risk of dust.

Levels of sulphur and nitrogen in the studied feedstocks were low compared to coal, although nitrogen in particular was elevated in the leaves and was higher in willow than the other feedstocks. These elements have a direct impact on gaseous emissions of the respective oxides, which are both considered primary pollutants and hence regulated for many applications. Chlorine contents were heavily dependent on the feedstock, with *Miscanthus* containing some of the highest levels, together with the poplar and willow leaves. As well as contributing to acid gas emissions, chlorine is considered to be one of the highest risk elements contributing to boiler corrosion in biomass combustion systems, although these impacts can sometimes be mitigated by the presence of sulphur and upstream removal of the chlorine. Acid gases will also lead to degradation of the amine used in post-combustion carbon capture and storage (CCS) systems and hence high levels of control will be necessary in BioCCS applications. Fuel quality specifications for conversion plant will always include limits on sulphur, nitrogen and chlorine. Buyers should check the levels of leaf material in willow and poplar and consider specifying a harvesting window or, in the case of poplar tops harvested during the growing season, a storage period to ensure that leaf material is shed.

Compared to most coals, the ash levels seen in the project feedstocks were low, with the SRF trunks showing the lowest levels. While coal ash is primarily alumino-silicate based, the biomass ash compositions were very different. For most of the feedstocks, the ash was primarily composed of calcium and potassium compounds; the exception to this was *Miscanthus*, which also contained significant levels of silica. Potassium (and sodium) are linked to a number of detrimental effects within boilers, including slagging, fouling, agglomeration of fluidised beds, corrosion, deactivation of deNO_x catalysts and formation of fine particulate matter. As a result, equipment suppliers will often impose limits on inputs of these elements to the conversion system. Calcium can have positive and negative impacts, the former including capture of acidic gases into the ash (allowing easier removal). The impact on e.g. slagging can vary depending on the presence of other elements such as potassium, sodium and aluminium.

The importance of the trace metals contained in fuel for conversion plant is primarily due to environmental concerns (i.e. air and water emissions), but the feedstocks used in this project were generally so low in these elements for this not to be an issue. Lead and zinc in particular have been identified as presenting a corrosion risk in boilers (particularly in combination with chlorine, sodium and potassium) and lead in ash may also raise occupational health concerns; but only at higher levels than were seen in this project (for example some waste wood combustion).

The levels of ash, chlorine content and calculated alkali index for the *Miscanthus* samples were interesting to compare against the other data in light of the general industry perception of this feedstock as being ‘problematic’ - they were actually similar to the SRF conifer and poplar tops for these parameters. By contrast, some of the *Miscanthus* pellets had elevated sodium levels (caused by addition of caustic soda to improve pellet throughput) which would have severe consequences for conversion plants in terms of corrosion and fouling. This illustrates that common commercial practice can have significant impact on fuel quality and that good communication between supplier and end-user is necessary to maintain reliable fuel quality.

The standards available for wood pellets were provided in Table 2-6 to allow a comparison with the levels found in the various feedstocks during this project. Table 4-1 summarises the results for both phases of the project and provides a comparison to A1 classifications, which is the premium pellet with the most stringent limits for trace elements and other species, and also against I3 classifications which have the least demanding levels. This emphasises the fact if there are known issues with ash %, nitrogen, chlorine, cadmium and zinc levels within a feedstock type, then feedstock buyers should review their selection of feedstock species and plant parts.

In light of the potential advantages of these biomass feedstocks for conversion (especially relative to coal), there is scope to use them for co-firing in coal-fired plant or other conversion plants set up to take account of the high nitrogen and chlorine levels in leaves, needles and grasses, such as *Miscanthus*. In addition there is scope to make use of the individual strengths and weaknesses of these biomass feedstocks by mixing them to achieve a bio-blend that matches the requirements of the biomass conversion plant. The most realistic approach would be to blend these feedstocks at the point of use or at an intermediate re-processing plant (for example by producing mixed pellets).

Table 4-1: Comparison of feedstocks against two wood pellet standards

Dark green = all samples were lower than selected wood pellet standard; light green = most samples were lower than selected wood pellet standard; orange = some samples were lower than selected wood pellet standard but many were above; red = no samples were lower than selected wood pellet standard. Where plant parts had been analysed separately, the parts meeting the selected wood pellet standard are noted.

Property Class	Reference standard	A1	I3	*Miscanthus*		Willow SRC		Poplar SRF		Conifer SRF	
Origin/source (permitted feedstocks)	ISO 17225-1	Stemwood Chemically untreated wood residues.	Forest, plantation, virgin wood. By-products and residues from wood processing industry. Chemically untreated wood residues.	**A1**	**I3**	**A1**	**I3**	**A1**	**I3**	**A1**	**I3**
Net CV, kJ/kg (ar)	ISO 18125	≥16,500	≥16,500								
Nitrogen %wt. (d)	ISO 16948	≤0.3	≤0.6					Stems	Stems	Stem wood	Stem wood; bark
Sulphur %wt. (d)	ISO 16994	≤0.04	≤0.05			Stems	Stems	Stems; tops with no leaves	Stems; tops with no leaves		Stem wood; bark
Chlorine %wt. (d)	ISO 16994	≤0.02	≤0.1				Stems	Stems	Stems;	Stem wood	
Arsenic mg/kg (d)	ISO 16968	≤1	≤2								
Cadmium mg/kg (d)	ISO 16968	≤0.5	≤1					Stems	Stems		
Chromium mg/kg (d)	ISO 16968	≤10	≤15								
Copper mg/kg (d)	ISO 16968	≤10	≤20					Stems; tops with no leaves			
Lead mg/kg (d)	ISO 16968	≤10	≤20								
Mercury mg/kg (d)	ISO 16968	≤0.1	≤0.1								
Nickel mg/kg (d)	ISO 16968	≤10	-		-	Stems	-	Stems; tops	-		-
Zinc mg/kg (d)	ISO 16968	≤100	≤200				Stems	Stems; tops with no leaves			

5 Conclusions

An extensive, robust dataset, presented in Deliverable D11, has been constructed to inform the ETI on the variability in feedstock properties of UK produced energy biomass types, the causes of these variations and the relationship between the feedstock properties and the provenance data collected. On the basis of the summary tables, which draw on the analyses presented in Deliverable D6 and Deliverable D12, and composite figures, the hypotheses (shown in italics) can be answered as follows:

- *The feedstocks examined range from Miscanthus, through woody deciduous plants grown for only a few years and regenerated by coppicing (willow and poplar), to small deciduous and evergreen trees (poplar and Sitka spruce respectively), therefore we hypothesise that the feedstocks will differ in their fuel properties and/or composition.* Significant variation was seen between the different feedstocks in terms of their fuel properties and composition in terms of both the mean values and the range of the data. For example, the *Miscanthus* showed higher levels of chlorine than the conifer SRF. The importance of this variability will differ depending on the chemical parameter and the conversion system being considered.

- *With the exception of Miscanthus, the feedstocks are differentiated into plant parts that have different functions, e.g. mechanical support versus photosynthesis; therefore we hypothesise that these plant parts will differ in their fuel properties and/or composition.* This hypothesis was investigated for willow SRC, poplar SRF and conifer SRF but not *Miscanthus* for which separation into leaf and stem is not commercially feasible at an operational scale. For SRC and SRF, plant part did have a significant impact. Levels of chemical elements were highest in the leaves when they were sampled in late July/early August (poplar SRF) and September (willow SRC). In willow SRC, concentrations where lower in the stems than the leaves. In poplar SRF, the general pattern was for lower concentrations in the tops followed by the stems but the differences between these parts were smaller in the spring than the summer. In conifer SRF, concentrations were generally higher in the tops than the stem wood with bark intermediate and the differences between plan parts were smaller in spring than summer. The lowest concentrations were found in the stem wood. A similar pattern was found in gross calorific value across plant parts. By contrast net calorific value tended to be lowest in the leaf samples of willow SRC and poplar SRF, while in poplar SRF and conifer SRF, the tops had a higher net calorific value than the stems.

  Biological material when in active growth has cells containing high levels of genetic material and all the compounds necessary for cell division, maintenance and growth as well as photosynthesis. The distribution of many elements within the plant changes seasonally according to the cellular activity. As winter approaches and active growth, photosynthesis, and cell maintenance decline, cell contents are moved within the plant, for example to roots, for storage leaving the cell wall, which is essentially inert, to fulfil a support function. These relationships are also relevant to the impact of time of harvesting addressed in point 5 below.

- *Feedstock properties will differ depending on the climate the crop is exposed to.* Within the range of average climate zones covered in the UK-based project, climate zone (as defined in terms of long-term averages of temperature and precipitation) had little influence on fuel composition.
- *Feedstock properties will differ depending on the soil composition and characteristics of the site.* Within the range of soil types examined in the project, soil type had very little influence on fuel properties and/or composition. Similarly, the analysed soil parameters showed few correlations with the corresponding feedstock composition.
- *Feedstock properties will differ according to the time of year that the biomass is harvested (Phase 1 focussed on poplar SRF and conifer SRF) Harvest time will affect the fuel properties and/or composition of Miscanthus and willow SRC (Phase2).* In Phase 1, feedstock properties of poplar and conifer SRF did differ when harvested in the spring compared to summer harvests, with an impact on the poplar SRF being particularly apparent. In the tops of poplar SRF, there were increases from spring to summer in moisture, zinc, potassium, and the Alkali Index as well as the oxides K_2O and SiO_2. Conifer SRF stem wood increased in levels of MgO but decreased in calcium, potassium, sodium, and silicon as well as the oxides Na_2O and SiO_2. Conifer SRF bark decreased in nitrogen, phosphorus and P_2O_5. Conifer SRF tops increased in P_2O_5, SiO_2 but decreased in levels of lead, sodium and the oxides of $CaCO_3$, MgO, Na_2O. These differences were more pronounced for the tops than the lower part of the stem; for the poplar SRF this may be due to the inclusion in the second harvest of leaves that are essentially absent from the first harvest - poplar leaves were high in zinc, potassium and Alkali Index. In Phase 2, *Miscanthus* showed a general decrease through late autumn, winter and early spring in moisture content, ash, carbon, nitrogen, chlorine, molybdenum, zinc, bromine, phosphorus, silicon, and calcium accompanied by an increase over the same period in net calorific value, volatile matter, and sodium. Only a few characteristics of willow SRC grown at six sites from north west to southern England showed statistically significant differences across three simulated harvesting times (mid-November, mid-January and mid-March) – gross calorific value, chromium, and calcium carbonate, potassium oxide and phosphorus - with the majority showing no difference. For the characteristics that did change, a variety of patterns was evident: gross calorific value decreased from November to January and then increased to March; chromium increased across the three sampling times; $CaCO_3$ was similar in November and January but increased to March; K_2O decreased across the three sampling times..
- *Feedstock properties will change with storage.* Storage had a strong influence on most feedstocks, particularly for moisture content and related properties for *Miscanthus*, which was stored for up to six months, and poplar SRF and conifer SRF which were both stored for three months. In this instance storage of willow SRC had no operationally important impacts but this finding should not be assumed to be a generalisation as the storage time was only one month.
- *Within a given field, feedstock properties will be relatively uniform.* This hypothesis was investigated for *Miscanthus* and willow SRC. For some feedstock characteristics (for example gross calorific value, chromium, copper, nickel, arsenic, mercury, lead, iron, and sodium), the

variation within fields was much greater than that between different sites. Similar behaviour between the two feedstocks was seen for a number of individual fuel quality parameters.

- *The process of pelletisation will influence the fuel properties and/or composition*. This hypothesis was tested for *Miscanthus* only. There was a marked change in physical and chemical properties of *Miscanthus* following pelletisation. The results indicated that there was a relatively high risk of product contamination, either from deliberate use of additives, from other materials or wear products from the grinding process of the pellet mill itself. However due to the limited number of samples available from the pelletisation process no clear conclusions could be made on changes to the chemical compositional aspects which were not directly related to the additives used by the pellet producer.
- *The feedstock characteristics of Miscanthus and willow SRC will differ from one year to the next at a given site.* The levels of many feedstock characteristics were broadly similar from one year to another but this was not the case for all parameters and some important properties, e.g. gross calorific value, magnesium and phosphorus, differed. Looking at seasonal changes where they were shown to be significant in the Phase 2 study of seasonal trends, some parameters had broadly similar dynamics, e.g. moisture content, net calorific value, ash, and chlorine (even though the absolute levels were slightly different). On the other hand, although the general seasonal patterns of nitrogen levels were broadly similar in the two years, the direction of change was not always the same on a particular date in the spring. No direct comparisons were possible in willow SRC because the crops sampled in the first year were harvested that spring and were therefore not at a stage for sampling in the following year. These differences are likely to be due to differences in environmental factors, e.g. temperature and rainfall, but may also be due to aging of the rhizome and stool since year of planting was related to changes in both cadmium in *Miscanthus* and sodium in willow SRC.
- *The feedstock characteristics of willow SRC varieties will differ from one variety to another in a consistent manner from one location to another.* There was a certain degree of consistency in willow variety properties across sites from Northern Ireland to Southern England, with approximately 40% of the parameters analysed showing statistically consistent rankings for the varieties tested (Endurance, Nimrod, Resolution, Sven, Terra Nova, and Tora). Considering the results as a whole no variety combined the best ranking in all parameters. For the majority of parameters however, there was not a consistent ranking. Volatile matter, sulphur and chlorine content for example did not show consistent rankings and neither did the alkali index.

The fuel properties and/or composition of Miscanthus are influenced by the storage method and duration. In 14% of analysed feedstock characteristics, which included ash, nitrogen, sulphur, zinc, bromine and calcium, storage treatments did have a significant influence; 43% were affected by storage but there was no influence of storage treatment; and another ca 43% of the feedstock characteristics tested were not significantly affected by storage. These results suggest that no single type of storage is likely to minimise the deterioration in all aspects of feedstock quality with storage.

6 Key findings

- The sampling procedures were robust and consistent giving a high degree of confidence in the dataset (Deliverable D11).
- Chemical properties of feedstocks differed in ways that have the potential to affect the downstream conversion.
- The Gross Calorific Value was lowest for the *Miscanthus*, the willow SRC and trunks of the other feedstocks, increasing in the tops and was highest in the leaves and bark.
- *Miscanthus* had the most variable moisture content as harvested and was strongly influenced by season falling from 60-70 % in November to 10-20 % in late spring; the trunk wood and tops contained typically 50-60% moisture with the leaves containing >60 % moisture.
- The Net Calorific Value (NCV) of *Miscanthus* was strongly influenced by season; by the usual harvest time it was generally twice that of the other feedstocks but was also very variable. For the woody biomass, the NCV was broadly similar for the stems and tops but the NCV of leaves tended to be lower than for the woodier parts of the plant. The bark and stem wood of the conifer SRF had similar NCV
- Ash levels and nitrogen in the stems of the woody biomass were very low, increasing in the tops, with the leaves containing the highest levels; conifer SRF bark levels were comparable with those in the conifer SRF tops; *Miscanthus* levels were comparable with those in the tops of the woody biomass types. In *Miscanthus,* both ash and nitrogen concentrations declined during autumn, winter and early spring.
- Sulphur was much higher in leaves than the other plant parts.
- Chlorine levels in *Miscanthus* declined during autumn, winter and spring, but even so were highest and were very variable. The willow SRC leaves contained markedly higher levels of chlorine than leaves from the poplar SRF. The trunks generally contained chlorine levels that were lower than the limit of analytical detection of 0.01%.
- Trace and minor elements: within the woody feedstock types, the trunks contained the lowest levels followed by increasing concentrations in the tops and finally the leaves. For the majority of trace and minor elements, the bark of conifer SRF contained similar concentrations to the tops.
- Leaves showed particularly high levels of zinc, which is a potential corrosion concern, and cadmium which is of environmental concern.
- Ash composition:, with the exception of the *Miscanthus*, all of the feedstock ashes were predominantly composed of calcium carbonate, with potassium oxide levels also high. By contrast, the *Miscanthus* samples contained significant levels of silica in their ash.

- On the basis of alkali index, *Miscanthus* was comparable to tops of woody plants though poorer than woody stems. The high alkali index of willow and poplar leaves suggested potential for slagging and fouling. Stem wood of the conifer SRF had levels below the threshold for imported wood pellets
- Harvesting time had a marked effect. In *Miscanthus* a general decrease through late autumn, winter and early spring was observed in moisture content, ash, carbon, nitrogen, chlorine, molybdenum, zinc, bromine, phosphorus, silicon, and calcium accompanied by an increase over the same period in net calorific value, volatile matter, and sodium. Considered as a whole these results suggest that to maximise *Miscanthus* quality, harvesting should be delayed until at least the beginning of March, with chlorine and ash a particular concern if harvesting is earlier in the year which also risks losing the advantages of low moisture content and higher NCV.
- Only a few characteristics of willow SRC showed statistically significant differences across three simulated harvesting times - GCV (DAF), chromium (d), $CaCO_3$ (na), K_2O (na), and P_2O_5 (na) - with the majority showing no difference. For the characteristics that did change, a variety of patterns was evident. Our results suggest that willow SRC growers have considerable flexibility over harvesting times. This window should be limited to after leaf fall through to bud burst because inclusion of leaf material risks raising the moisture content, and ash, nitrogen, sulphur and chlorine levels considerably.
- Changes in poplar and conifer SRF between spring and summer were probably associated with the mobilisation of stored energy and nutrients to support the new season's leaf and needle growth.
- Storage had a marked effect, particularly the longer durations (3 months for SRF and 6 months for *Miscanthus*). In *Miscanthus*
  - ca 43% of the feedstock characteristics tested were not significantly affected by storage;
  - another 43% were affected by storage but there was no influence of the method of storage; the majority of these changes decreased fuel quality; the exceptions were potassium, the oxide of potassium and the alkali index which were all significantly lower (i.e.. improved) after storage
  - in the remaining 14% of analysed feedstock characteristics, which included ash, nitrogen, sulphur, zinc, bromine and calcium, storage treatments did have a significant influence; again the majority of these changes decreased fuel quality.

  The experimental storage treatments were representative of the majority of commercial systems currently used in Britain in terms of the storage method and duration. These results suggest that no single type of storage is likely to minimise the deterioration in all aspects of feedstock quality and the choice of storage type is more likely to be dictated by what type of storage is available and perhaps the contamination risk on the farm, especially in the absence of any price differential linked to quality

- In SRF, the changes in composition were generally more common in the tops and when samples were felled in July and stored until late October (in comparison to the stems and samples collected in April/May and stored until July). This is probably associated with loss of leaves and needles.
- There was a certain degree of consistency in willow variety properties across sites from Northern Ireland to Southern England, with approximately 40% of the parameters analysed showing statistically consistent rankings for the varieties tested (Endurance, Nimrod, Resolution, Sven, Terra Nova, and Tora). Volatile matter, sulphur and chlorine content for example did not show consistent rankings and neither did the alkali index. Considering the results as a whole, no variety combined the best ranking in all parameters and there was not a consistent ranking for the majority of parameters.
- Soil type was not a key determinant of feedstock characteristics; this is thought to be because the sites had average or below average levels of metals/metalloids.
- Climate zone was generally not influential for SRF crops, but was more significant for *Miscanthus*.
- Plant part had a dominant impact within willow SRC, poplar SRF and conifer SRF biomass.
- For the in-field variation studies, whether more variation was seen within each site or between sites depended on the parameter. Both *Miscanthus* and willow SRC gave similar patterns for which elements were more variable within a field and which were more variable between fields.
- Pelletisation of *Miscanthus*: the major change associated with pelletisation of *Miscanthus* was an increase in bulk density; the dry ash content was generally higher after pelletisation. The results indicated that there was a relatively high risk of product contamination, either from deliberate use of additives, or from other materials or wear products from grinding process or the pellet mill itself.
- Of the ETI samples, only the conifer SRF stem wood met the strictest criteria for current relevant standards of industrial pellets.

7 Acknowledgements

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Uniper: Stewart Bradley and Duncan Credland

8 References

The following references are specific to Deliverable D13. Full references for Phase 1 and Phase 2 are given in Deliverable D6 and Deliverable D12 respectively.

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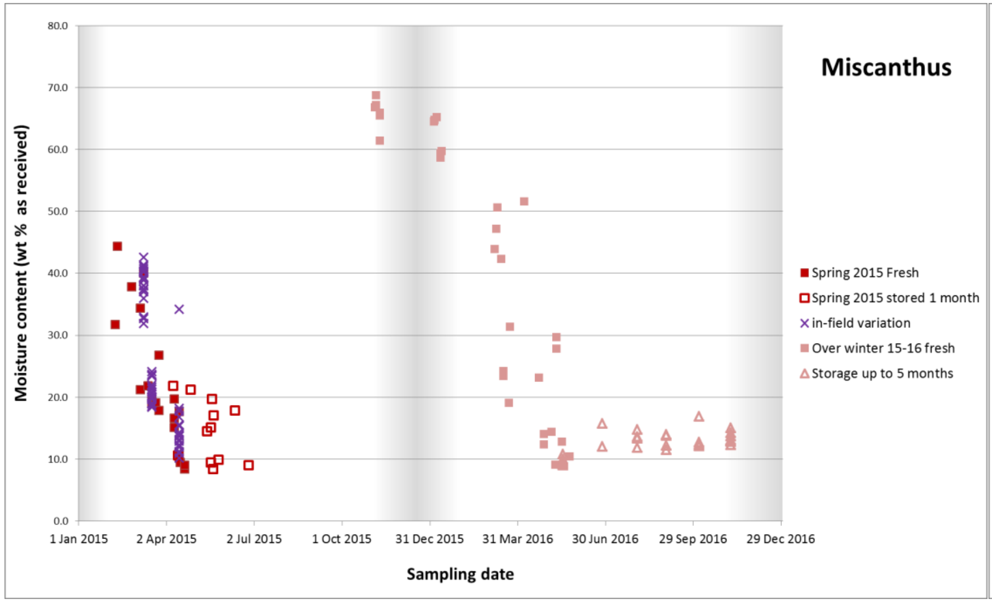
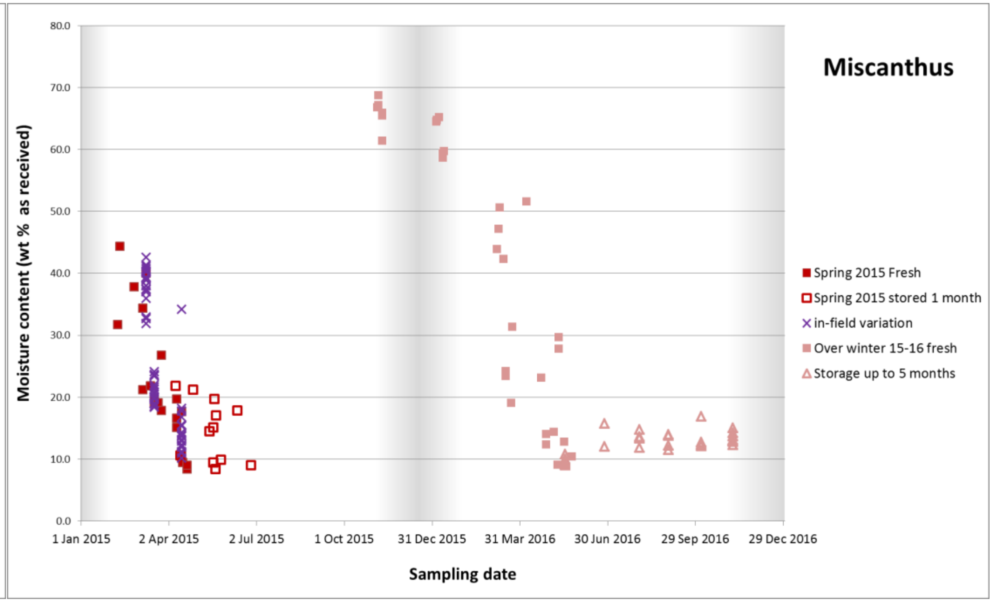
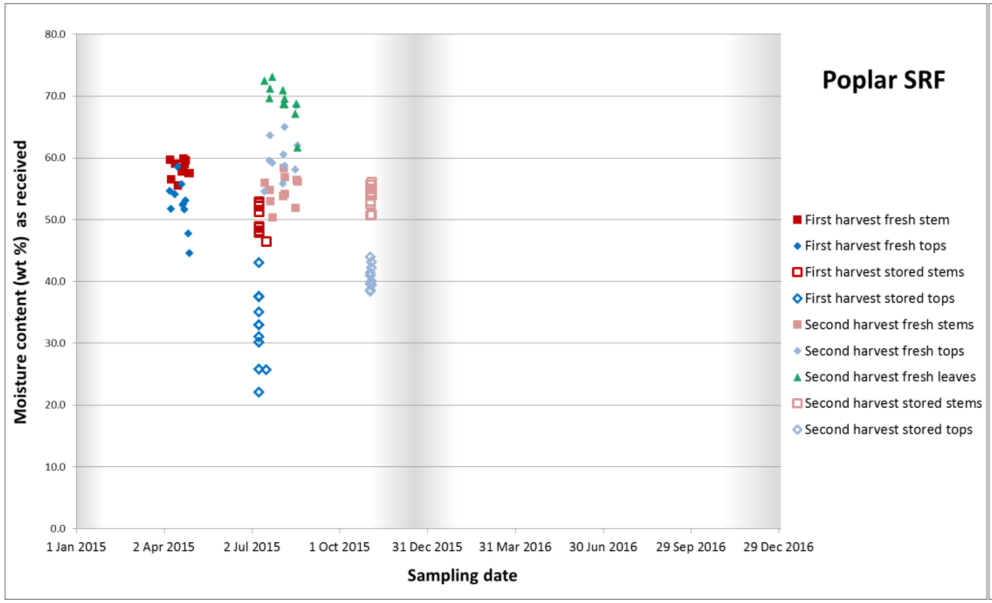
Phyllis2, database for biomass and waste, https://www.ecn.nl/phyllis2, Energy Research Centre of the Netherlands

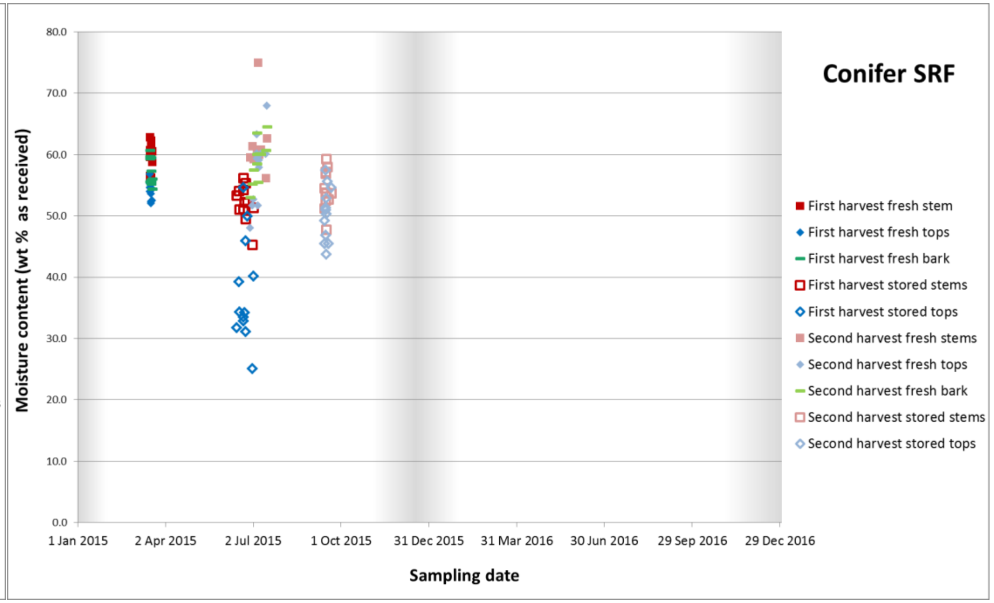
9 Appendices

MOISTURE	**Units of % wt in as received fuel**
General	*Miscanthus:* Dominated by seasonal effects, falling from 30-40 to 10-20 in spring 2015 and from 60-70 to 10-20 in winter 2015 through to spring 2016 Willow SRC, poplar SRF and conifer SRF generally lay between 50 and 60.
Source of variation	Impact
Climate zone	*Miscanthus:* no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: no statistically significant effect of climate zone Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: no statistically significant effect of soil type Poplar SRF: no statistically significant effect of soil type Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* In Phase 2 storage had over a long period increased moisture content (MC) slightly from the very low initial level at baling; in Phase 1 there was a small additional fall in MC in the one month following baling. Storage method was not statistically significant. Willow SRC: Erratic response with some increases and some decreases; no pattern over the limited period of outdoor uncovered storage. Poplar SRF: Moisture decreased especially the tops (56 to 36) Conifer SRF: Moisture decreased especially the tops
Location within field	*Miscanthus*: variation between fields was greater than within fields. Willow SRC: variation between fields was greater than within fields.
Plant part	Willow SRC leaves had slightly higher moisture contents than stem samples. For poplar in spring, stems tended to have a higher moisture content than the tops but in summer moisture increased in the order stems < tops< leaves. For conifer plant parts differed by only 10% and there was little difference between plant parts.
Season	*Miscanthus:* major impact of season, with moisture content declining over autumn, winter and spring Willow SRC: little seasonal change Poplar SRF: little seasonal change in stems but tops in summer had higher moisture content than in spring (51 vs 42) Conifer SRF: little seasonal change
Variety (willow SRC)	Varietal differences were large, exceeding seasonal differences. Endurance had the lowest moisture content while Nimrod and Terra Nova had the highest moisture content.

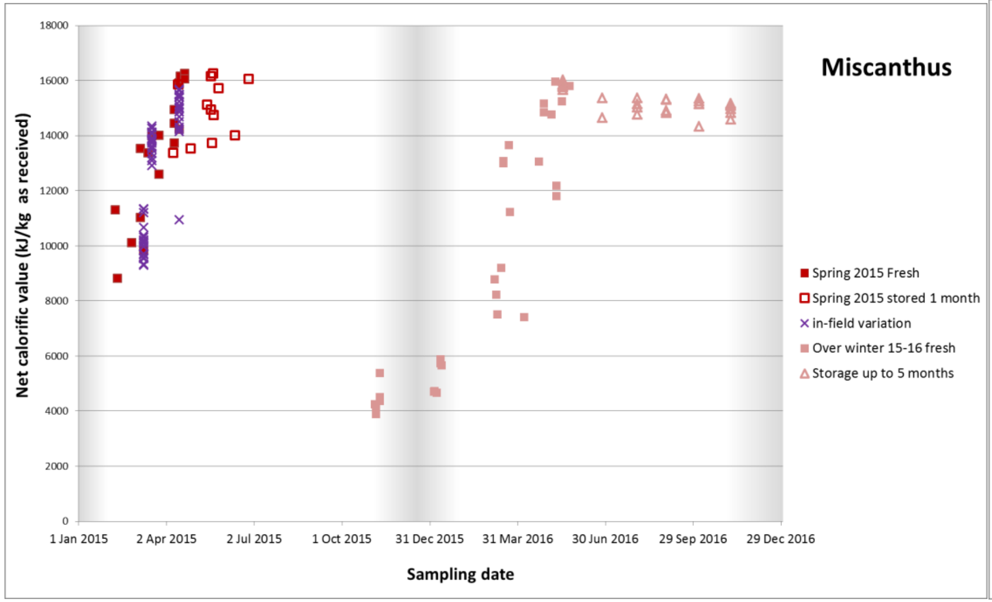

Miscanthus
Moisture content (wt % as received)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

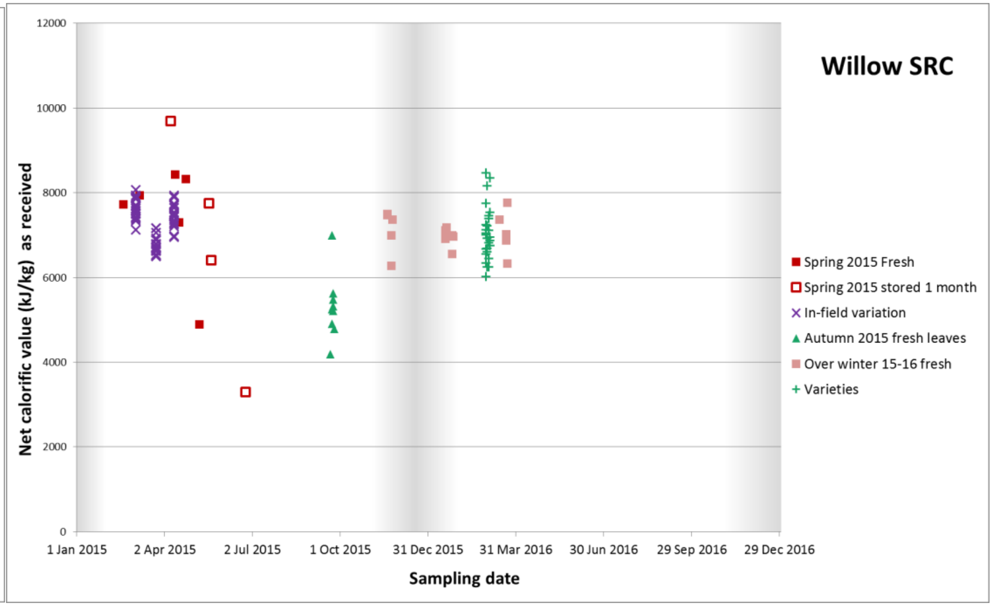

Miscanthus
Moisture content (wt % as received)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

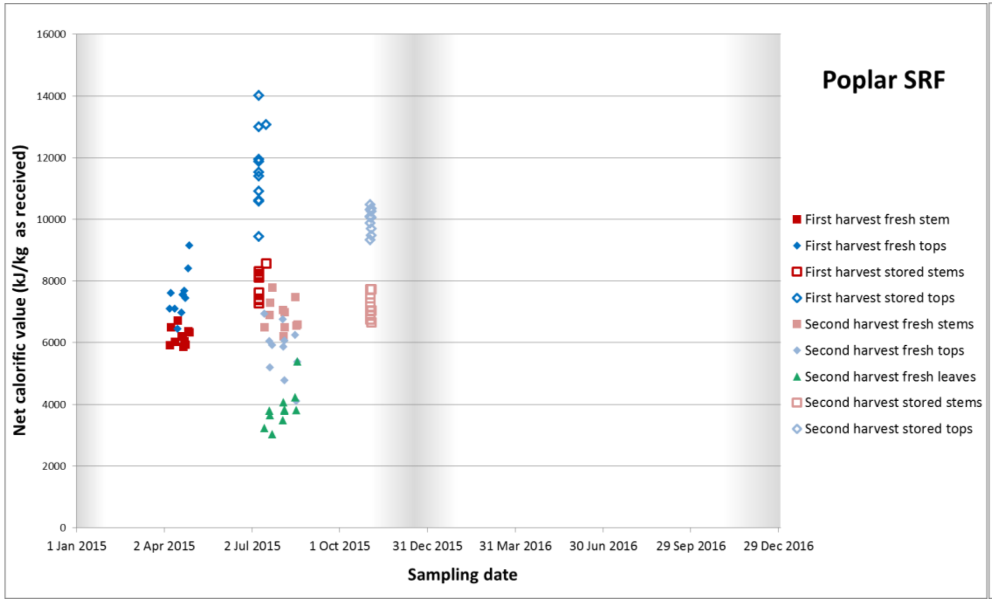

Poplar SRF
Moisture content (wt %) as received
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves
Second harvest stored stems
Second harvest stored tops

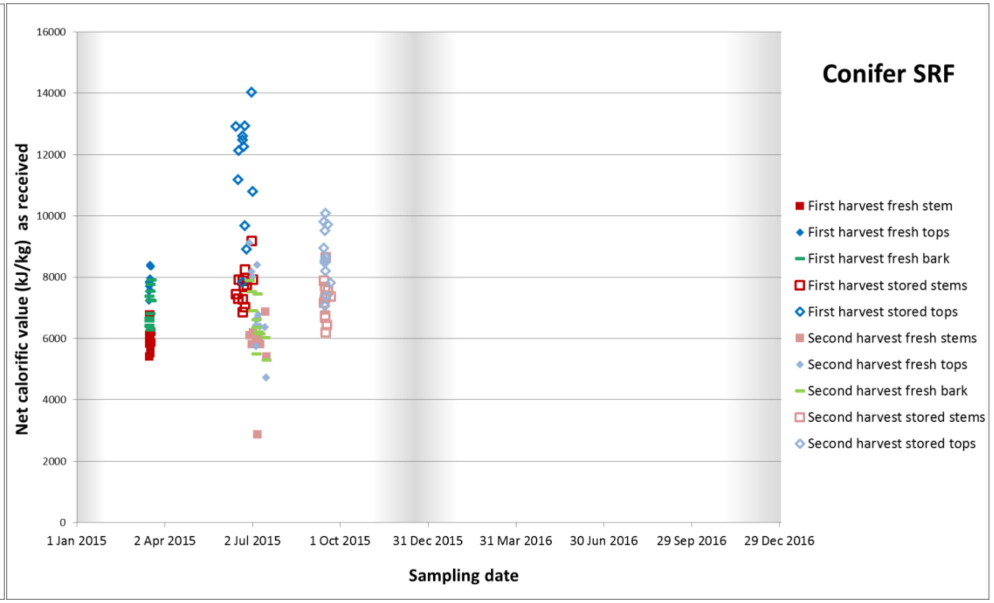

Conifer SRF
Moisture content (wt % as received)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark
Second harvest stored stems
Second harvest stored tops

NET CALORIFIC VALUE	**In units of kJ/kg in as received fuel**
General	*Miscanthus* NCV was strongly influenced by seasonal changes but by spring had the highest NCV – at up to 16,000 this was twice the other feedstocks. The woodier parts of willow SRC, poplar SRF, and conifer SRF had values in the range 6,000-8,000 but the leaves had values below 4,000
Source of variation	
Climate zone	*Miscanthus*: no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: no statistically significant effect of climate zone Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: no statistically significant effect of soil type Poplar SRF: no statistically significant effect of soil type Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* in Phase 2 NCV fell slightly during storage from the very high values at baling; in Phase 1 there was a slight increase in NCV. Storage method was not statistically significant. Willow SRC: variable response. Poplar SRF: increased in both stems and tops Conifer SRF: increased in both stems and tops
Location within field	*Miscanthus* and willow SRC: in both feedstocks variation between fields was greater than within fields; in-field variation was the of the same order as changes recorded over late spring/early summer
Plant part	Leaves had lower NCV than tops and stems. In conifer SRF, bark and stem wood had similar NCV
Season	*Miscanthus:* major impact of season, increasing over autumn, winter and spring and between cutting and baling Willow SRC: little seasonal change Poplar SRF: in absolute terms there was little seasonal change, though tops were higher in the spring samples (9605 vs 7875). Conifer SRF: in absolute terms there was limited seasonal change, the NCV of tops and bark were higher in the spring samples than the summer samples (e.g. 7030 vs 6514 for bark).
Variety (willow SRC)	Varietal differences were comparatively large, exceeding within field, site-site, and seasonal changes with Endurance and Terra Nova having low NCV and Nimrod and Resolution having high NCV

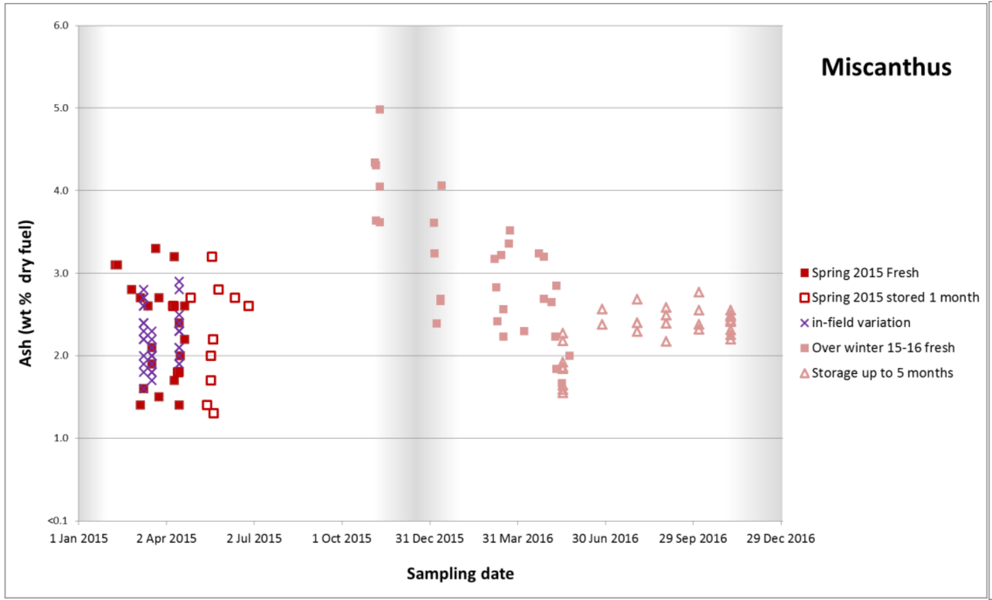

Miscanthus
Net calorific value (kJ/kg as received)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

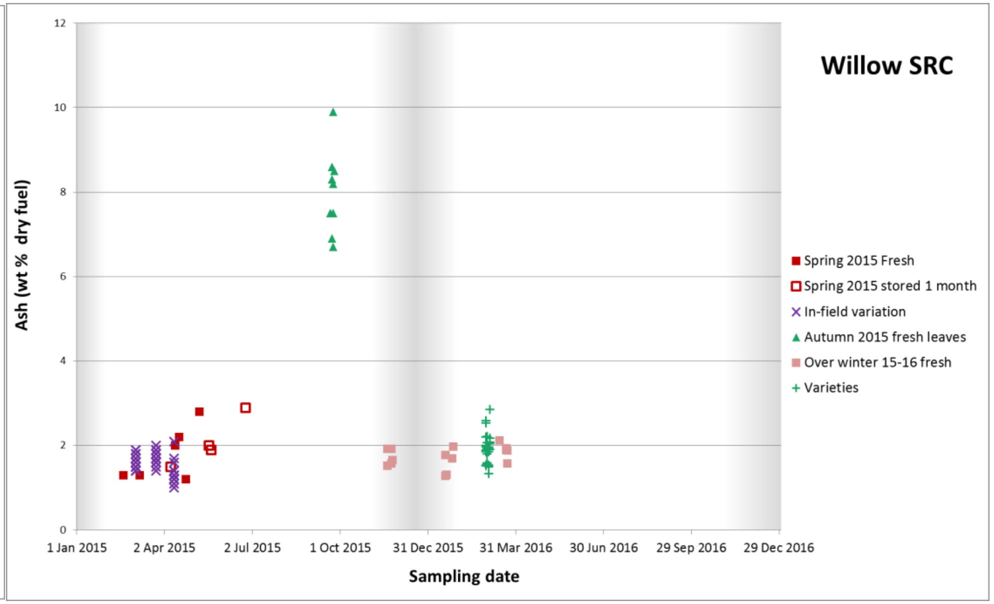

Willow SRC
Net calorific value (kJ/kg) as received
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

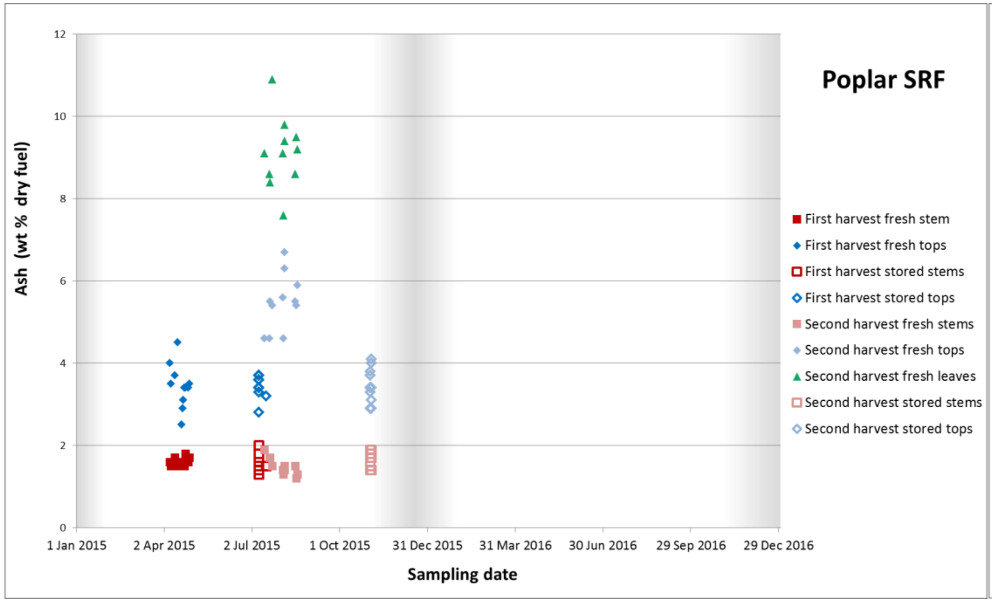

Poplar SRF
Net calorific value (kJ/kg as received)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves
Second harvest stored stems
Second harvest stored tops

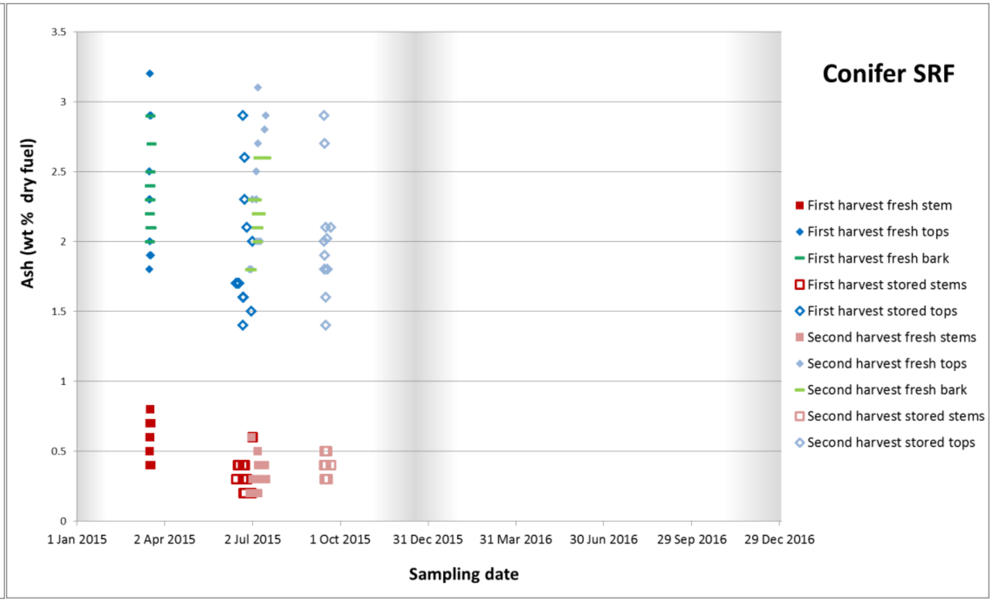

Conifer SRF
Net calorific value (kJ/kg) as received
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark
Second harvest stored stems
Second harvest stored tops

ASH	**Units of wt % in dry fuel**
General	*Miscanthus:* variable, generally 1.5-3.0 in the spring of 2015 but fell consistently throughout the autumn and winter of 2015-16 to reach 2.0-3.5 in spring 2016. Willow SRC: generally 2.0-3.5 except for the leaves which were much higher Poplar SRF: stems had 1.0-2.0; tops were 3-4 in the spring rising to 5-7 in the summer, while the leaves (in autumn) were 8-10 Conifer SRF: stems were 0.25-0.5 while the bark and tops were 1.75-3
Source of variation	
Climate zone	*Miscanthus*: warm/dry climates had higher ash levels (2.4) than warm/moist sites (1.5) Willow SRC: insufficient samples to test statistically Poplar SRF: no definite trend for stem or tops Conifer SRF: no definite trend for stem or tops
Soil type	*Miscanthus:* no significant impact Willow SRC: no definite trend Poplar SRF: no definite trend for stem or tops Conifer SRF: no definite trend for stem wood or tops
Storage	*Miscanthus*: little impact in spring 2015 of one months' storage; the 2016 storage experiment indicated an increase over the first 1-2 months. Storage method was statistically significant – the increase associated with storage was greater for barn-stored samples. Willow SRC: no definite trend Poplar SRF: no definite trend for stem samples but the levels in tops harvested in summer decreased over the following 3 months Conifer SRF: slight decrease in levels in stems harvested in spring and stored for 3 months and also in tops harvested in spring and summer
Location within field	*Miscanthus* and willow SRC: variation within fields was of the same order as differences between fields and seasonal changes
Plant part	Stems< tops< leaves. In the conifer SRF, levels in bark and tops were similar
Season	*Miscanthus*: levels fell noticeably in the autumn and winter; in spring there was no obvious seasonal pattern Willow SRC: no definite trend Poplar SRF: no definite trend for stem samples but the levels in tops increased from spring to summer Conifer SRF: no definite trend for stem wood, bark or tops
Variety (willow SRC)	Varietal differences were greater than seasonal and within-field differences but there were not statistically significant varietal differences.

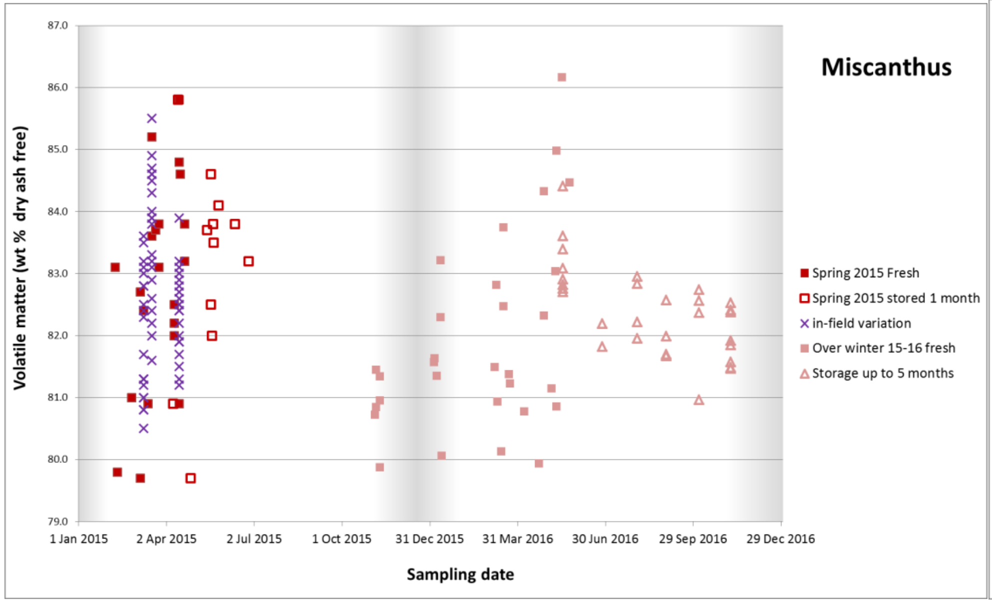

Miscanthus
Ash (wt % dry fuel)
6.0
5.0
4.0
3.0
2.0
1.0
<0.1
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

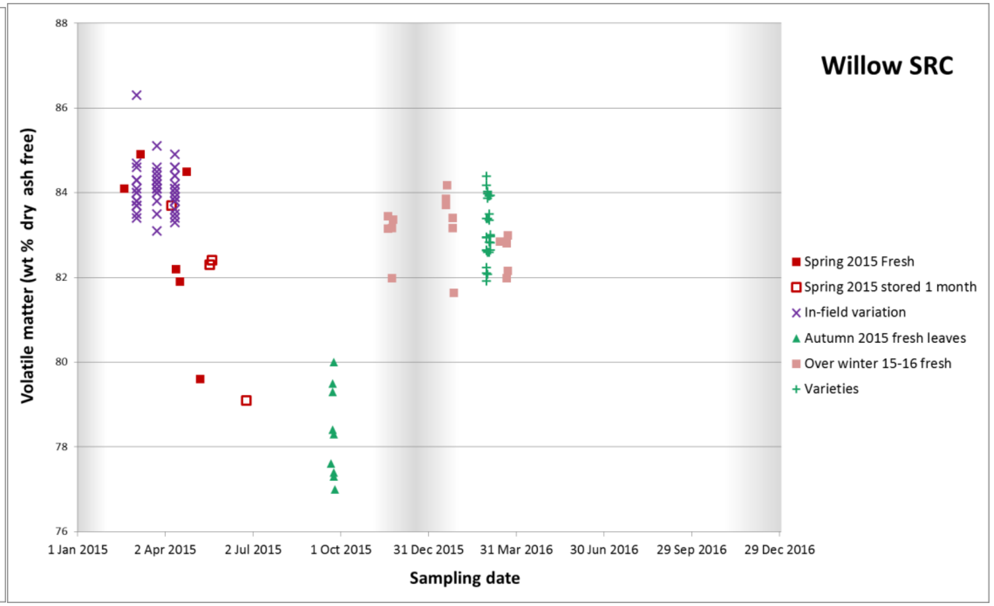

Willow SRC
Ash (wt % dry fuel)
12
10
8
6
4
2
0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

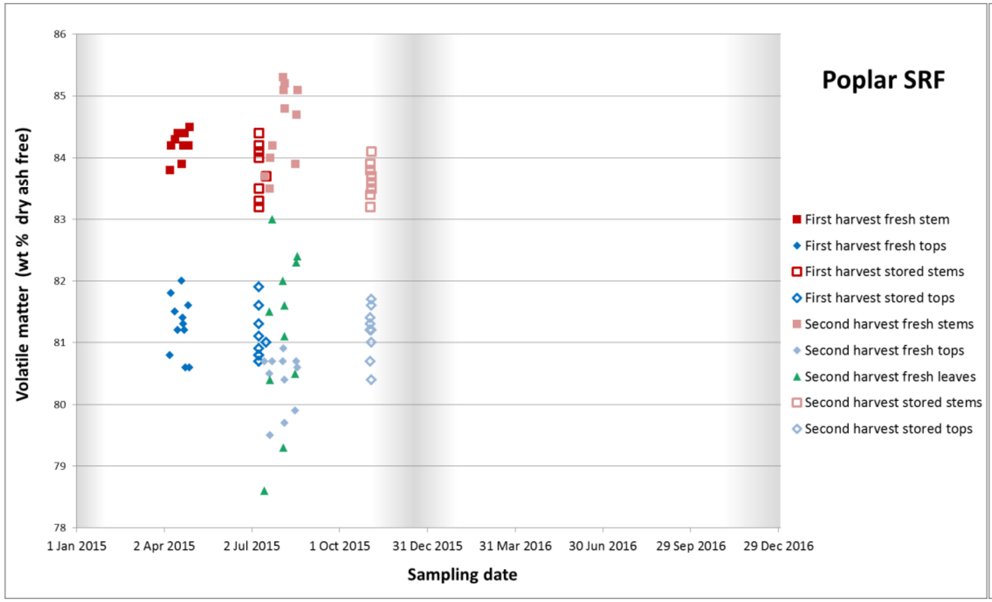

Poplar SRF
Ash (wt % dry fuel)
12
10
8
6
4
2
0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves
Second harvest stored stems
Second harvest stored tops

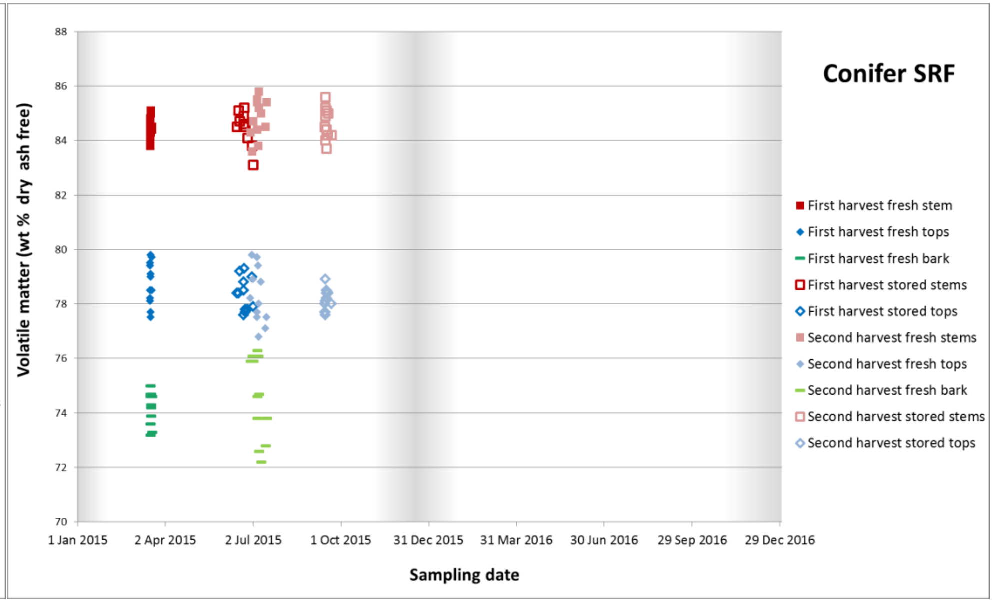

Conifer SRF
Ash (wt % dry fuel)
3.5
3
2.5
2
1.5
1
0.5
0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark
Second harvest stored stems
Second harvest stored tops

VOLATILE MATTER	In units of % in dry, ash-free fuel
General	For all feedstocks, volatile matter was generally 80-85 % but was lower for conifer tops (77-80 %) and bark (72-76 %)
Source of variation	
Climate zone	*Miscanthus:* no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: no statistically significant effect of climate zone Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: no statistically significant effect of soil type Poplar SRF: no statistically significant effect of soil type Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* slight decrease, most noticeably in the early months of storage. Storage method was not statistically significant. Willow SRC: no pattern over the limited period of outdoor uncovered storage Poplar SRF: slight differences but these were within the analytical repeatability therefore not worth emphasising Conifer SRF: no statistically significant effect of storage
Location within field	*Miscanthus* and willow SRC: variation within fields was of the same order as differences between fields and seasonal changes; in-field differences of 2-3 %, which was similar to site-site and seasonal differences
Plant part	Conifer bark < tops < stem wood. For poplar and willow, leaves < stems, which included bark
Season	*Miscanthus:* slight increase during autumn, winter and spring Willow SRC: no definite trend Poplar SRF: slight increase in stems but slight decrease in tops from spring to summer Conifer SRF: slight decrease in tops from spring to summer but these were within the analytical repeatability therefore not worth emphasising
Variety (willow SRC)	Varietal differences were not significant and were similar to seasonal and within-field differences.

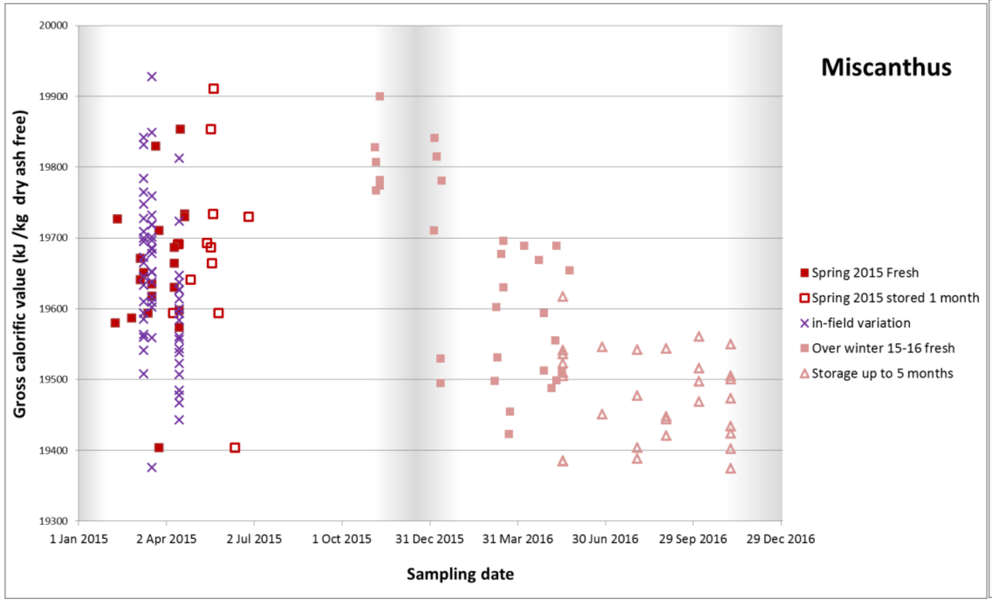

Miscanthus
Volatile matter (wt % dry ash free)
87.0
86.0
85.0
84.0
83.0
82.0
81.0
80.0
79.0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

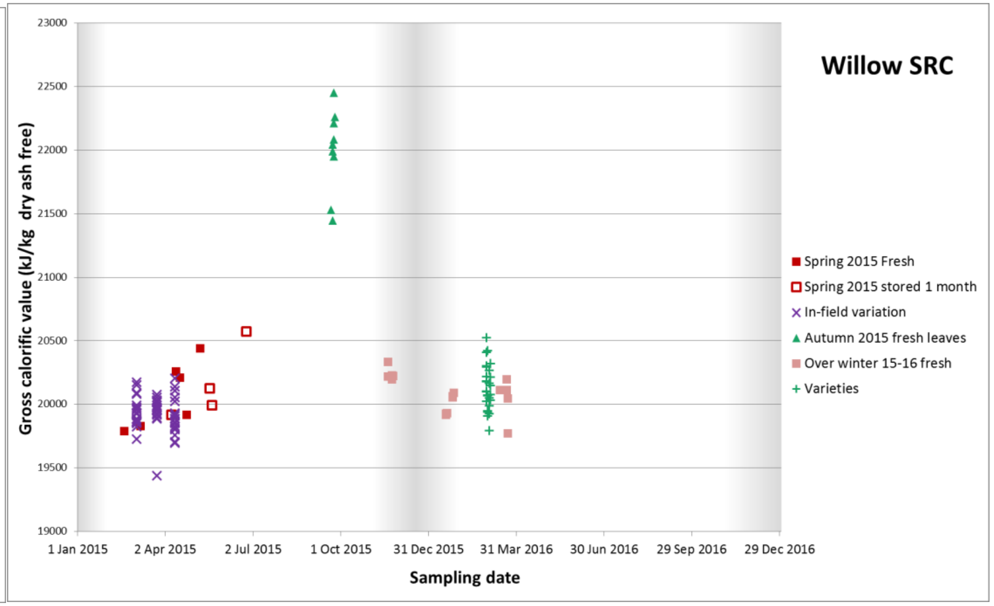

Willow SRC
Volatile matter (wt % dry ash free)
88
86
84
82
80
78
76
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

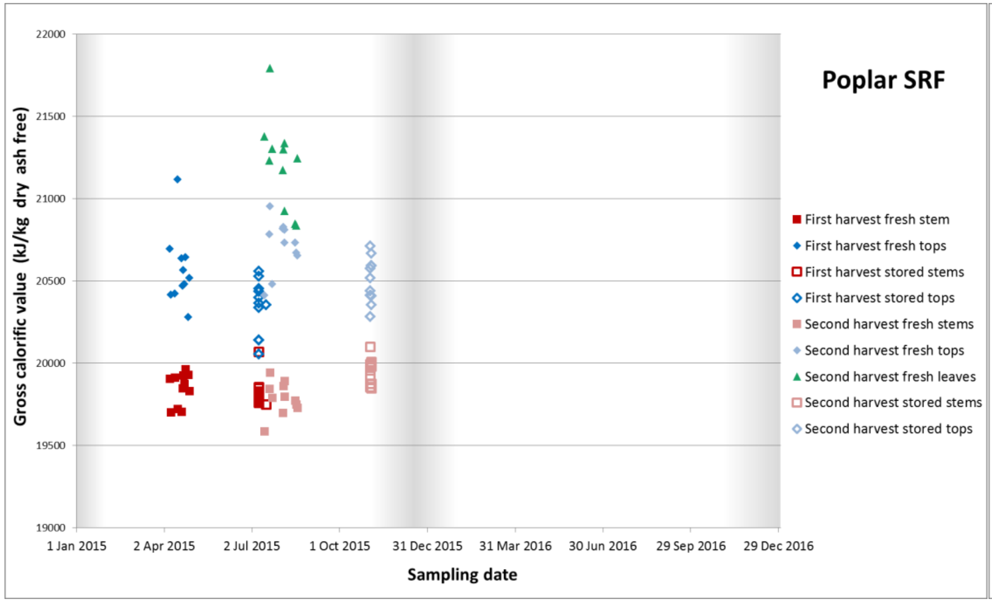

Poplar SRF
Volatile matter (wt % dry ash free)
86
85
84
83
82
81
80
79
78
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves
Second harvest stored stems
Second harvest stored tops

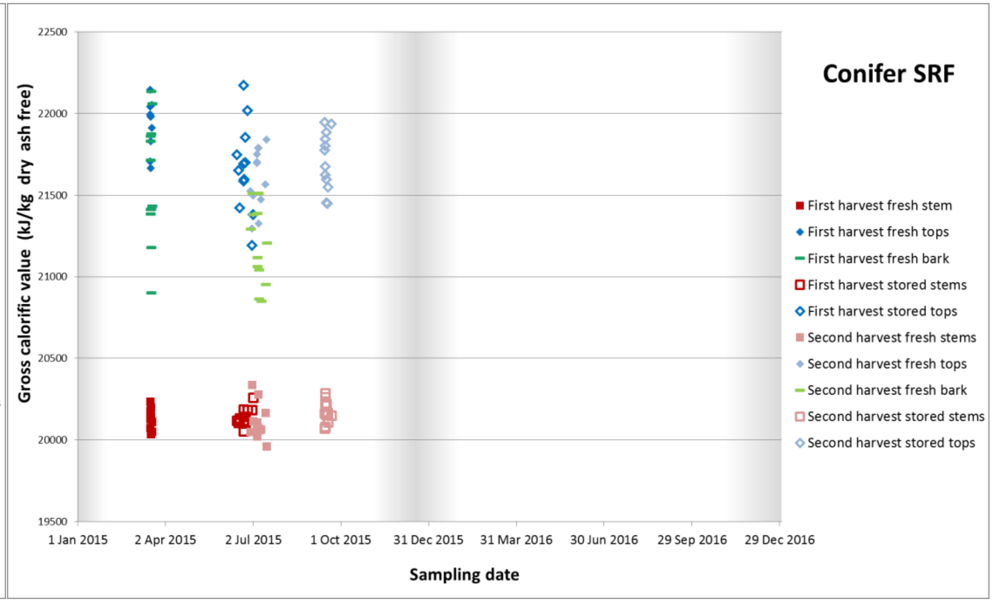

Conifer SRF
Volatile matter (wt % dry ash free)
88
86
84
82
80
78
76
74
72
70
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark
Second harvest stored stems
Second harvest stored tops

GROSS CALORIFIC VALUE	**In units of kJ/kg in dry, ash-free fuel**
General	*Miscanthus* and the more traditional fractions of the woodier feedstocks had values of 19,450 to 20,400 with *Miscanthus* tending to have the lowest values. *Miscanthus:* values generally lay within a relatively narrow range of 19,450 – 19,700 Willow SRC: stems were between 19,700 – 20,400 although leaves were higher at ca 22,000 Poplar SRF: stems were between 19,700 – 20,000, tops ca 21,000 and leaves were higher at ca 21,500 Conifer SRF: stem wood lay within a narrow range of 20,000 – 20,400 and tops and bark were more variable with values between 21,000 and 22,000
Source of variation	
Climate zone	*Miscanthus:* no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: no statistically significant effect of climate zone Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: no statistically significant effect of soil type Poplar SRF: no statistically significant effect of soil type Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* no definite trend. Storage method was not statistically significant. Willow SRC: tended to decrease slightly in autumn and increase again in spring Poplar SRF: stems increase slightly when stored in summer, tops decrease slightly when stored in both spring and summer Conifer SRF: no statistically significant effect of storage
Location within field	*Miscanthus* and willow SRC: in both feedstocks in-field variation was greater than between fields; differences of 400 recorded within fields which was similar to site-site and seasonal differences from winter through spring
Plant part	Leaves > stems for willow SRF; leaves > tops > stems for poplar SRF; and tops > bark > stem wood for conifer SRF
Season	*Miscanthus:* GCV decreased over autumn, winter and early spring (there was little change between cutting and baling) Willow SRC: GCV decreased slightly over autumn Poplar SRF: no difference between spring and summer in stems but GCV of tops increased slightly Conifer SRF: no difference between spring and summer in stems but GCV of tops and bark decreased slightly
Variety (willow SRC)	Varietal differences were greater than seasonal and of the same order as within-field differences. Nimrod had the greatest ash concentrations.


Miscanthus
Gross calorific value (kJ /kg dry ash free)
20000
19900
19800
19700
19600
19500
19400
19300
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

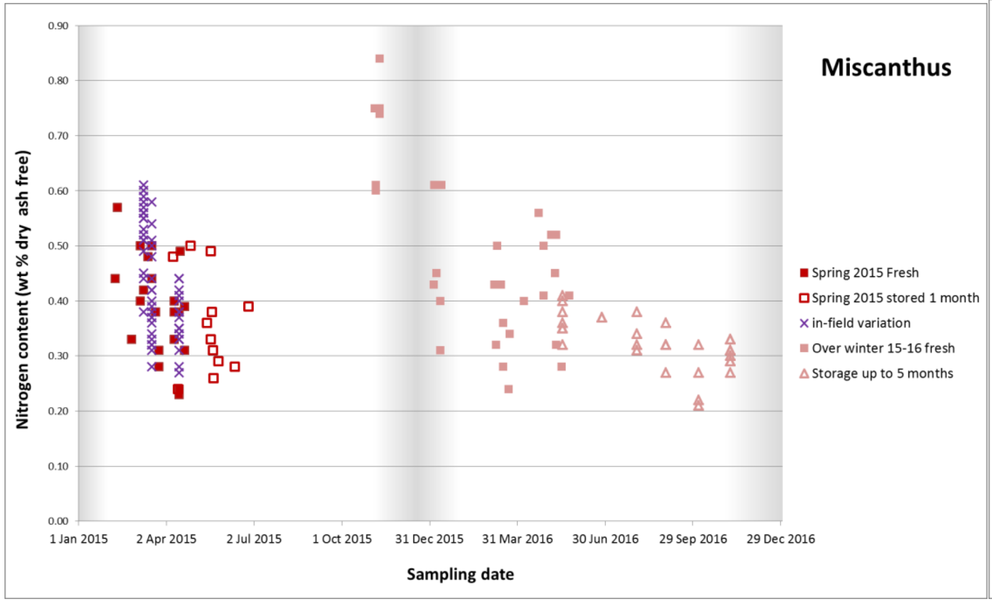

Willow SRC
Gross calorific value (kJ/kg dry ash free)
23000
22500
22000
21500
21000
20500
20000
19500
19000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

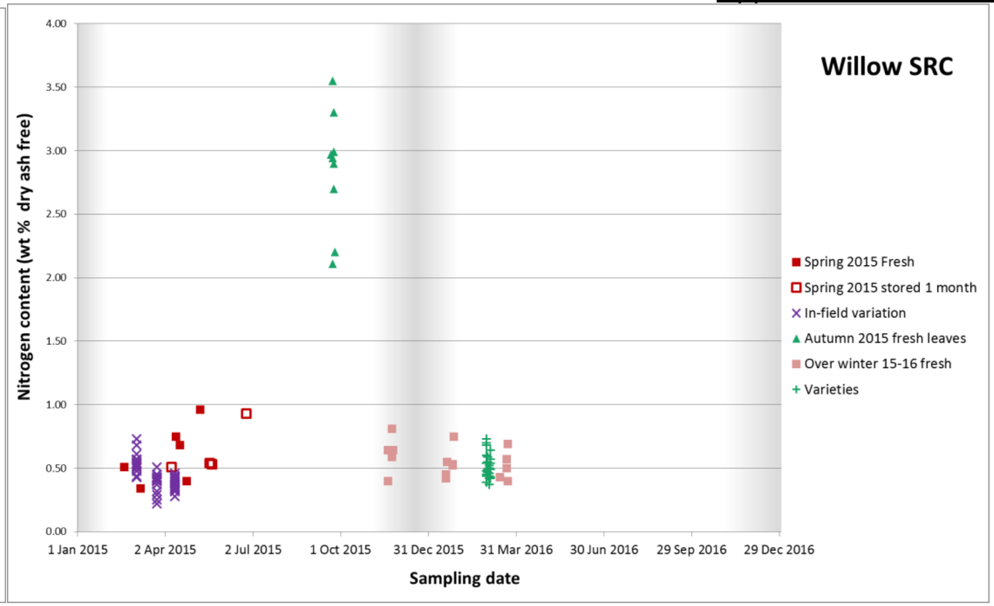

Poplar SRF
Gross calorific value (kJ/kg dry ash free)
22000
21500
21000
20500
20000
19500
19000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves
Second harvest stored stems
Second harvest stored tops

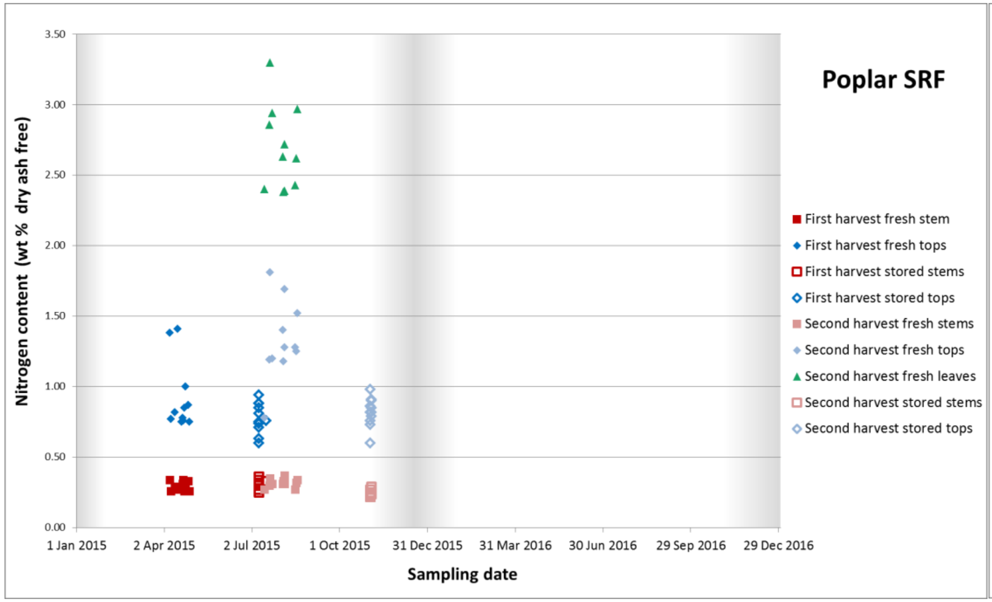

Conifer SRF
Gross calorific value (kJ/kg dry ash free)
22500
22000
21500
21000
20500
20000
19500
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark
Second harvest stored stems
Second harvest stored tops

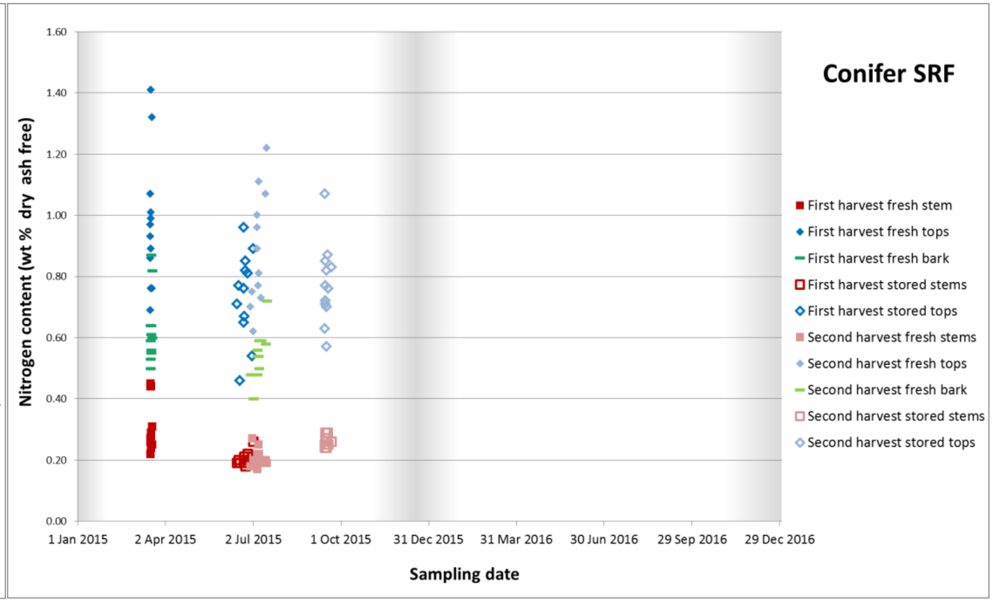
NITROGEN CONTENT	In units of % wt in dry, ash-free fuel
General	Nitrogen levels in the usual feedstocks were low (<1) and broadly similar but tops and leaves had higher nitrogen concentrations *Miscanthus:* values generally between 0.25 and 0.6 with the exception of the autumn samples which had higher nitrogen levels (0.6 – 0.85) Willow SRC: stems were generally between 0.25 and 0.75 but the leaves were much higher (2.0 – 3.5) Poplar SRF: stems consistently about 0.25, but the levels were higher in the tops (0.6 – 1.6) and much higher in the leaves (2.4 – 3.4) Conifer SRF: stem wood ranged from 0.2 – 0.3, but the levels were higher in the bark (0.4 – 0.7) and higher in the tops (0.6 – 1.4)
Source of variation	
Climate zone	*Miscanthus:* no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: although not significant as a main factor, climate zone interacted with harvest time and soil type in its impact on stem nitrogen concentrations; nitrogen concentrations in stems were lower when sampled in the summer than in the spring from sites in light and medium soils in the warm/dry climate zone and light soils in the warm/moist climate zone whereas levels were higher in the summer than the spring from samples on sites with medium soils in the warm/moist climate zone (see Table 8-3 of Deliverable D6 for values) Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: leaf samples from light soils showed higher levels of N than those from medium soils (3.06 vs 2.43 mg/kg) Poplar SRF: no statistically significant effect of soil type Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* nitrogen levels decreased during long term storage especially in bales stored outside uncovered Willow SRC: no discernible pattern over the limited period of outdoor uncovered storage Poplar SRF: no effect on levels in stems but nitrogen in tops decreased during 3 months' storage Conifer SRF: nitrogen in stem wood decreased slightly when storage began in spring but increased slightly when stored in summer; tops concentrations decreased on both occasions (0.9 to 0.8).
Location within field	*Miscanthus* and willow SRC: for both feedstocks the variation within fields was similar to the variation between fields; differences of 0.4 were recorded within fields which was similar to site-site and seasonal differences from winter through spring
Plant part	Stems < bark < tops << leaves
Season	*Miscanthus:* strong seasonal decrease from autumn through to early spring but may be some evidence of a slight increase in late spring Willow SRC: no consistent pattern over spring 2015 and 2016 Poplar SRF: no difference in stem nitrogen but levels in tops increased between spring and summer Conifer SRF: levels in stem wood, bark and tops decreased slightly between spring and summer. This was only statistically significant for bark samples which fell from 0.6 to 0.5 .

Variety (willow SRC)	Varietal differences were significant with Resolution having consistently low nitrogen and Nimrod, Terra Nova and Endurance being low. Varietal differences were of the same order as seasonal and also within and between site differences.

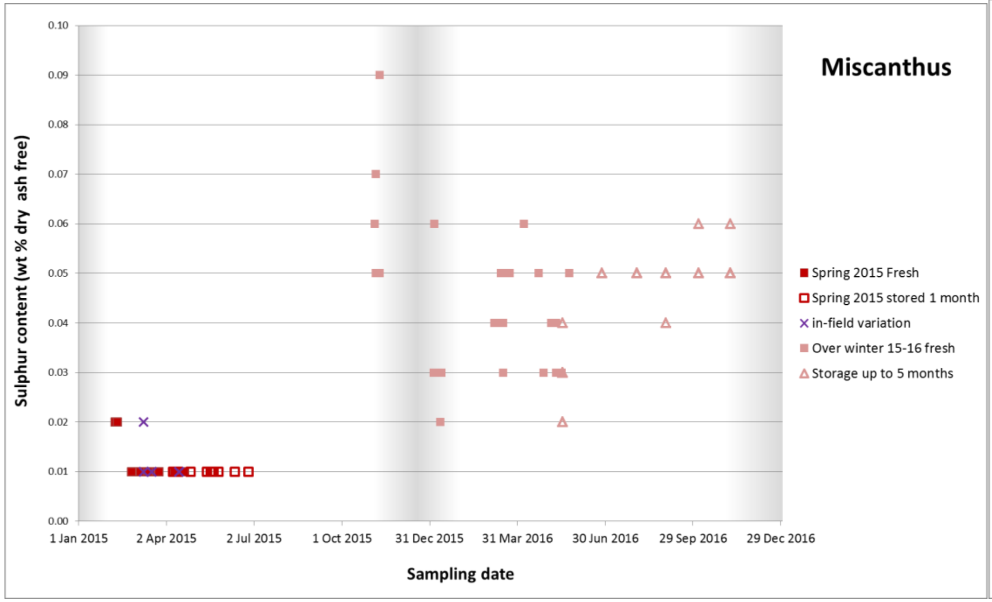

Miscanthus
Nitrogen content (wt % dry ash free)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

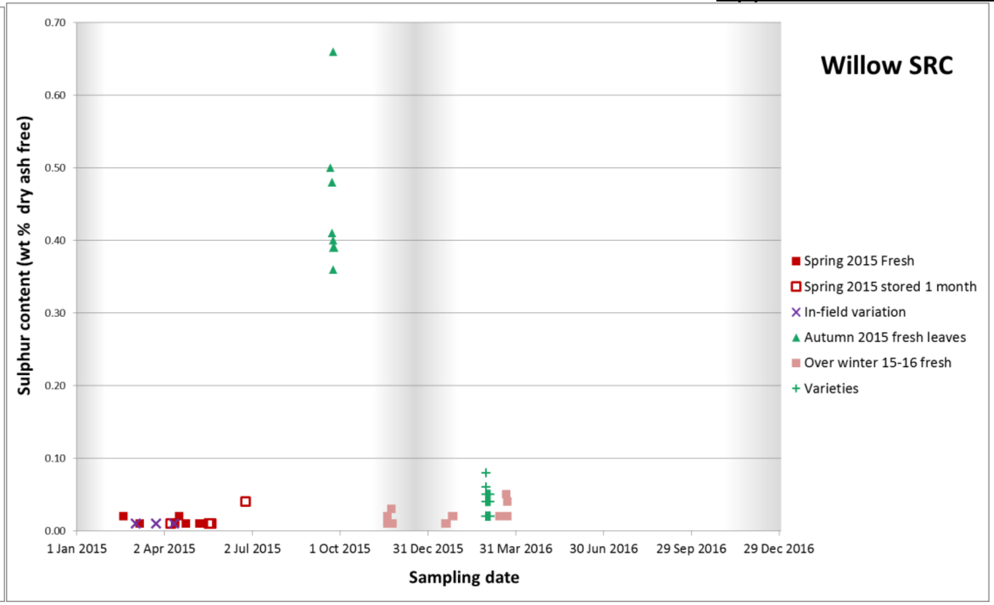

Willow SRC
Nitrogen content (wt % dry ash free)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

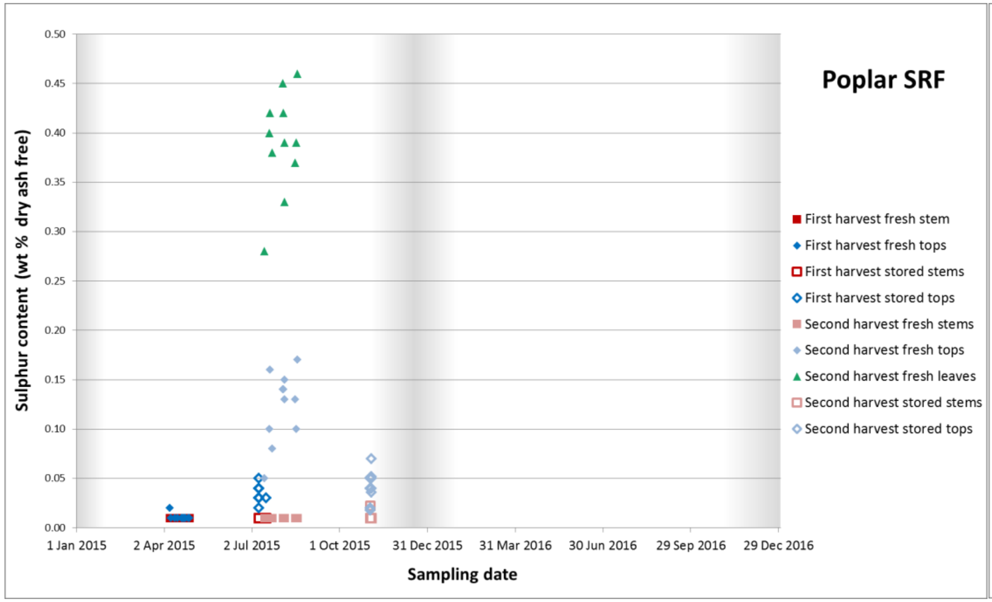

Poplar SRF
Nitrogen content (wt % dry ash free)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves
Second harvest stored stems
Second harvest stored tops

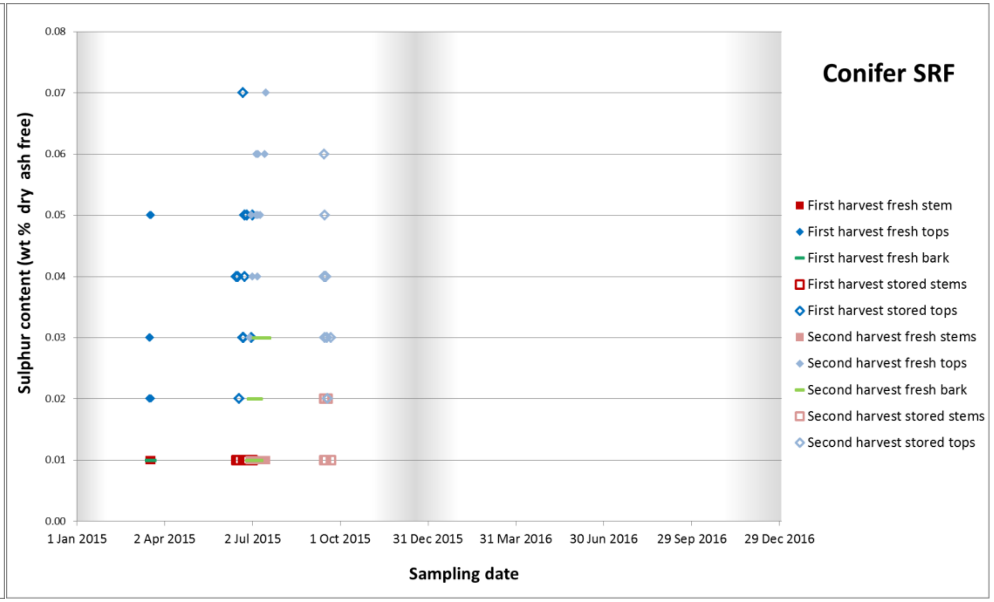

Conifer SRF
Nitrogen content (wt % dry ash free)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark
Second harvest stored stems
Second harvest stored tops

SULPHUR CONTENT	In units of % wt in dry, ash-free fuel
General	Sulphur levels in the usual feedstocks were very low (often close to the limit of detection of 0.01) and broadly similar; bark and tops of conifer SRF were also low (<0.07) whereas leaves and tops of the broadleaved species were higher, ranging from 0.3 – 0.5 *Miscanthus:* although values were very low, levels from autumn, winter, and spring of the second year were higher than in spring 2015.
Source of variation	
Climate zone	*Miscanthus:* no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: no statistically significant effect of climate zone Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: no statistically significant effect of soil type Poplar SRF: the increase in sulphur in poplar tops between spring and summer was more marked on medium soils (0.02 to 0.09) than on light soils (0.02 to 0.09) Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* storage in the first spring had no effect but values seemed to increase during storage, especially when stored in barns Willow SRC: no discernible pattern over the limited period of outdoor uncovered storage Poplar SRF: stems were not affected by storage; sulphur content of tops increased when stored from spring (0.02 increasing to 0.04) but decreased when stored from summer (0.13 falling to 0.05) Conifer SRF: no effect of storage on the very low stem wood values but for tops storage beginning in spring increased sulphur concentrations (0.03 iincreasing to 0.04) but decreased sulphur concentration when storage began in summer (0.05 decreasing to 0.04)
Location within field	*Miscanthus* and willow SRC: for *Miscanthus* the in-field variation exceeded the variation between fields; for willow SRC there was essentially no difference within fields in these very low sulphur concentrations
Plant part	Stems and bark < tops << leaves
Season	*Miscanthus:* no seasonal impact in the first spring but values seemed to decrease during autumn 2015 and then stabilise in spring 2016 Willow SRC: no impact Poplar SRF: no difference in stem sulphur concentration but levels in tops increased between spring and summer (see under soil type) Conifer SRF: no difference in stem wood sulphur concentration but levels in bark and tops increased slightly between spring and summer
Variety (willow SRC)	Varietal differences were not significant.

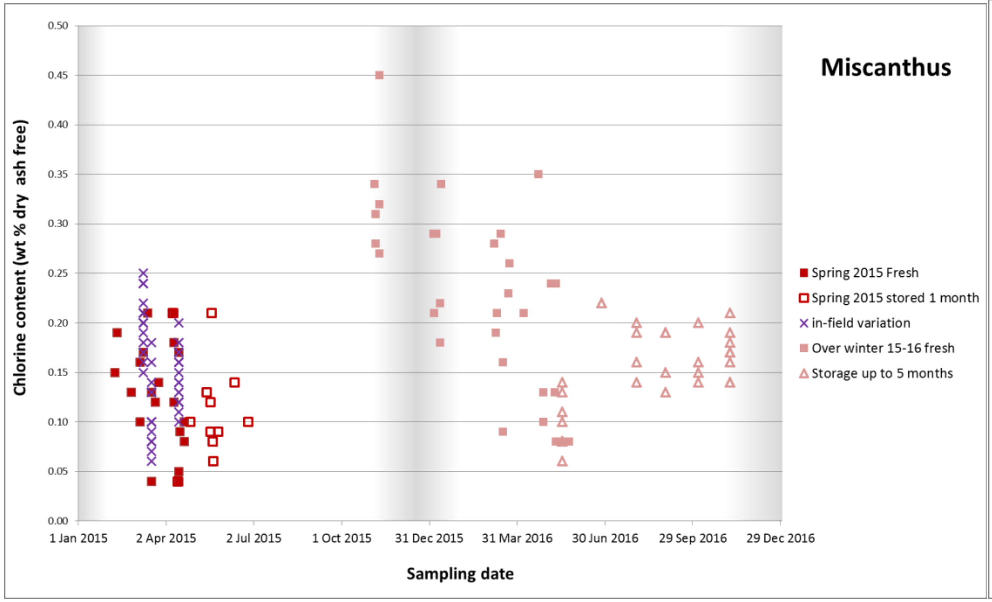

Miscanthus
Sulphur content (wt % dry ash free)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

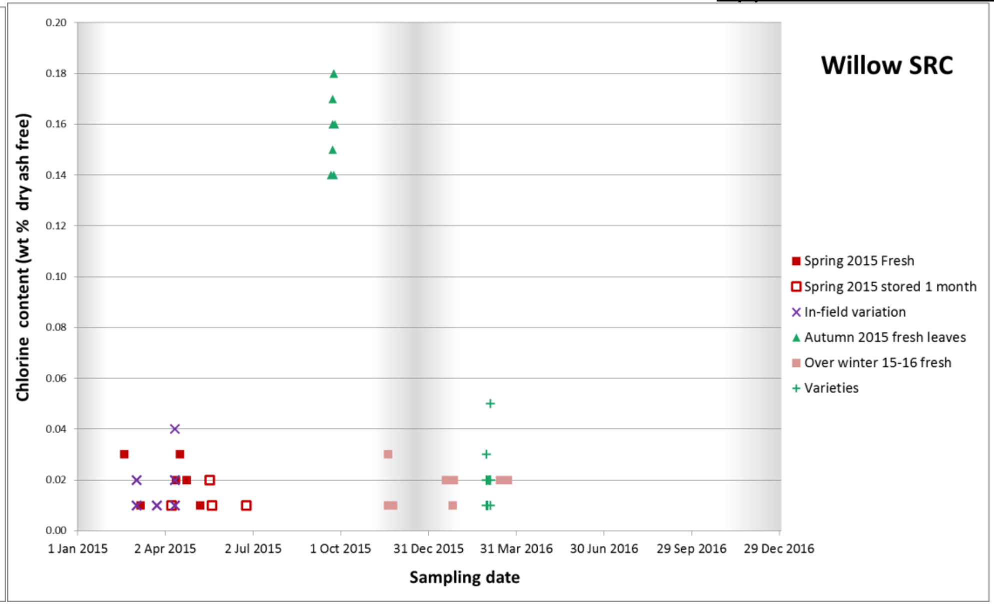

Willow SRC
Sulphur content (wt % dry ash free)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

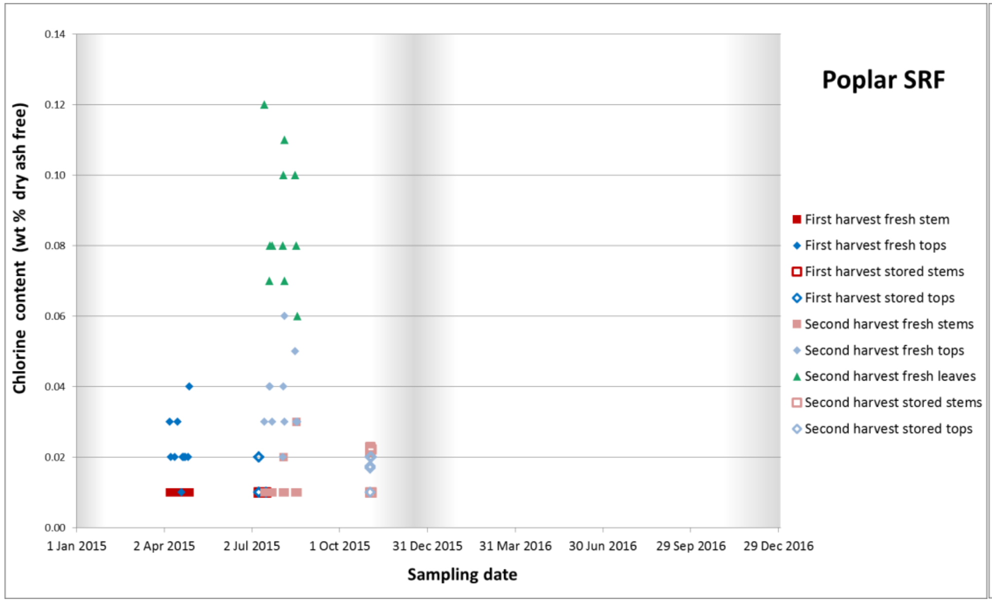

Poplar SRF
Sulphur content (wt % dry ash free)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves
Second harvest stored stems
Second harvest stored tops

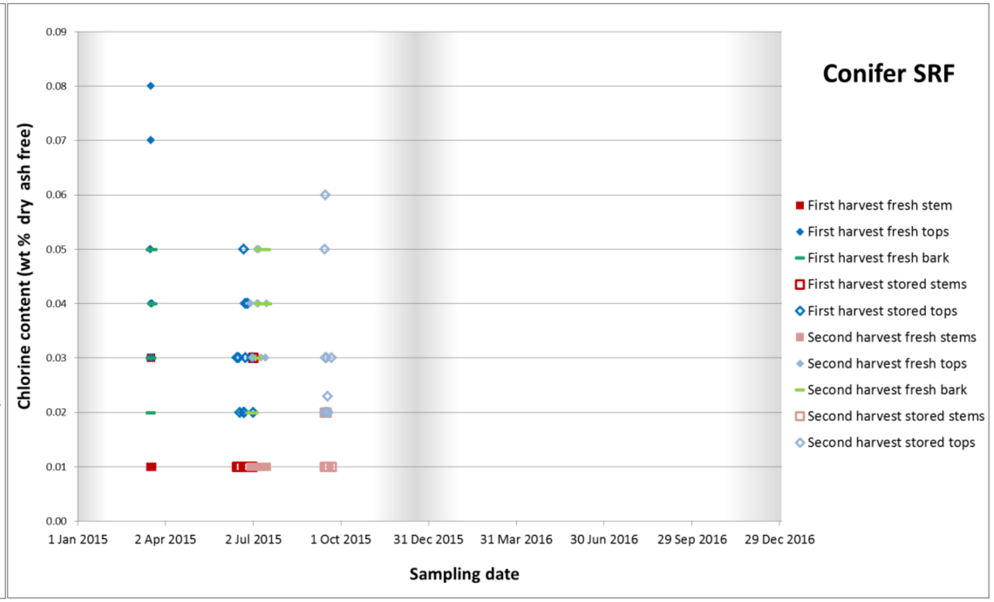

Conifer SRF
Sulphur content (wt % dry ash free)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark
Second harvest stored stems
Second harvest stored tops

CHLORINE CONTENT	In units of % wt in dry, ash-free fuel
General	Chlorine levels in the woody components were very low (often close to the limit of detection of 0.01) and broadly similar; leaves and tops of the broadleaved species, especially willow, were higher, ranging up to 0.18. With the exception of the leaves of willow and poplar, *Miscanthus* had the highest concentrations of 0.07 to 0.2 in the spring of both 2015 and 2016.
Source of variation	
Climate zone	*Miscanthus:* no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: no statistically significant effect of climate zone Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: no statistically significant effect of soil type Poplar SRF: no statistically significant effect of soil type Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* chlorine levels increased especially toward the beginning of the storage period although there was no effect of storage method Willow SRC: no discernible pattern over the limited period of outdoor uncovered storage Poplar SRF: stems were not affected by storage; although the absolute levels were very low, chlorine content of tops decreased when stored from spring and summer Conifer SRF: there was a slight reduction in chlorine levels in tops in storage (0.05 to 0.03).
Location within field	*Miscanthus* and willow SRC: for *Miscanthus* the in-field variation was less than the variation between fields – there were differences of 0.1 % within field which was similar to site-site and seasonal differences from winter through spring. The reverse was found for willow SRC where in-field variation was greater than variation between fields.
Plant part	Stem wood and stems < tops and bark < leaves
Season	*Miscanthus:* seasonal changes were evident in the second year – chlorine levels fell through autumn, winter and spring Willow SRC: no effect Poplar SRF: no difference in stem chlorine concentration but levels in tops increased between spring and summer Conifer SRF: no difference in stem wood or bark chlorine concentration but levels in tops decreased between spring and summer
Variety (willow SRC)	Varietal differences were not significant

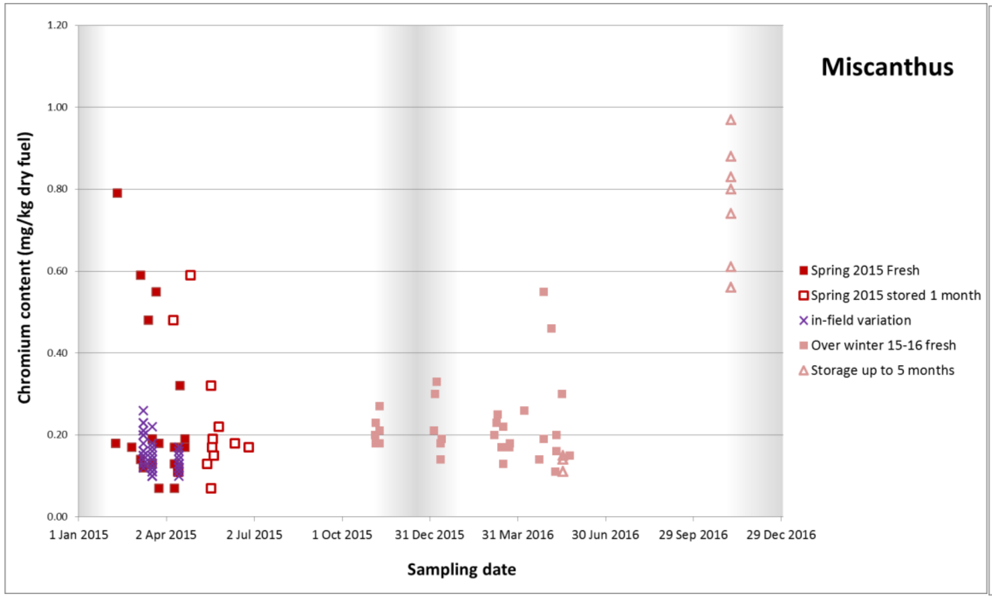

Miscanthus
Chlorine content (wt % dry ash free)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

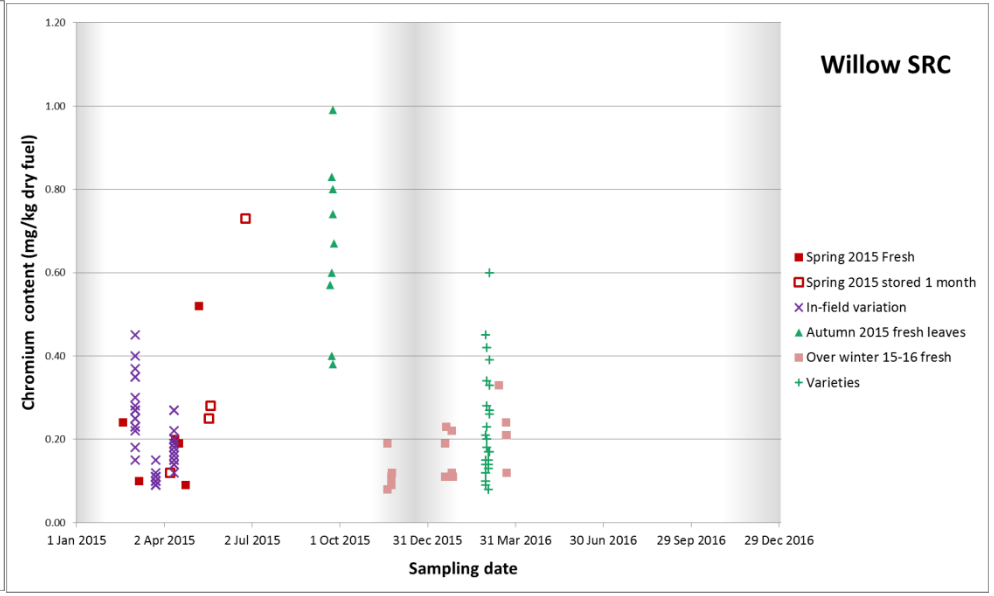

Willow SRC
Chlorine content (wt % dry ash free)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

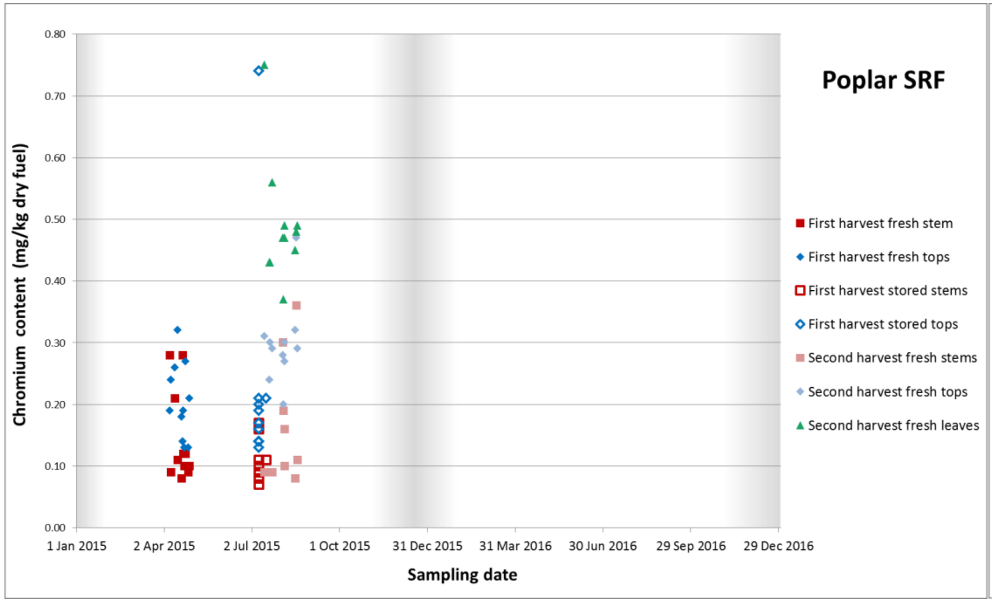

Poplar SRF
Chlorine content (wt % dry ash free)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves
Second harvest stored stems
Second harvest stored tops

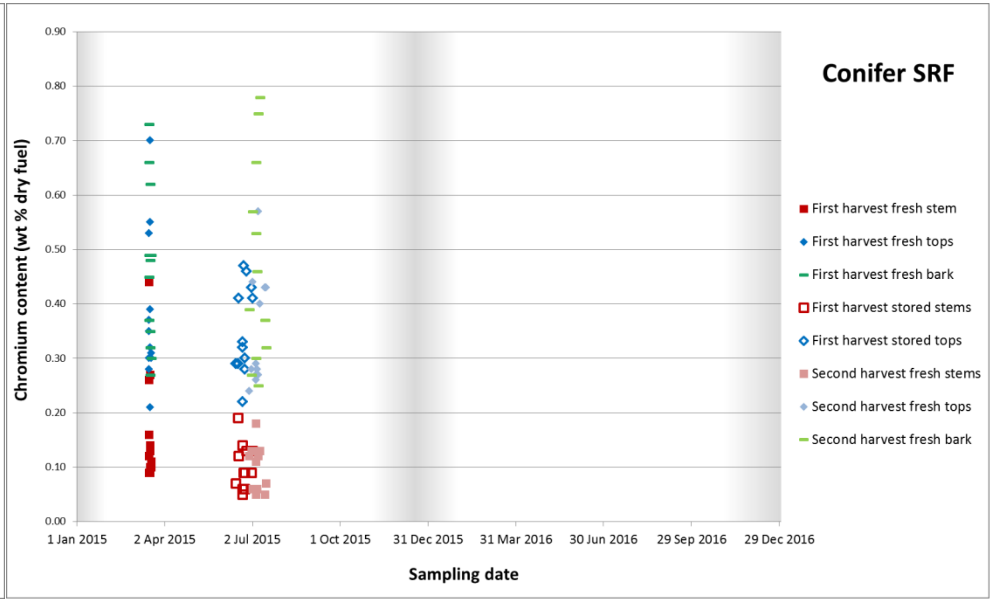

Conifer SRF
Chlorine content (wt % dry ash free)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark
Second harvest stored stems
Second harvest stored tops

CHROMIUM CONTENT	In units of mg/kg in dry fuel
General	Chromium levels were low (0.1 to 0.4) and broadly similar across feedstocks with the exception of leaves which ranged from 0.4 – 0.8
Source of variation	
Climate zone	*Miscanthus:* no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: no statistically significant effect of climate zone Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: samples from light soils showed lower levels of Cr than from medium soil (0.16 vs 0.28 mg/kg) and there was a significant two factor interaction with storage but neither are unlikely to have operation impact. Poplar SRF: no statistically significant effect of soil type Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* large increase associated with storage for 6 months but storage method was not statistically significant. Willow SRC:. Phase 1 samples stored for 1 month showed higher levels of Cr than fresh samples (0.22 vs 0.16), but the difference is unlikely to have operational impact. This was also significant under two factor analysis with soil type. Poplar SRF: levels in stems and tops stored in spring generally decreased during 3 months' storage Conifer SRF: levels in stem stored in spring generally decreased slightly during 3 months' storage (0.12 to 0.10), though unlikely to have an operational impact.
Location within field	*Miscanthus* levels varied little (range of 0.1) within the fields sampled nevertheless in-field variation was greater than variation between sites; in-field variation in willow SRC also exceeded variation between fields; in-field differences were greater (ca 0.2) and exceeded than the differences between sites and seasons
Plant part	Stems < tops and bark < leaves
Season	*Miscanthus:* no seasonal differences Willow SRC: increased concentration over winter and particularly in early spring Poplar SRF: no difference between spring and summer levels in stems or tops Conifer SRF: no difference between spring and summer levels in stem wood, bark or tops
Variety (willow SRC)	Varietal differences could not be statistically evaluated but seemed substantial

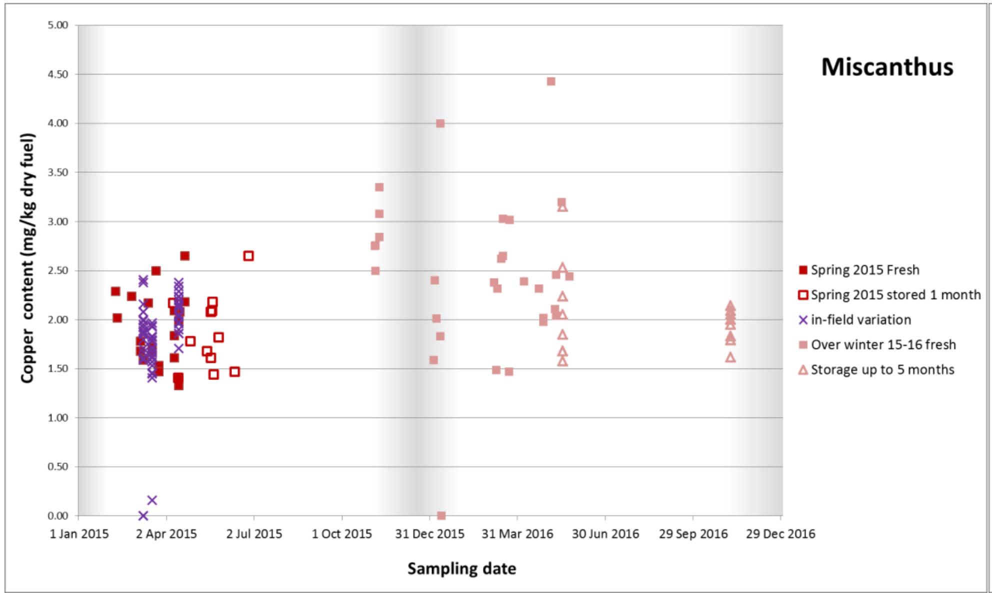

Miscanthus
Chromium content (mg/kg dry fuel)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

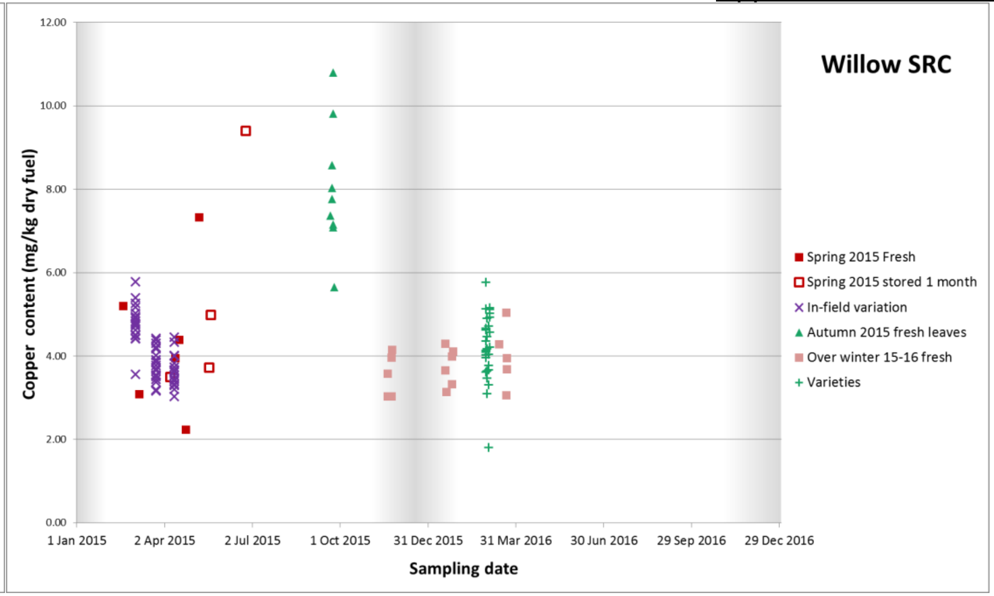

Willow SRC
Chromium content (mg/kg dry fuel)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

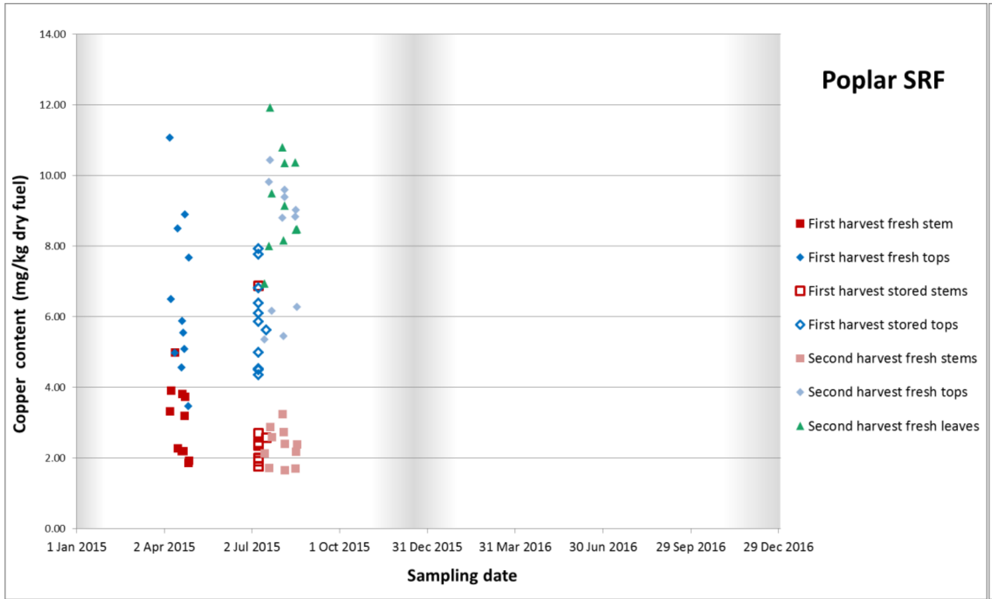

Poplar SRF
Chromium content (mg/kg dry fuel)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

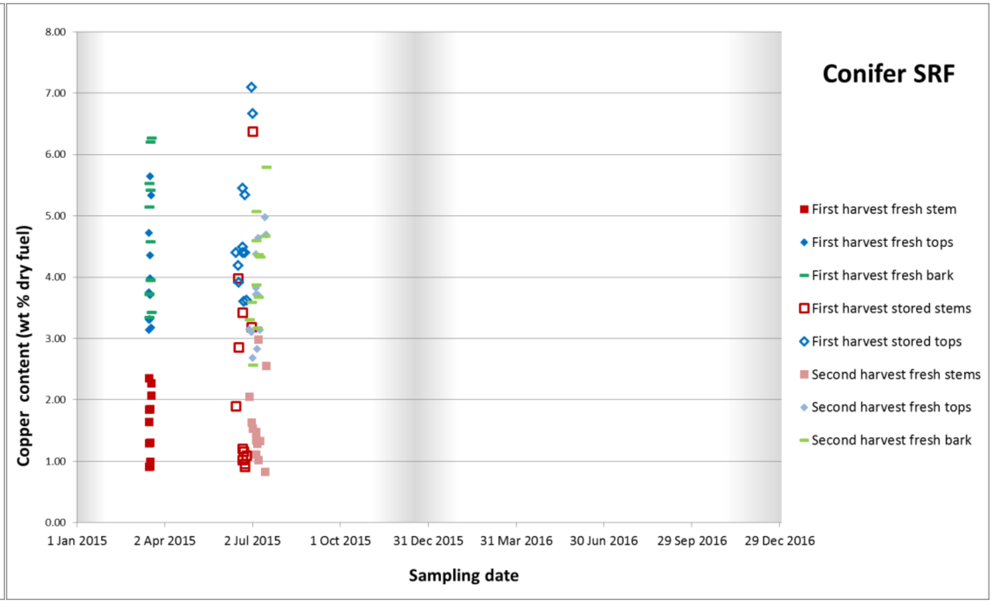

Conifer SRF
Chromium content (wt % dry fuel)
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

COPPER CONTENT	**In units of mg/kg in dry fuel**
General	Copper levels were low (0.1 - 0.4) and broadly similar but the leaves of willow SRC and poplar SRF had higher concentrations (0.4 – 0.8)
Source of variation	
Climate zone	*Miscanthus:* no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: no statistically significant effect of climate zone Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: copper levels in samples from light soils were lower than from medium soils (3.8 vs 4.9), but this is unlikely to have operational impact. This was also significant under two factor analysis with storage Poplar SRF: copper levels in stem samples from light soils were higher than from medium soils (3.0 vs 2.2), but this is unlikely to have an operational impact. Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* no statistically significant effect of storage or method Willow SRC: Phase 1 samples showed an increase in copper in storage (4.1 vs 3.8), but this is unlikely to have operational impact. This was also significant under two factor analysis with soil type. Poplar SRF: no statistically significant effect of storage Conifer SRF: copper in stem samples increased in storage from 1.5 to 2.3 , and in tops from 3.9 to 4.8, though fell in bark samples from 4.6 to 4.1, but none are likely to have operational impact.
Location within field	*Miscanthus* and willow SRC: for both feedstocks, in-field variation exceeded variation between fields; differences within fields were in the range of 1 – 2.
Plant part	Levels in stems < tops and conifer bark < leaves
Season	*Miscanthus:* there was no seasonal trend Willow SRC: there was no seasonal trend Poplar SRF: The copper level in the spring tops samples was lower than in the summer samples (6.2 vs 8.1), but this is unlikely to have operational impact Conifer SRF: the slight decreases in copper concentration in tops from spring to summer are unlikely to have an operational impact
Variety (willow SRC)	Varietal differences were significant - Tora had the lowest copper levels and Nimrod the highest

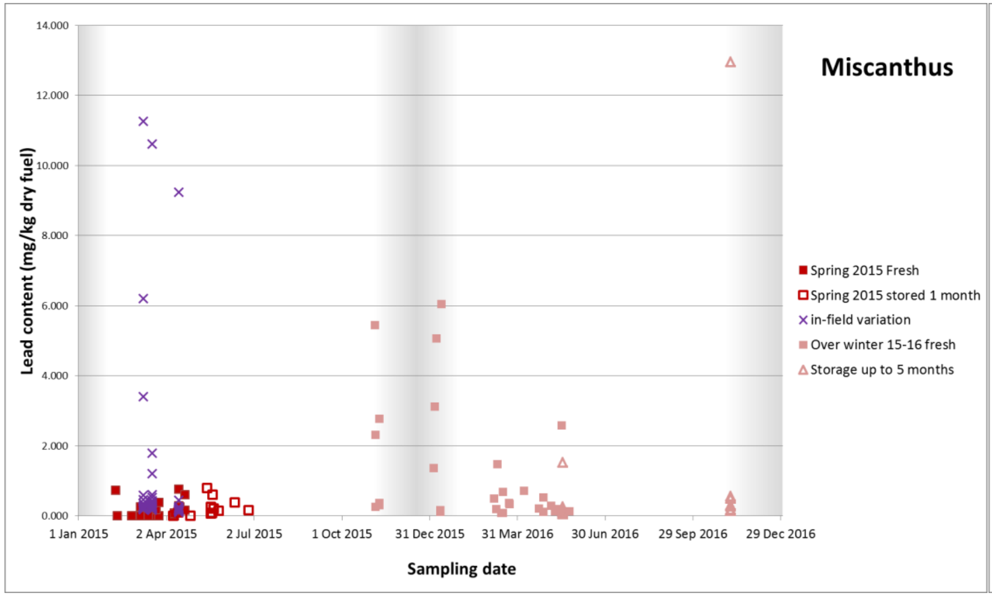

Miscanthus
Copper content (mg/kg dry fuel)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

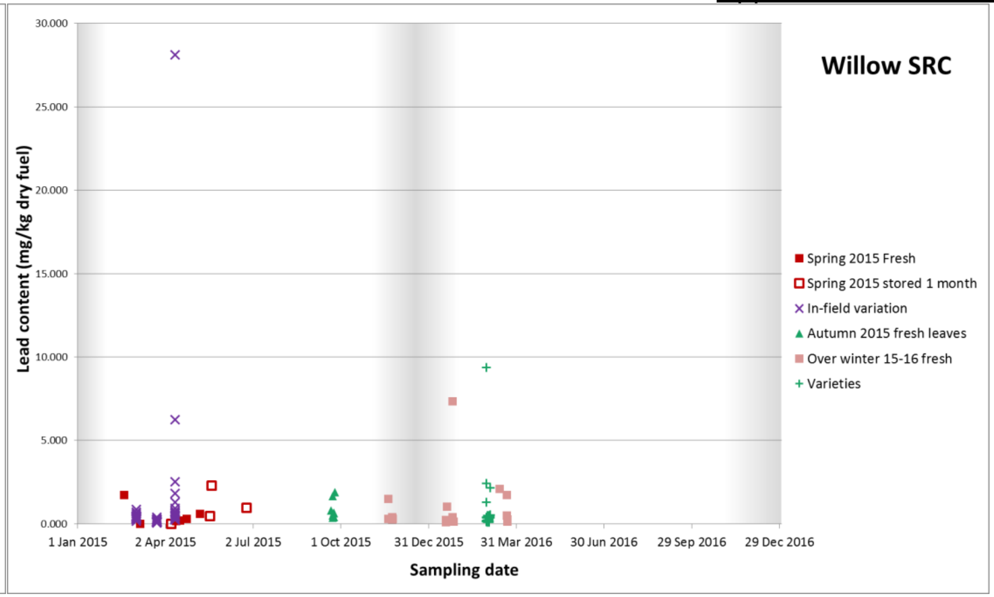

Willow SRC
Copper content (mg/kg dry fuel)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

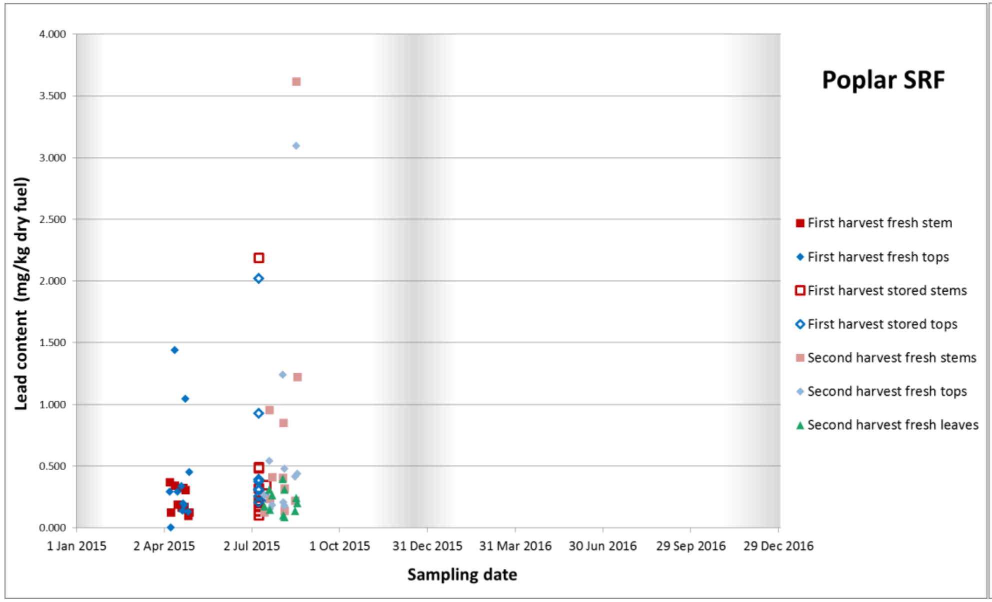

Poplar SRF
Copper content (mg/kg dry fuel)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

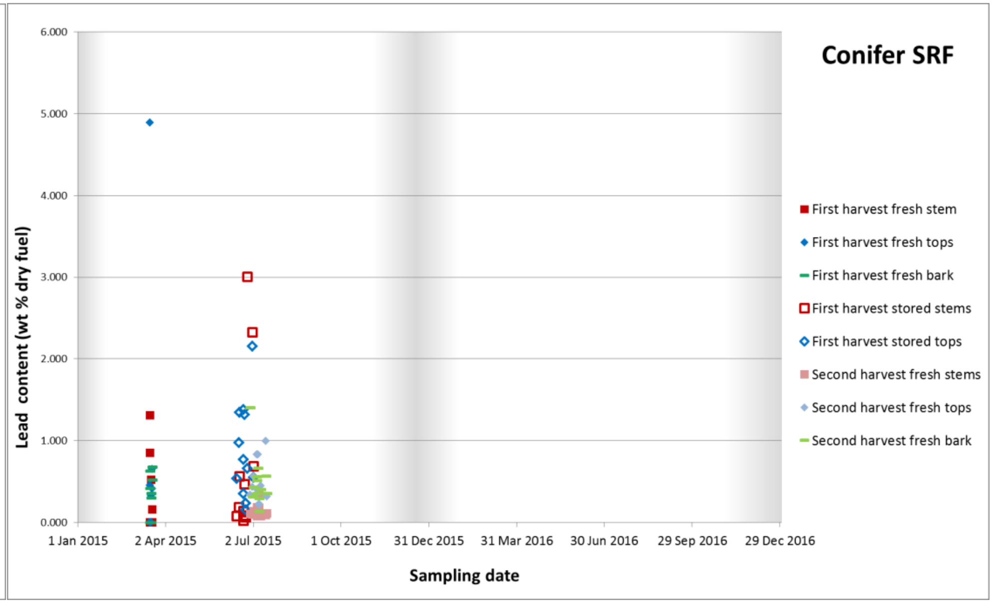

Conifer SRF
Copper content (wt % dry fuel)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

LEAD CONTENT	**In units of mg/kg in dry fuel**
General	Lead concentrations were generally below 1.0 for poplar SRF and conifer SRF with occasional values reaching 3.0 – 5.0. The general levels for willow SRC and *Miscanthus* were below 2.0 but both had occasional very high values.
Source of variation	
Climate zone	*Miscanthus:* no statistically significant effect of climate zone Willow SRC: no statistically significant effect of climate zone Poplar SRF: no statistically significant effect of climate zone Conifer SRF: no statistically significant effect of climate zone
Soil type	*Miscanthus:* no statistically significant effect of soil type Willow SRC: the lead content of leaves from light soils was significantly lower than that from medium soils (0.5 vs 1.4). Poplar SRF: no statistically significant effect of soil type Conifer SRF: no statistically significant effect of soil type
Storage	*Miscanthus:* no effect of storage or method Willow SRC: no statistically significant effect of storage Poplar SRF: no statistically significant effect of storage Conifer SRF: the lead content of tops increased during storage from 0.5 to 0.9.
Location within field	*Miscanthus* and willow SRC: for both feedstocks, there was much greater variability within than between sites
Plant part	Not a great difference between plant parts
Season	*Miscanthus:* no significant effect of harvesting time although values were generally lower in spring than autumn and winter Willow SRC: no significant effect of harvesting time Poplar SRF: no significant effect of harvesting time Conifer SRF: The lead content of tops samples taken in spring was higher than those taken in the summer (0.8 vs 0.5).
Variety (willow SRC)	Varietal differences were not significant

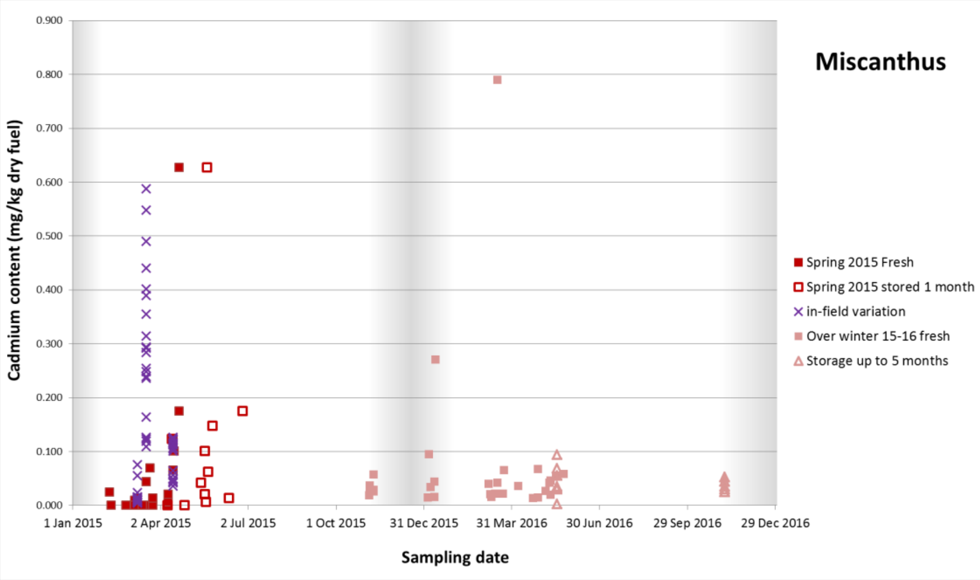

Miscanthus
Lead content (mg/kg dry fuel)
14.000
12.000
10.000
8.000
6.000
4.000
2.000
0.000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

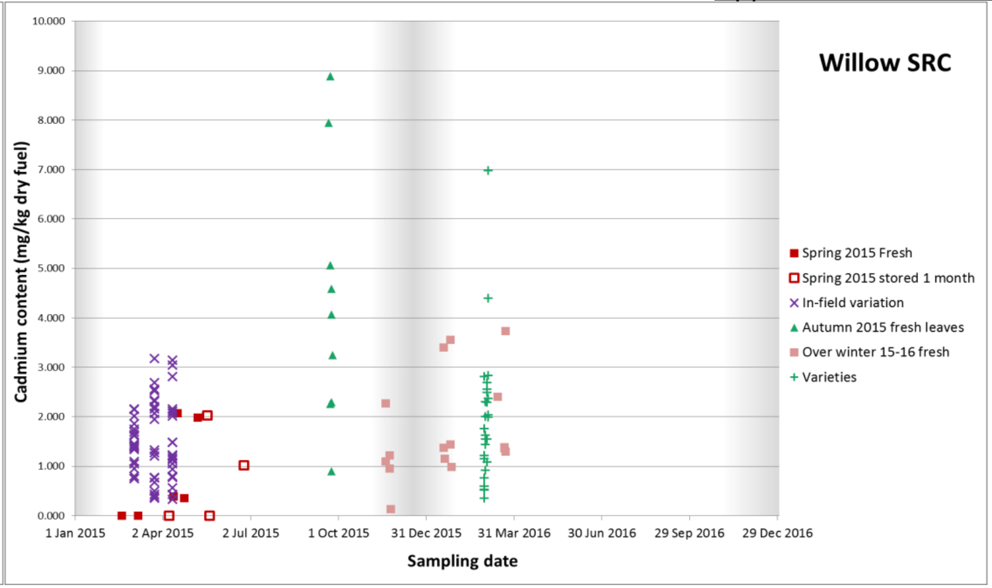

Willow SRC
Lead content (mg/kg dry fuel)
30.000
25.000
20.000
15.000
10.000
5.000
0.000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

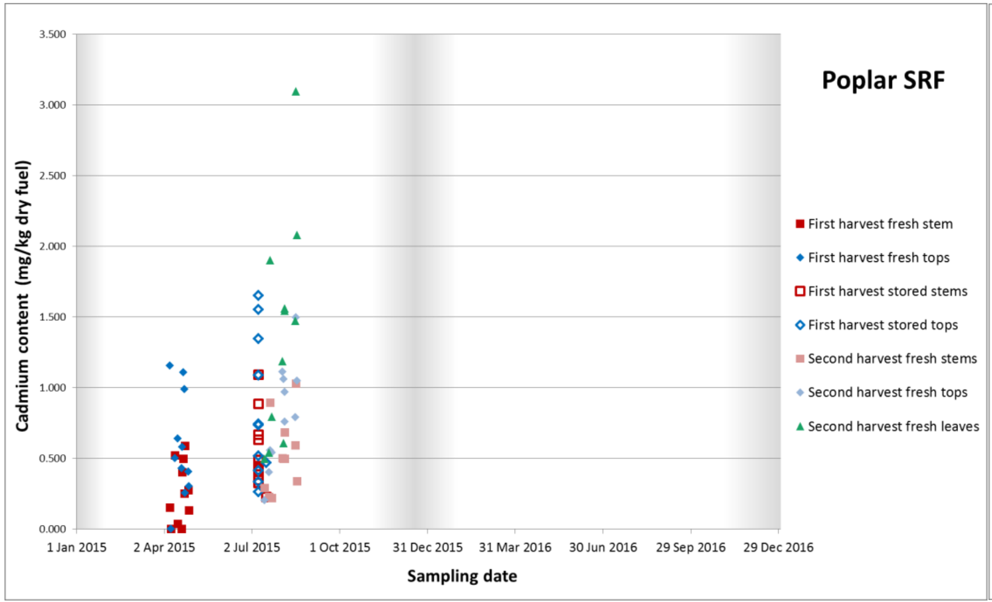

Poplar SRF
Lead content (mg/kg dry fuel)
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

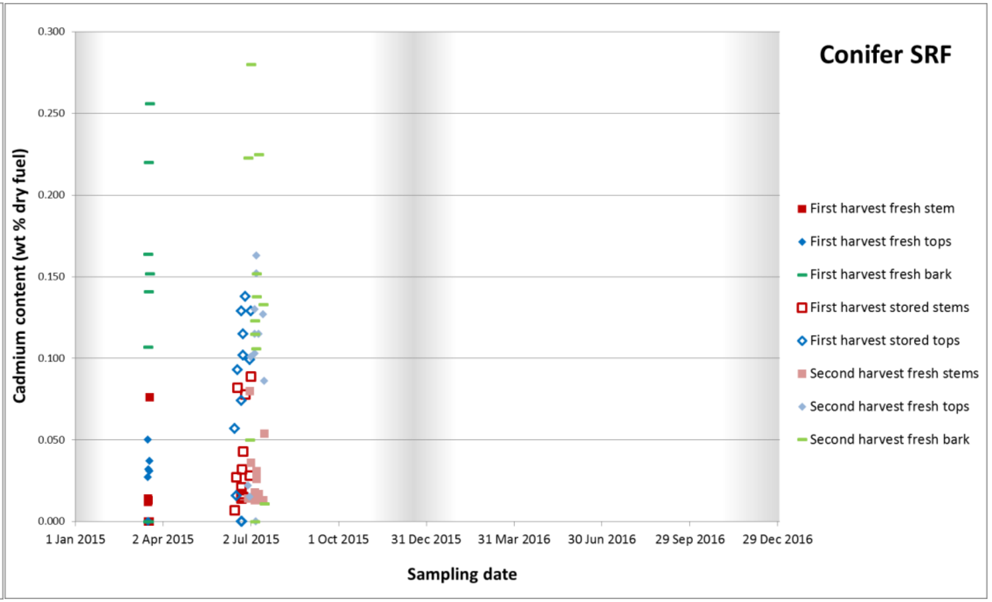

Conifer SRF
Lead content (wt % dry fuel)
6.000
5.000
4.000
3.000
2.000
1.000
0.000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

CADMIUM CONTENT	In units of mg/kg in dry fuel
General	Major species differences with willow SRC > poplar SRF > conifer SRF > *Miscanthus.* There were also differences between plant parts.
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: no significant effect of climate zone Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: in leaves levels were higher for sites with medium soils (6.7) than sites with light soils (3.2) Poplar SRF: there was an interaction with storage (see storage row) Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* no significant effect of storage or method Willow SRC: no significant effect of storage Poplar SRF: there was an increase in stem levels after storage but this was much greater at sites with medium soils than light soils. Concentrations in stems after storage on medium soils were 0.6 whereas the other mean values were all < 0.5. Conifer SRF: no significant effect of storage
Location within field	*Miscanthus*: variation between fields was greater than within fields. Willow SRC: variation within fields was greater than between fields.
Plant part	In willow SRC leaves > stems; in poplar SRF leaves > tops > stems; in conifer SRF bark > tops > stem wood
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: no significant effect of harvesting time Conifer SRF: no significant effect of harvesting time
Variety (willow SRC)	Varietal differences were not significant

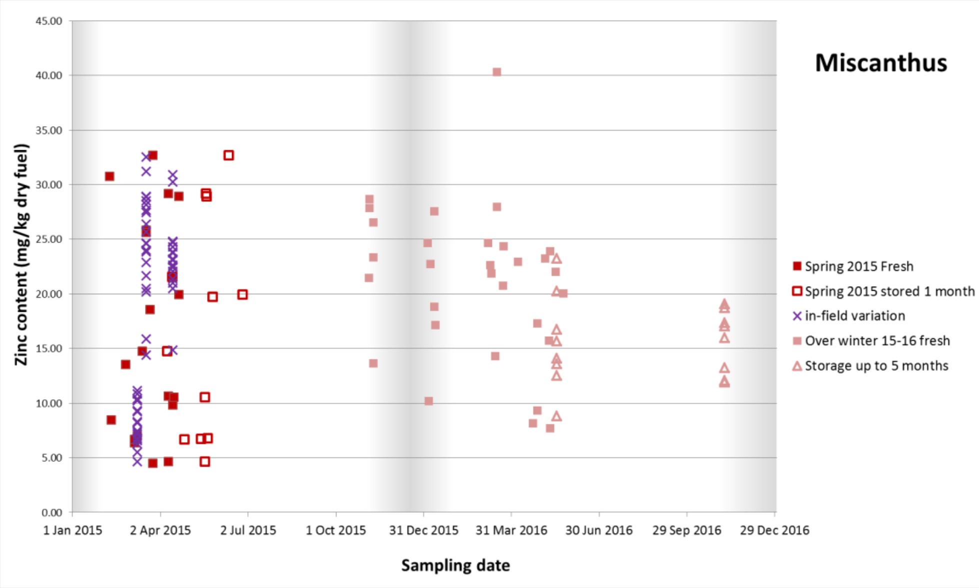

Miscanthus
Cadmium content (mg/kg dry fuel)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016

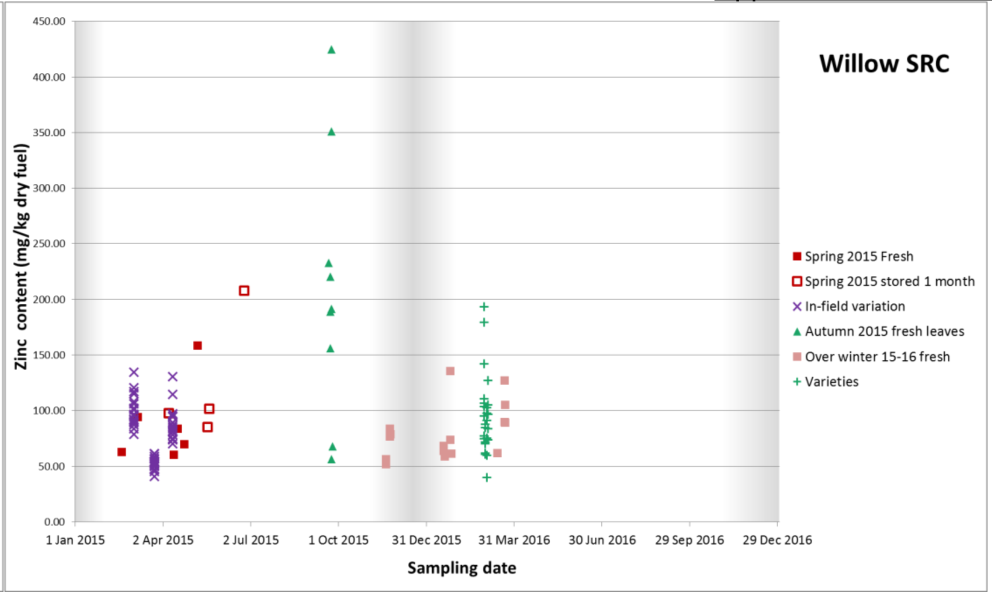

Willow SRC
Cadmium content (mg/kg dry fuel)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

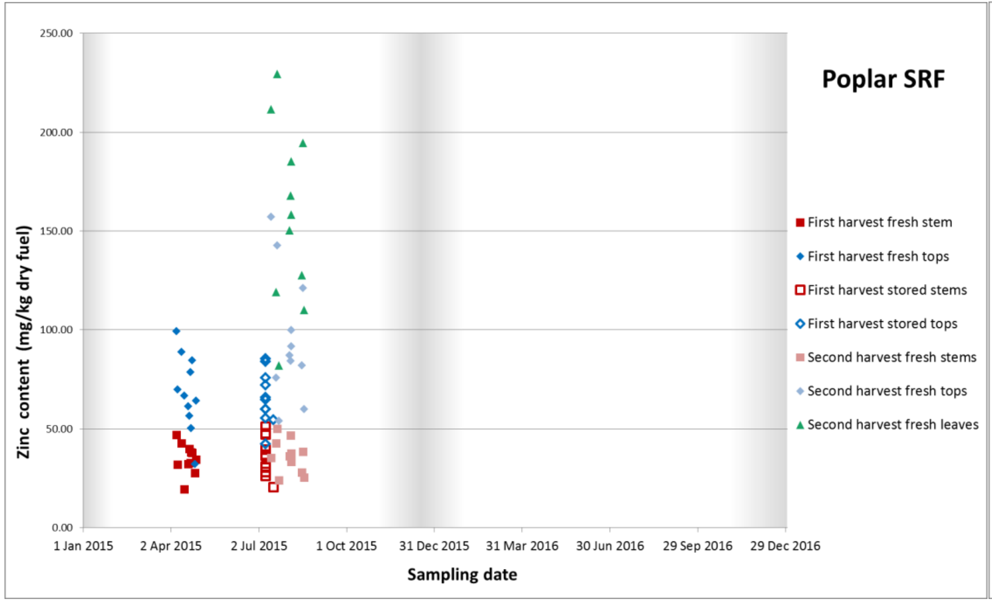

Poplar SRF
Cadmium content (mg/kg dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

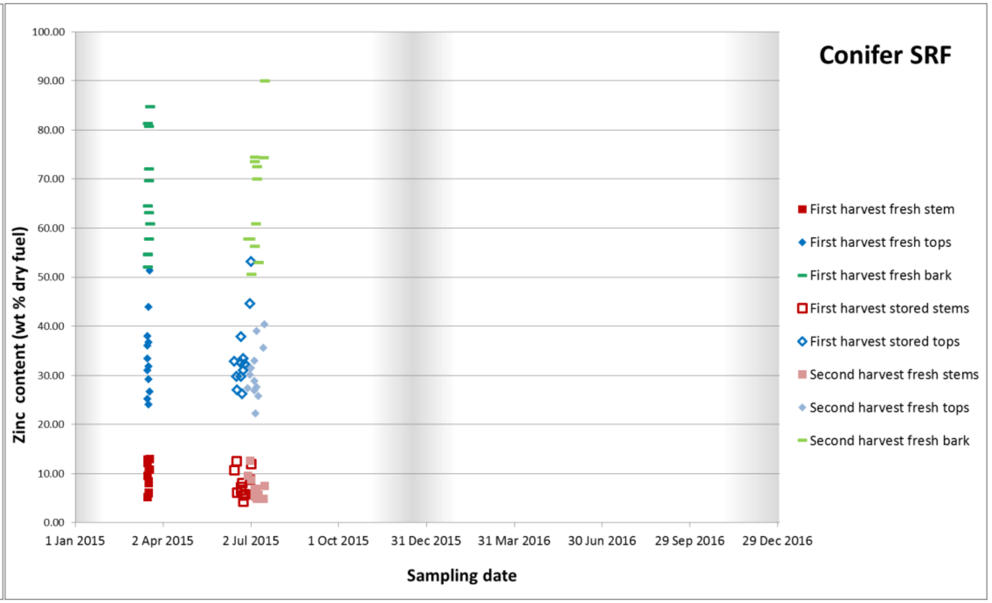

Conifer SRF
Cadmium content (wt % dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

ZINC CONTENT	In units of mg/kg in dry fuel
General	There were clear differences between feedstocks and plant parts. Both *Miscanthus* and conifer SRF were low: *Miscanthus* ranged from 5-30, conifer stem wood was also low (5 – 15) but the tops and bark were considerably higher, reaching 80. Poplar stems ranged from 20-50 but the tops and especially the leaves had higher concentrations (up to ca 250) while willow SRC stems ranged from 50-150 with leaves higher again reaching up to 250 or even 400.
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: no significant effect of climate zone Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: zinc in samples from light soils was lower than from medium soils (79 vs 97), but this is unlikely to have operational impact. This was also significant under two factor analysis with storage Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* changes during 6-months' storage depended on the method with levels increasing when bales were stored in barns but decreasing slightly when stored outside. Willow SRC: Phase 1 samples showed an increase in zinc in storage (95 vs 79) and there was significant under two factor analysis with soil type but neither is unlikely to have operational impact. Poplar SRF: no significant effect of storage Conifer SRF: the level of zin in stem samples fell in storage from 8.2 to 7.8, though this is unlikely to have an operational impact.
Location within field	*Miscanthus* and willow SRC: for *Miscanthus* the variation within fields was less than the differences among fields and for willow SRC in-field variation was greater than differences among fields.
Plant part	Stems < tops < bark < leaves
Season	*Miscanthus:* there was a significant seasonal trend with levels decreasing through autumn, winter and spring Willow SRC: no significant effect of harvesting time Poplar SRF: the zinc level in the spring tops samples was lower than in the summer samples (67 vs 96) which was large enough to be worthy of further study Conifer SRF: the zinc level in the spring stem wood and tops samples were higher than the summer samples (9 vs 7 for stem; 34 vs 31 for tops), though neither is likely to have operational impact.
Variety (willow SRC)	Varietal differences were not significant

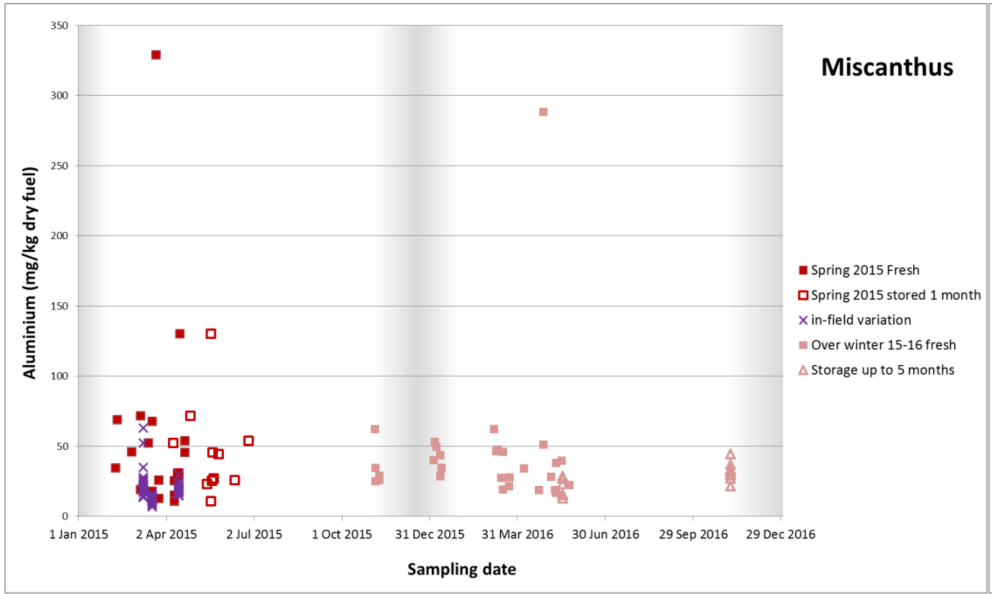

Miscanthus
Zinc content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

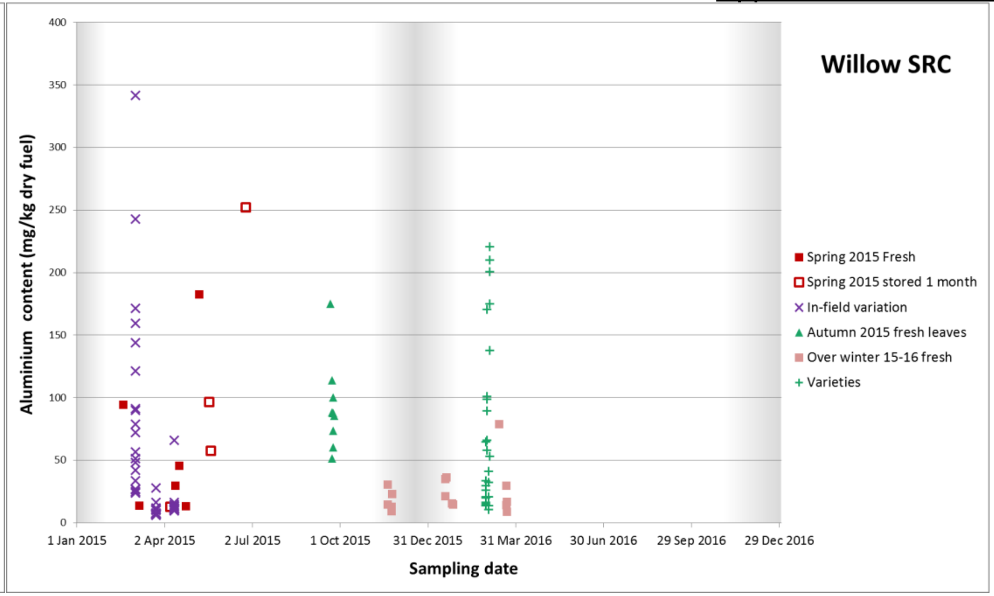

Willow SRC
Zinc content (mg/kg dry fuel)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

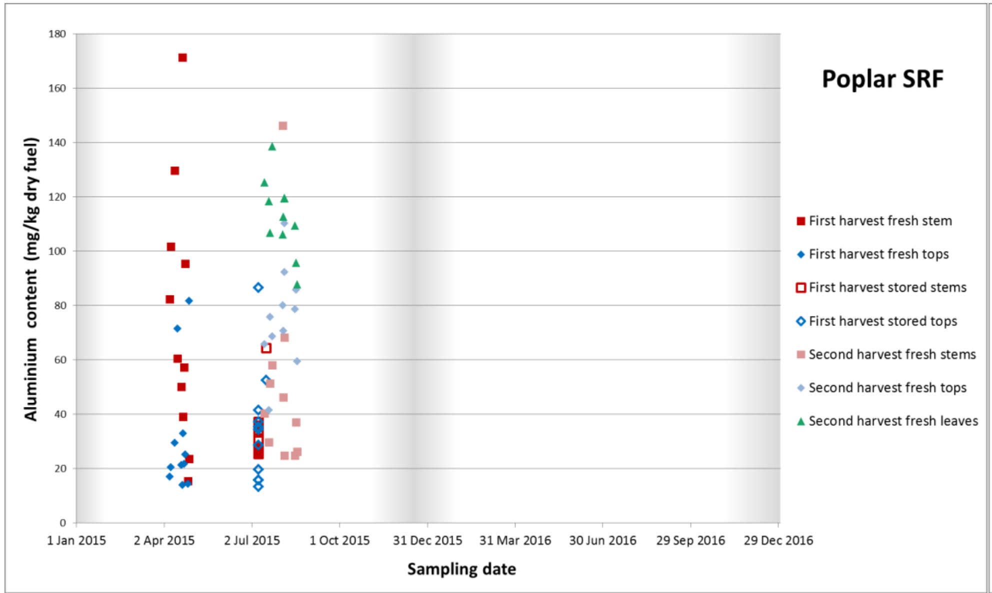

Poplar SRF
Zinc content (mg/kg dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

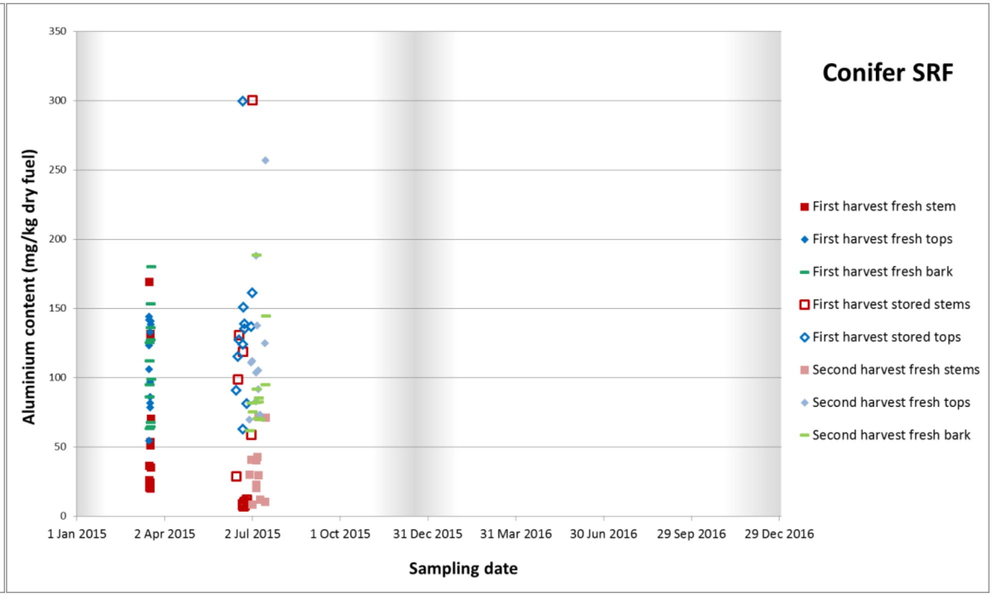

Conifer SRF
Zinc content (wt % dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

ALUMINIUM CONTENT	In units of mg/kg in dry fuel
General	For *Miscanthus,* willow SRC and conifer SRF aluminium levels were in the range 10 – 350 whereas levels in poplar SRF ranged from 10-170..
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: the level of aluminium in tops from the warm/dry climate zone was lower than from the warm/moist (41 vs 63), though this is unlikely to have operational impact. However the interaction between climate zone and soil type (levels of tops in warm/moist climate zones and medium soils were twice the levels in the other climate zone/soil type combinations) is worth further study. Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: leaf samples from light soils showed significantly lower levels of aluminium than from medium soils (76 vs 125), but this is also unlikely to have operational impact. Poplar SRF: the interaction between climate zone and soil type (levels of tops in warm/moist climate zones and medium soils were twice the levels in the other climate zone/soil type combinations) is worth further study. Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* concentrations increased with storage but there was no significant effect of the storage method. Willow SRC: phase 1 samples showed a significant increase in aluminium content following one month's storage (105 vs 63) but this is unlikely to have operational impact Poplar SRF: the aluminium content in stem samples fell during storage from 63 to 33 which is relevant for further study. Conifer SRF: only tops showed a difference in aluminium content in storage, with a slight increase from 116 to 135, though this is unlikely to have operational impact.
Location within field	*Miscanthus* and willow SRC: in-field variation was similar to between field variation for both
Plant part	The woodier plant parts were generally lower but the range overlapped with that of leaves so no distinct differences. Bark and stems of conifer SRF had similar levels of lead.
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: the level of aluminium in the spring tops samples was lower than in the summer samples (33 vs 75), though this is unlikely to have operational impact. Conifer SRF: no significant effect of harvesting time
Variety (willow SRC)	Varietal differences were not significant even though one field had values ranging from approx. 20 – 350.


Miscanthus
Aluminium (mg/kg dry fuel)
0
50
100
150
200
250
300
350
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

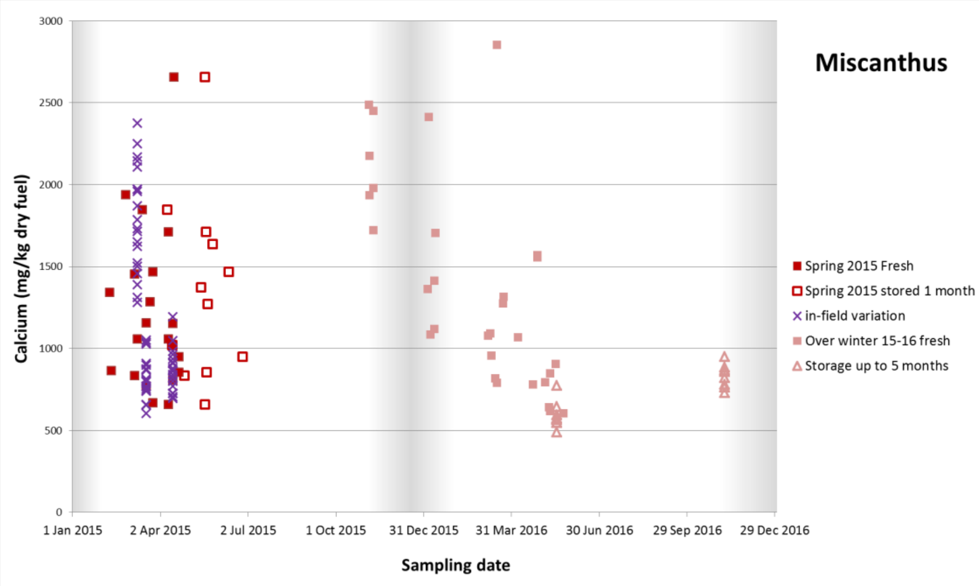

Willow SRC
Aluminium content (mg/kg dry fuel)
0
50
100
150
200
250
300
350
400
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

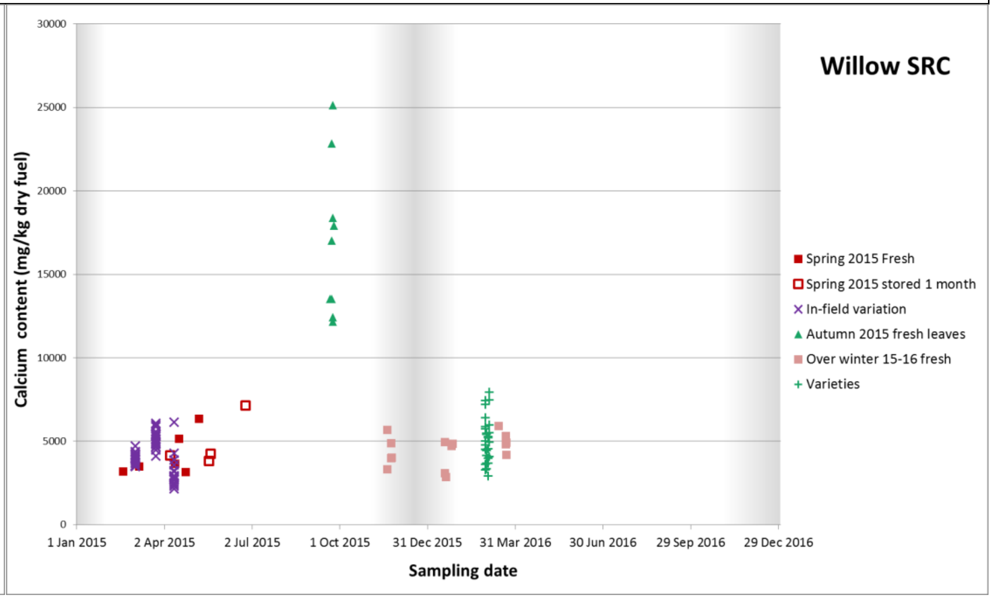

Poplar SRF
Aluminium content (mg/kg dry fuel)
0
20
40
60
80
100
120
140
160
180
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

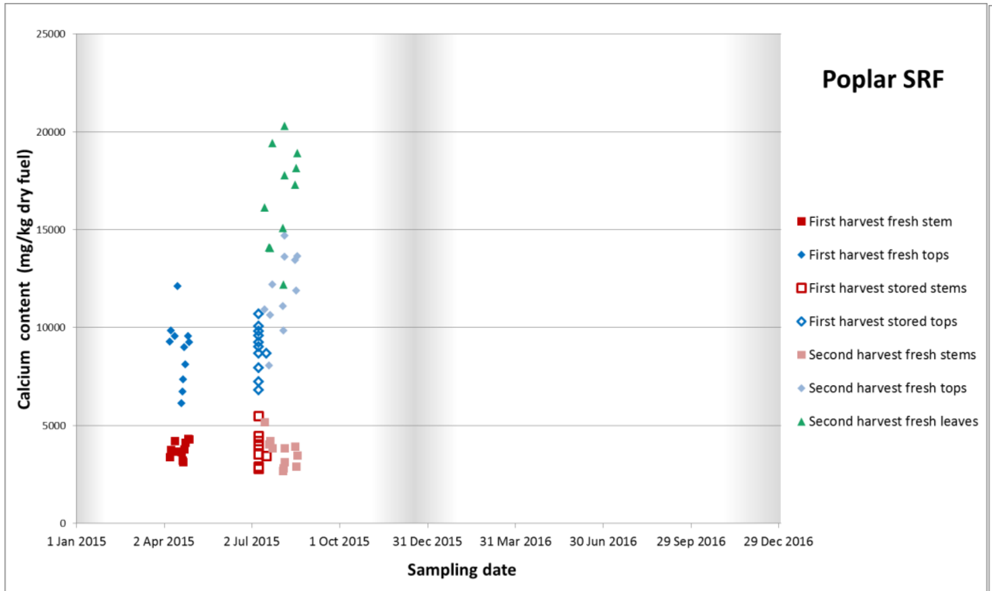

Conifer SRF
Aluminium content (mg/kg dry fuel)
0
50
100
150
200
250
300
350
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

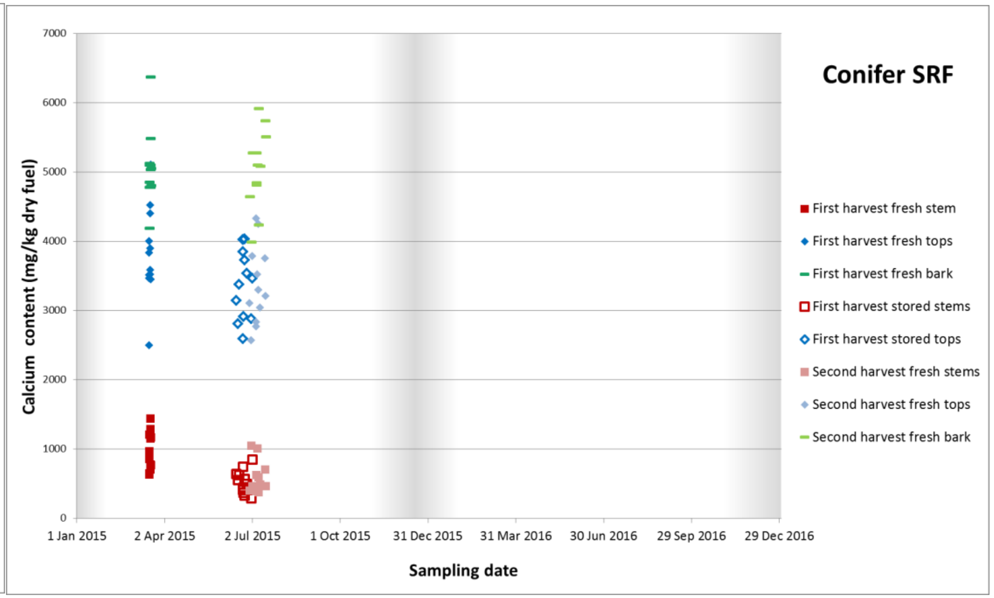
CALCIUM CONTENT	**In units of mg/kg in dry fuel**
General	There were major differences in calcium concentrations between feedstocks and plant parts. *Miscanthus* was generally the lowest with values ranging from 500 – 2,500. The stems of willow SRC ranged from 2,500 – 7,000 with even higher values in the leaves (12,000 to 25,000). The same pattern was evident in the SRF: poplar stems were 3,000 – 4,000 but the tops had values up to 15,000. Conifer stem wood had the lowest calcium levels (200 – 1,500) but the bark and tops had values up to 6,000.
Source of variation	
Climate zone	*Miscanthus:* levels of calcium in samples from warm/dry climate zone appeared lower than from warm moist climate zone (1096 vs 1304) and there was an interaction with storage but neither is likely to have operational impact. Willow SRC: no significant effect of climate zone Poplar SRF: no significant effect of climate zone Conifer SRF: calcium levels in bark samples from cold/wet climate zone were lower than from warm wet climate zones (4833 vs 5266) though this is unlikely to have operational impact.
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* In Phase 1 samples levels of calcium rose slightly from the level at harvest (1096) to the level at baling (1169), but this was not significant and is unlikely to have operational impact. However there was a significant two factor interaction with climate zone. In Phase 2, 6-month storage significantly increased calcium levels with the type of storage having an important influence (samples stored outdoors covered had the greatest increase) Willow SRC: no significant effect of storage Poplar SRF: no significant effect of storage Conifer SRF: calcium levels in both stem wood and tops samples fell in storage from 777 to 528 for stem wood and from 3594 to 3362 in tops.
Location within field	*Miscanthus* and willow SRC: for both the in-field variation was less than the variation between fields even though there was often a two-fold difference within a single field.
Plant part	Conifer stem wood < *Miscanthus* < poplar stems < conifer tops < conifer bark < poplar stems < leaves
Season	*Miscanthus:* there was a very clear decline in calcium through autumn and early spring Willow SRC: no significant effect of harvesting time Poplar SRF: the level of calcium in the spring tops samples was lower than in the summer samples (8,849 vs 11,817), though this is unlikely to have operational impact. Conifer SRF: calcium in spring stem samples was higher than in summer (748 vs 586).

Variety (willow SRC)	Varietal differences were significant with Resolution having consistently low calcium levels followed by Sven

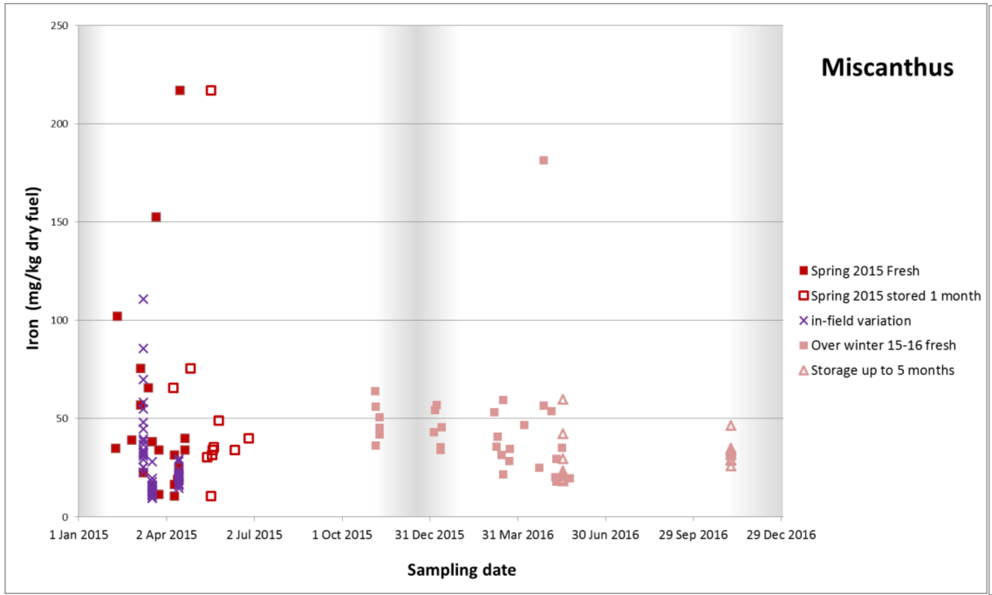


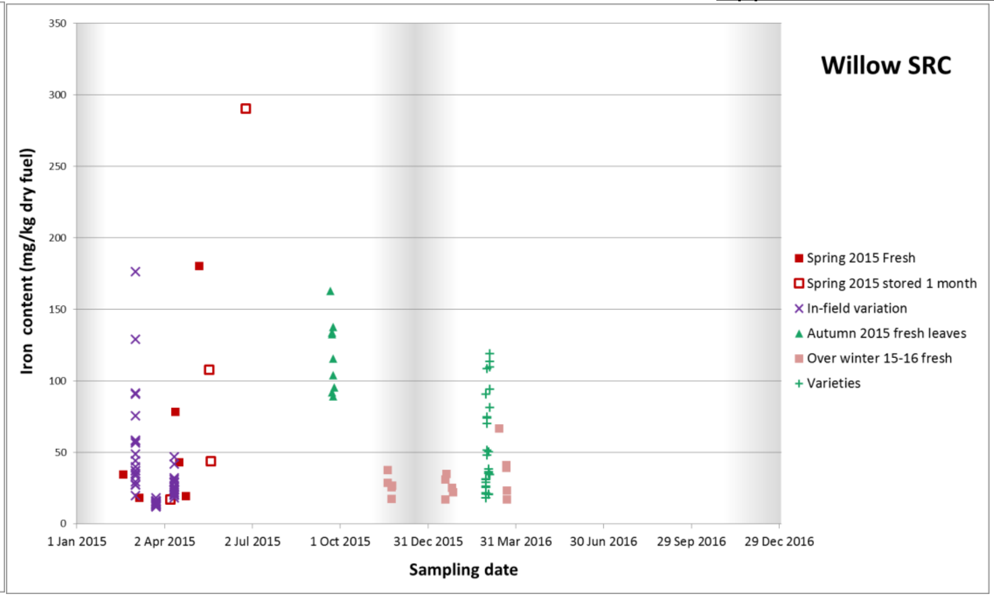


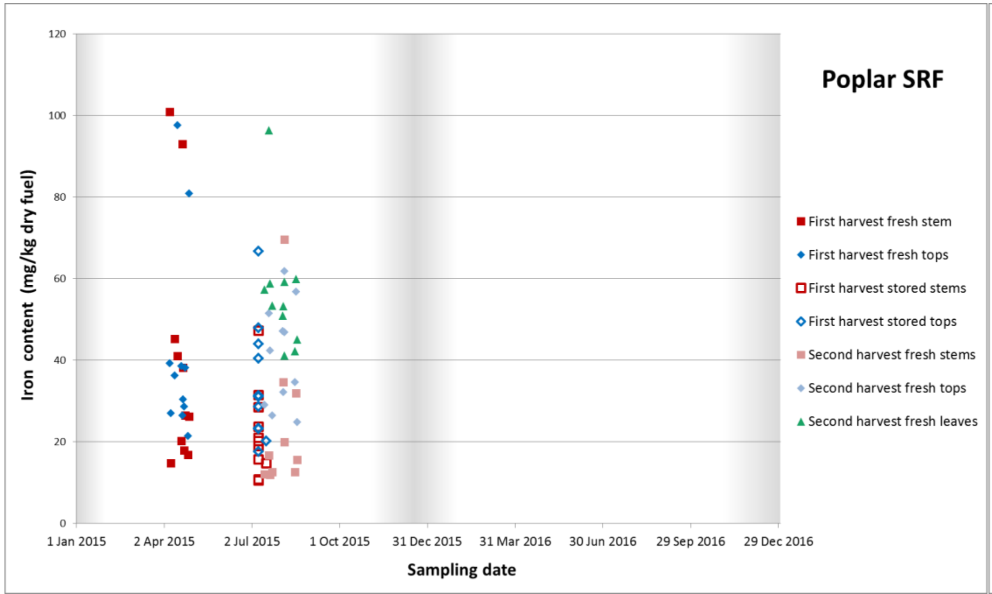


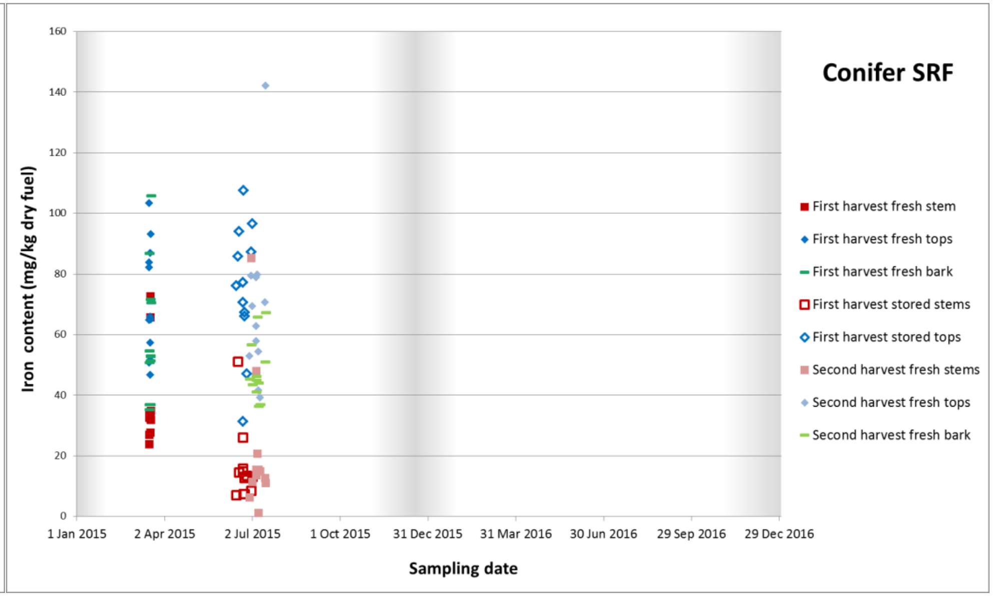


IRON CONTENT	In units of mg/kg in dry fuel
General	Values were generally in the range 10 – 50 though there were individual values up to 100 and even 300. For both *Miscanthus* and willow SRC the values were less variable in Phase 2 than Phase 1.
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: there was an interaction between climate zone and soil type with much higher iron on medium soils in warm moist climate zones 70) than the other combinations of soil type and climate zone which were all < 39. Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: there was an interaction between storage and soil type with stored samples on medium soils having almost four times greater iron levels than the other combinations of storage and soil type but this is unlikely to have operational impact. Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* no significant effect of storage or method Willow SRC: no significant effect of storage Poplar SRF: no significant effect of storage Conifer SRF: the level of iron in stem wood fell in storage from 44 to 16.
Location within field	*Miscanthus* and willow SRC: in-field variation was much greater than variation between fields (e.g. for willow SRC one field ranged from 15 – 20 but another ranged from 20 – 175)
Plant part	Within each of the feedstocks the woodier parts had lower iron concentrations. In willow SRF stems < leaves; in poplar SRF stems < tops < leaves; conifer SRF stem wood < bark and tops.
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: no significant effect of harvesting time Conifer SRF: the level of iron in spring samples of bark was slightly higher than summer samples though this is unlikely to have operational impact.
Variety (willow SRC)	Varietal differences were not significant although the range across the sites and varieties was comparatively large.

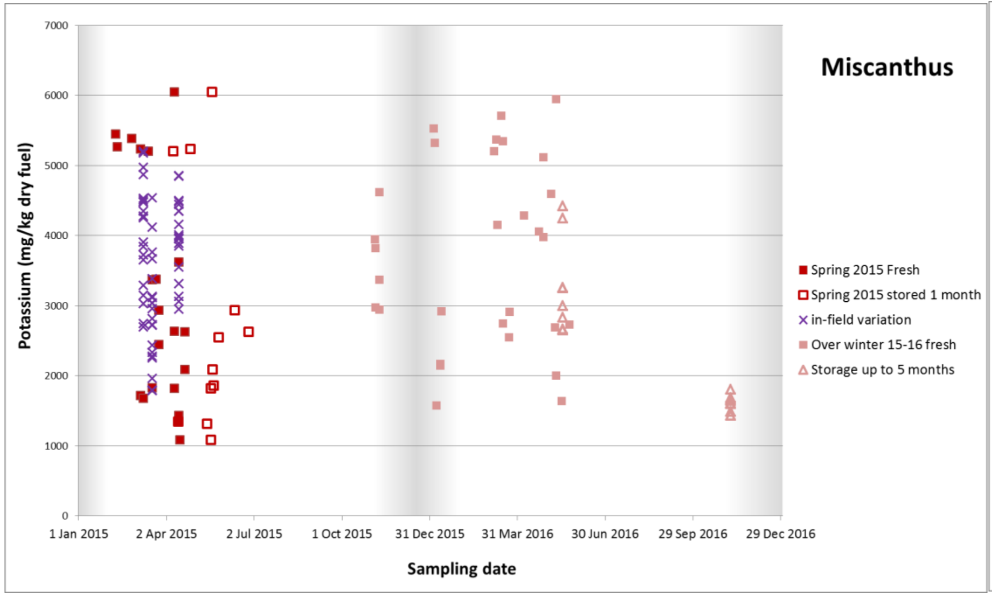

Miscanthus
Iron (mg/kg dry fuel)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016

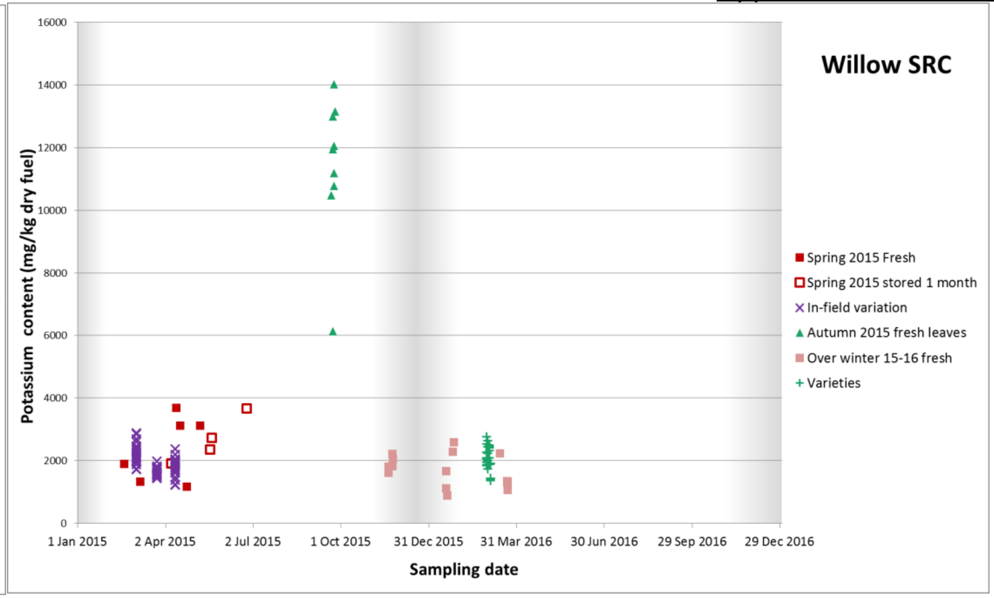

Willow SRC
Iron content (mg/kg dry fuel)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

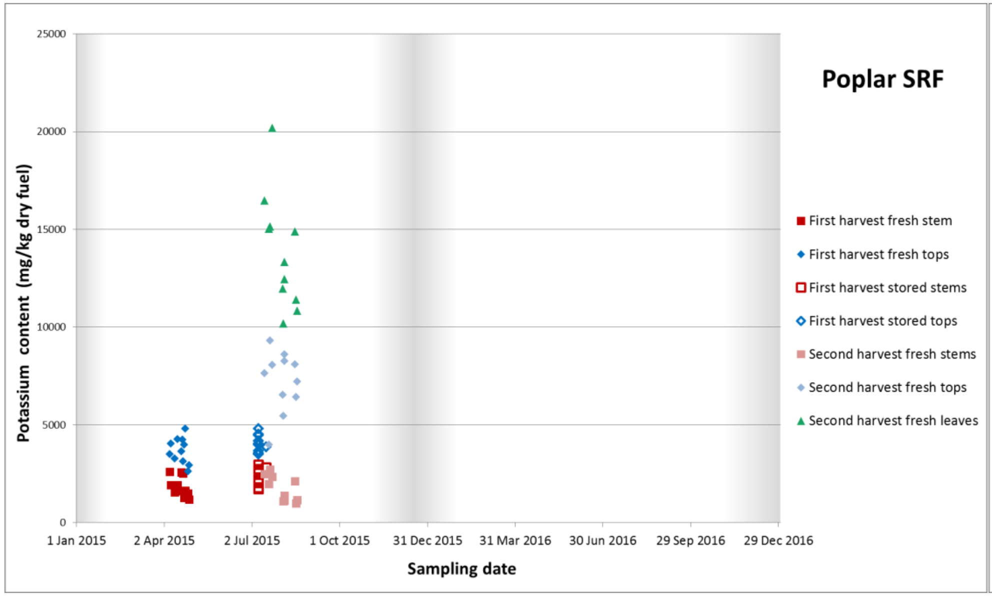

Poplar SRF
Iron content (mg/kg dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

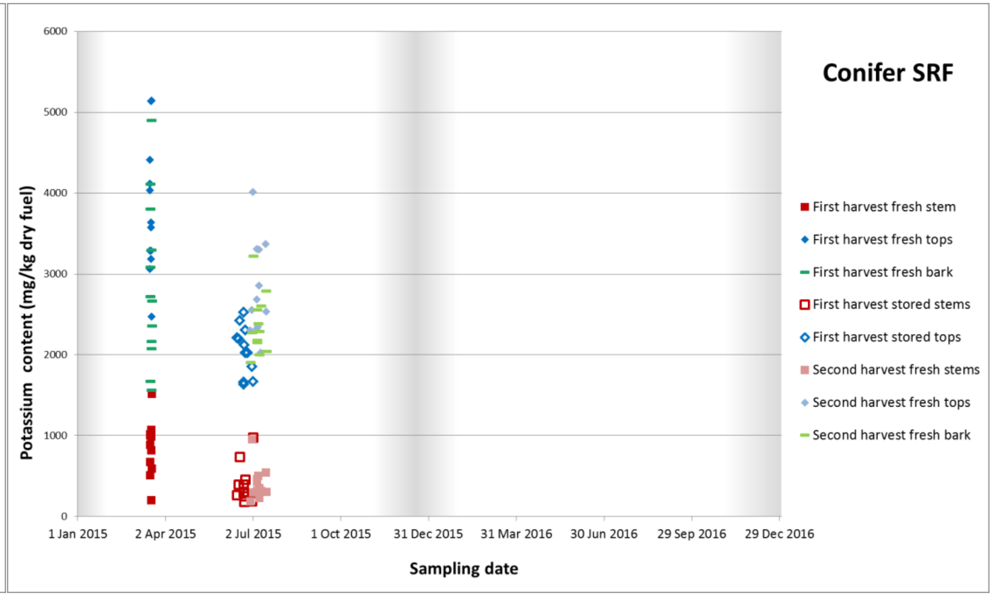

Conifer SRF
Iron content (mg/kg dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

POTASSIUM CONTENT	In units of mg/kg in dry fuel
General	Across the four feedstocks, levels were generally less than 5,000 but the leaves of willow SRC and poplar SRF as well as the tops of poplar SRF were much higher (up to 15,000). Conifer stem wood had overall the lowest potassium levels.
Source of variation	
Climate zone	*Miscanthus:* the warm/dry climate zone showed significantly higher potassium compared to warm/moist (3162 vs 1481) Willow SRC: no significant effect of climate zone Poplar SRF: for stems there was an interaction between climate zone and harvest time with the levels being especially low in samples harvested in summer in warm/moist climate zones (1189 cf 1848 – 2093) for the spring harvest and warm/dry soil type combinations. Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* large drop during long term storage but not influenced by storage method Willow SRC: no significant effect of storage Poplar SRF: the level of potassium in stored stem samples increased significantly from 1747 to 2360 Conifer SRF: the level of potassium in stem and tops samples fell in storage: from 635 to 391 for stems; 3288 to 2053 for tops.
Location within field	*Miscanthus* and willow SRC: for both the in-field variation was similar to the variation between fields
Plant part	Within each of the feedstocks the woodier parts had lower potassium concentrations. In willow SRF stems < leaves; in poplar SRF stems < tops < leaves; conifer SRF stem wood < bark and tops.
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: the level of potassium in the spring tops samples was significantly lower than in the summer samples (3831 vs 7226). Conifer SRF: the level of potassium in the spring stem samples was significantly higher than the summer samples (626 vs 408).
Variety (willow SRC)	Varietal differences were not significant.

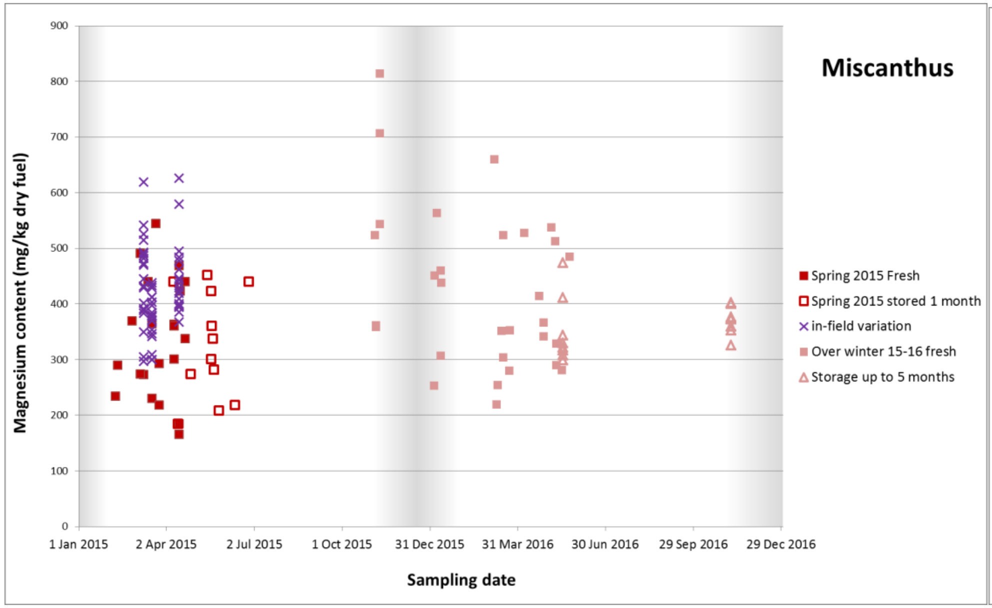

Miscanthus
Potassium (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

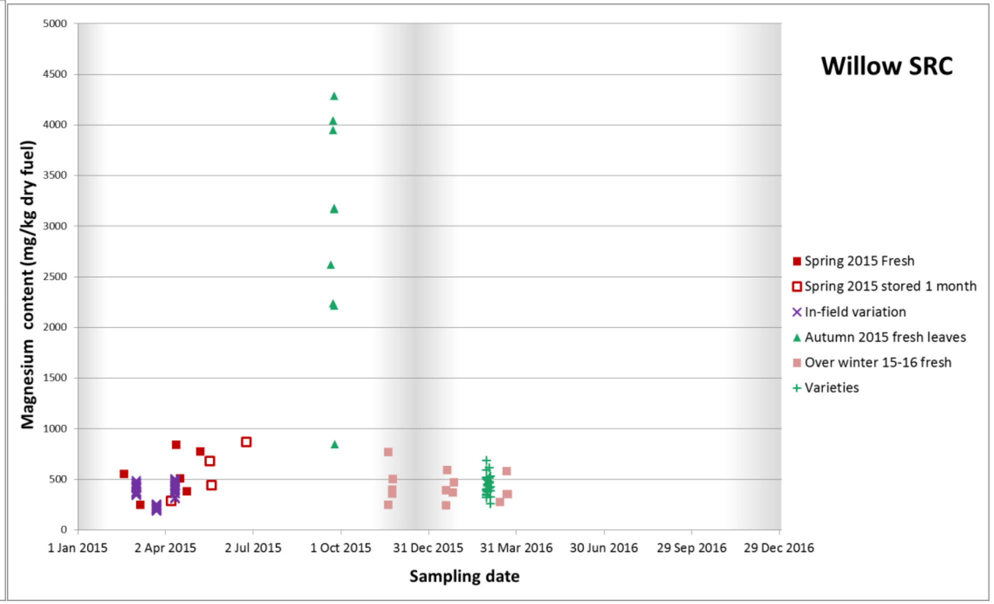

Willow SRC
Potassium content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

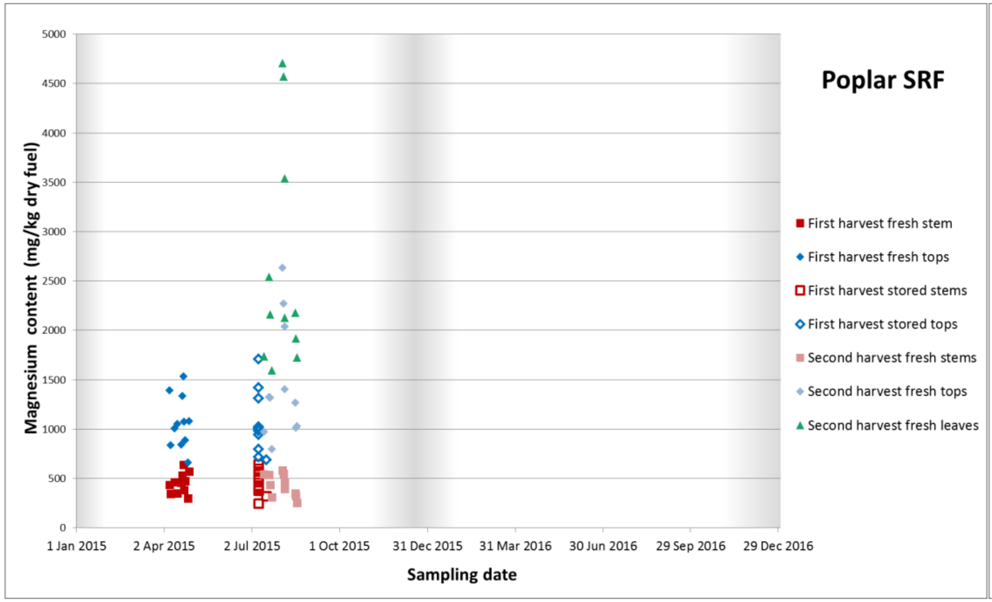

Poplar SRF
Potassium content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

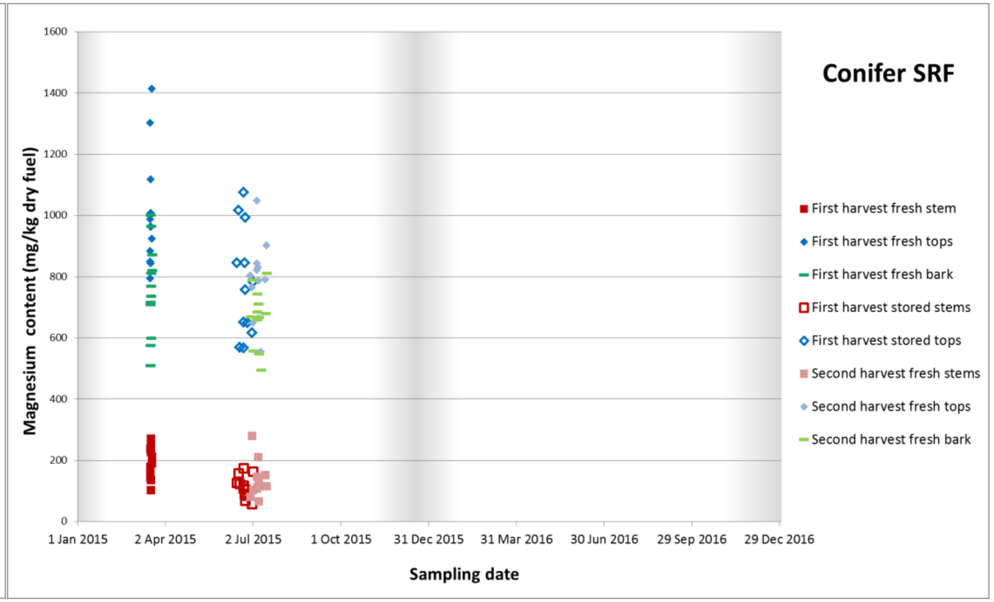

Conifer SRF
Potassium content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

MAGNESIUM CONTENT	In units of mg/kg in dry fuel
General	Concentrations in poplar SRF and conifer SRF tops were significantly higher than the other feedstocks, though leaves of both poplar and willow SRC were higher still.
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: concentrations in tops were significantly affected by the interaction between climate zone and harvest time but the differences were unlikely to have an operational impact. Stem concentrations were also affected by the interaction between climate zone and harvest time but the differences were within the repeatability of the lab analysis. Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* light soil showed significantly high level of magnesium than medium soil (368 vs 242 mg/kg) Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* no significant effect of storage or method Willow SRC: no significant effect of storage Poplar SRF: no significant effect of storage Conifer SRF: magnesium levels in both stem and tops samples decreased in storage (163 to 114 mg/kg for stems; 896 to 780 mg/kg for tops), though neither are likely to have an operational impact.
Location within field	*Miscanthus* and willow SRC: for *Miscanthus*, the in-field variation was greater than the variation between fields but for willow the reverse was observed
Plant part	Stems < tops and bark < leaves.
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: no significant effect of harvesting time Conifer SRF: the magnesium level in the spring bark samples was higher than in the summer samples (758 vs 669 mg/kg) though this is unlikely to have an operational impact.
Variety (willow SRC)	Varietal differences were significant with Endurance having the highest magnesium.

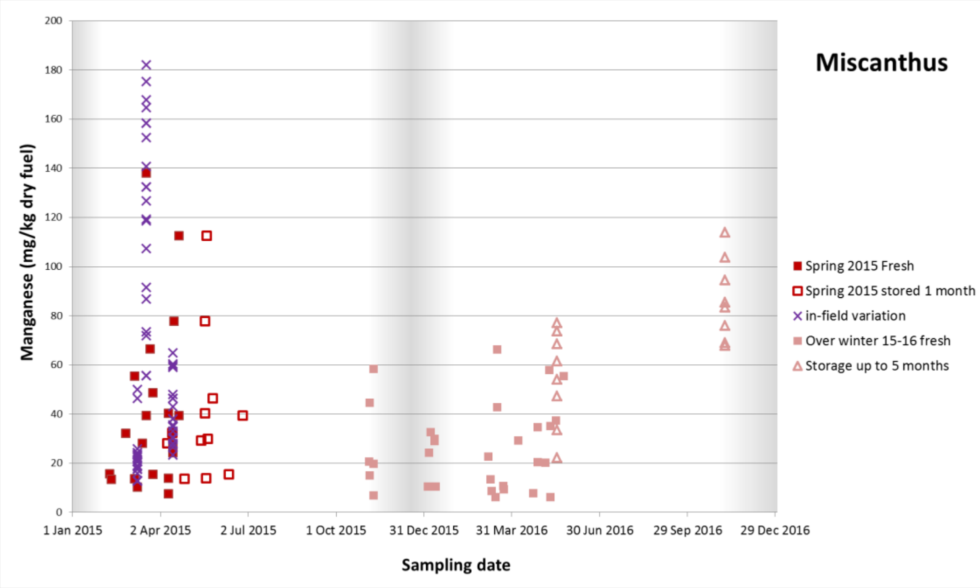

Miscanthus
Magnesium content (mg/kg dry fuel)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

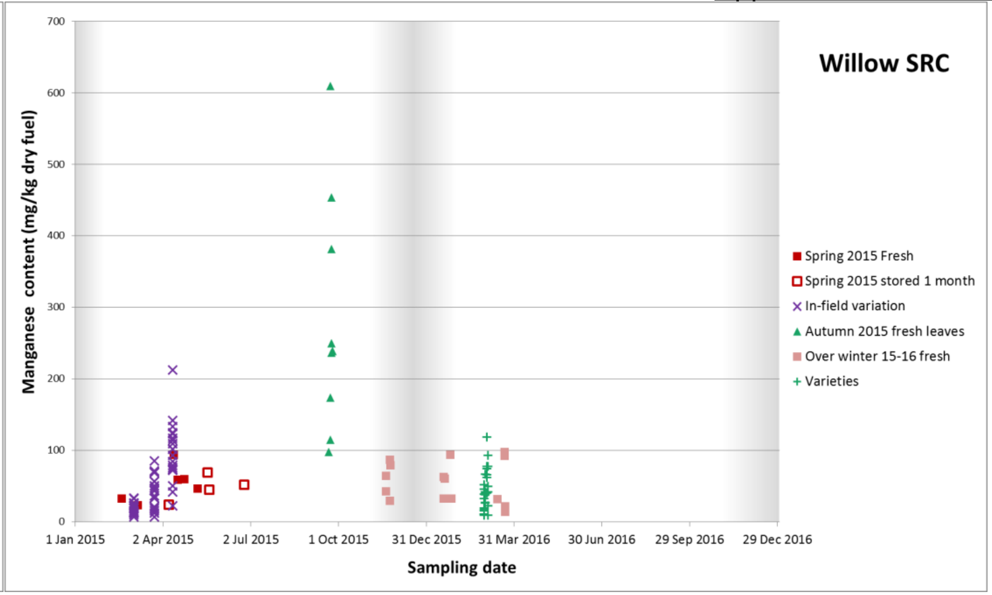

Willow SRC
Magnesium content (mg/kg dry fuel)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

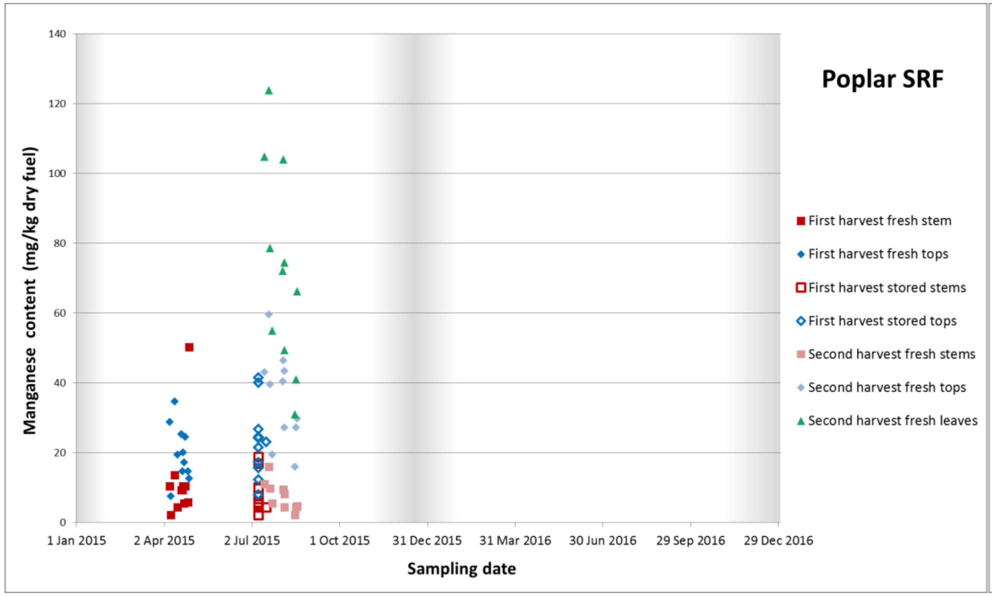

Poplar SRF
Magnesium content (mg/kg dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

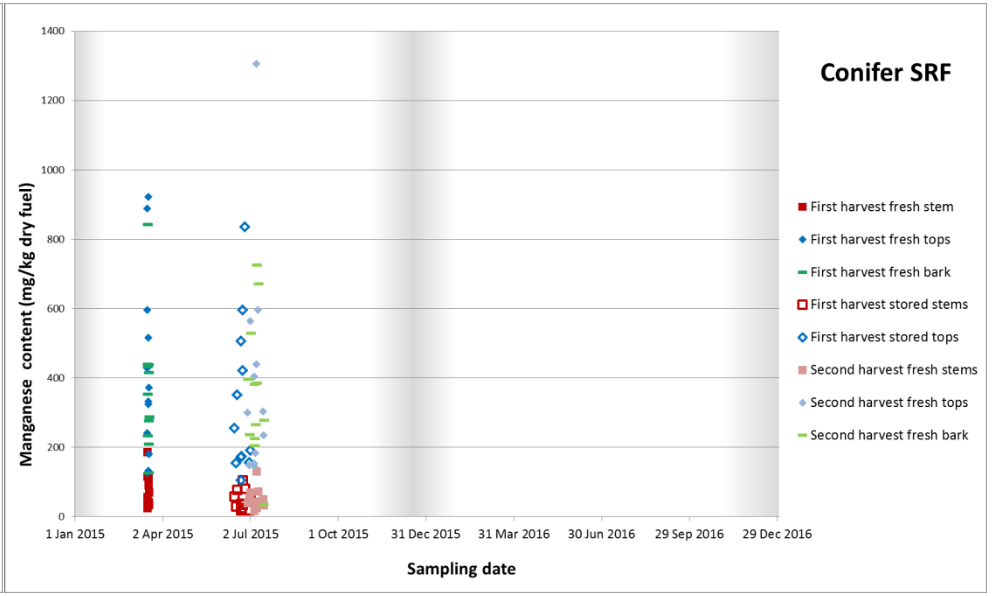

Conifer SRF
Magnesium content (mg/kg dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

MANGANESE CONTENT	In units of mg/kg in dry fuel
General	There were major differences between feedstocks with conifer SRF having higher manganese values than the other feedstocks – conifer stem wood was less than 150 but tops and bark were up to 600 and even 900. *Miscanthus* manganese levels were generally less than 60. Willow SRC levels were generally < 100 with leaves between 100 and 600. Poplar SRF stems were less than 20 with tops up to 60 and leaves reaching 100.
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: stems were influenced by complicated 3-factor interactions of climate zone, soil type and storage and of climate zone, soil type and harvest time but none were likely to be of operational significance. Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* long term storage was linked to a significant increase in manganese (from 55 to 87) but with no impact of storage method Willow SRC: no significant effect of storage Poplar SRF: no significant effect of storage Conifer SRF: The level of manganese in stem wood samples fell in storage from 63 to 46 which is of operational significance
Location within field	*Miscanthus* and willow SRC: For both feedstocks, the in-field variation was less than the variation between fields
Plant part	Within each of the feedstocks the woodier parts had lower manganese concentrations. In willow SRC stems < leaves; in poplar SRF stems < tops < leaves; conifer SRF stem wood < bark and tops.
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: the level of manganese in the spring tops samples was lower than in the summer samples (22 vs 36), though this is unlikely to have operational impact. Conifer SRF: no significant effect of harvesting time
Variety (willow SRC)	Varietal differences were significant with Endurance having the lowest manganese.

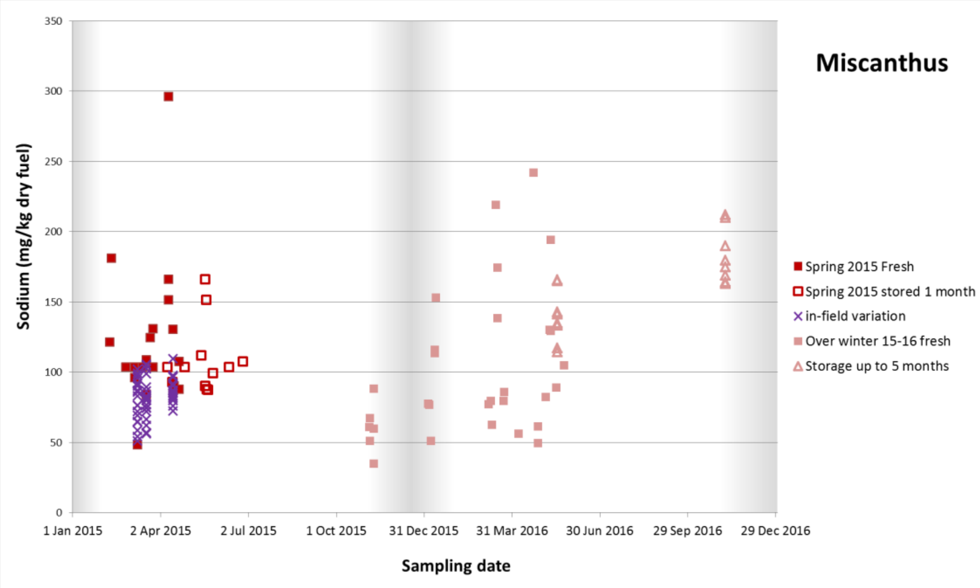

Miscanthus
Manganese (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

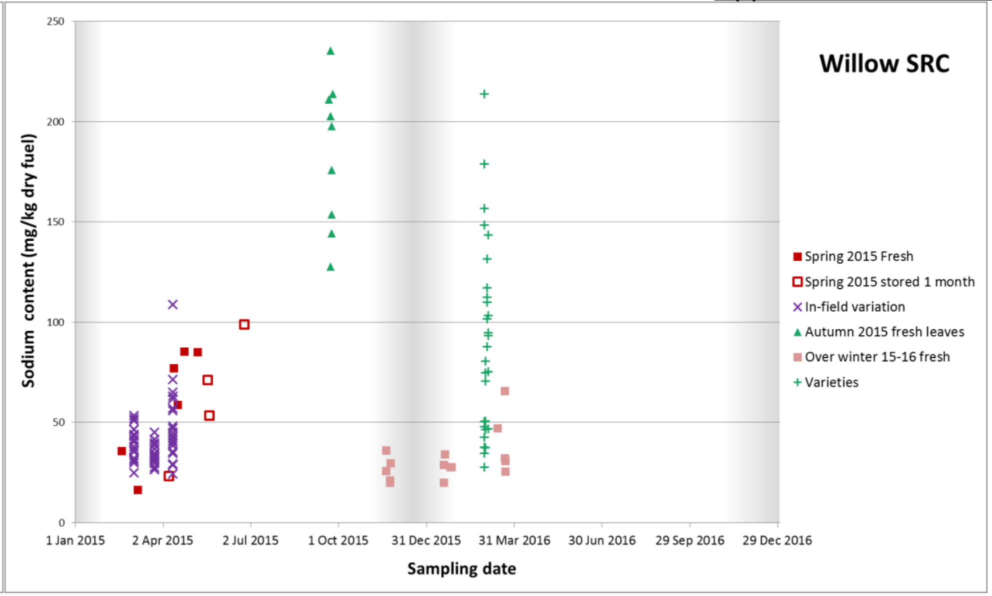

Willow SRC
Manganese content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

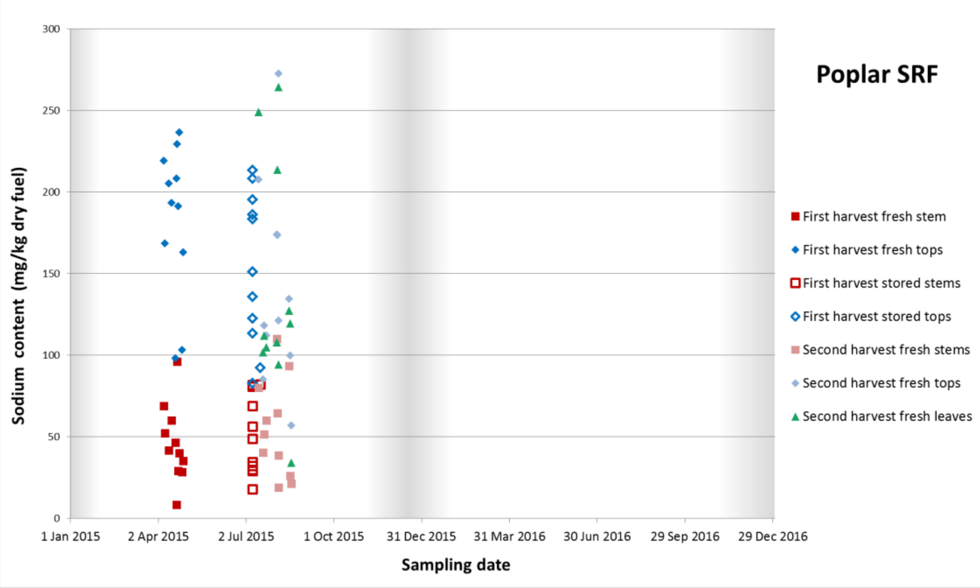

Poplar SRF
Manganese content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

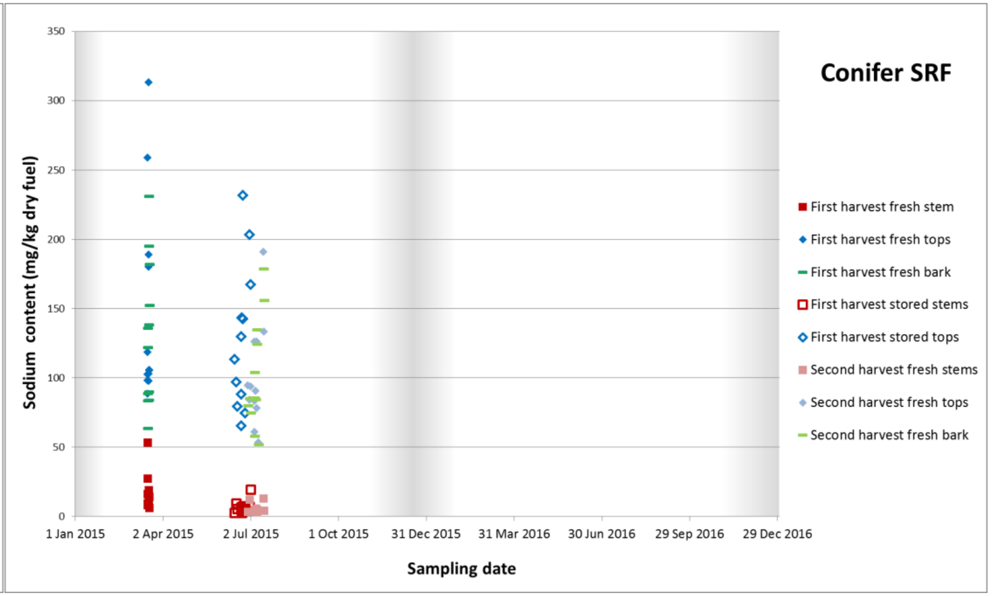

Conifer SRF
Manganese content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

SODIUM CONTENT	In units of mg/kg in dry fuel
General	The woody traditional feedstocks had generally sodium levels below 100 whereas *Miscanthus* levels ranged from 50 – 170. For willow SRC and poplar SRF the stem concentrations ranged from 20 – 70 with tops and leaves in the range 100-250. Conifer SRF stem wood had the lowest levels (< 25) though the tops and bark concentrations were 50-250. The spread within sites and varieties was very large but there were not consistent differences across sites.
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: the level of sodium in the tops from the warm/dry climate zone was lower than from the warm/moist climate zone (146 vs 195), though this is unlikely to have operational impact. Conifer SRF: the level of sodium in the bark from the cold/wet climate zone was lower than from the warm/moist climate zone (92 vs 140).
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: levels of sodium in leaf samples from light soils were lower than from medium soils (167 vs 220), but this is unlikely to have operational impact. Poplar SRF: levels of sodium in leaf samples from light soils were higher than from medium soils (177 vs 94). Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* long term storage was linked to a significant increase in sodium (from 139 to 183) but with no impact of storage method Willow SRC: no significant effect of storage Poplar SRF: the level of sodium in fresh tops samples was higher than stored samples (162 vs 153), though this is unlikely to have operational impact. Conifer SRF: the level of sodium in fresh stem samples was higher than stored samples (11 vs 7).
Location within field	*Miscanthus* and willow SRC: for both feedstocks the in-field variation was greater than the between field variation
Plant part	Stems < tops and bark < leaves
Season	*Miscanthus:* sodium levels increased through autumn, winter and spring but showed evidence of a decline and increasing variability in late spring Willow SRC: no significant effect of harvesting time Poplar SRF: the level of sodium in the spring tops samples was higher than in the summer samples (168 vs 141), though this is unlikely to have operational impact. Conifer SRF: the level of sodium in stem wood and tops was significantly higher in spring samples than summer: 12 vs 5 for stem; 137 vs 101 for tops. This declining trend was also observed in bark (131 vs 102) but this difference is unlikely to have an operational impact.
Variety (willow SRC)	Varietal differences were not significant although the range across the sites and varieties was large.

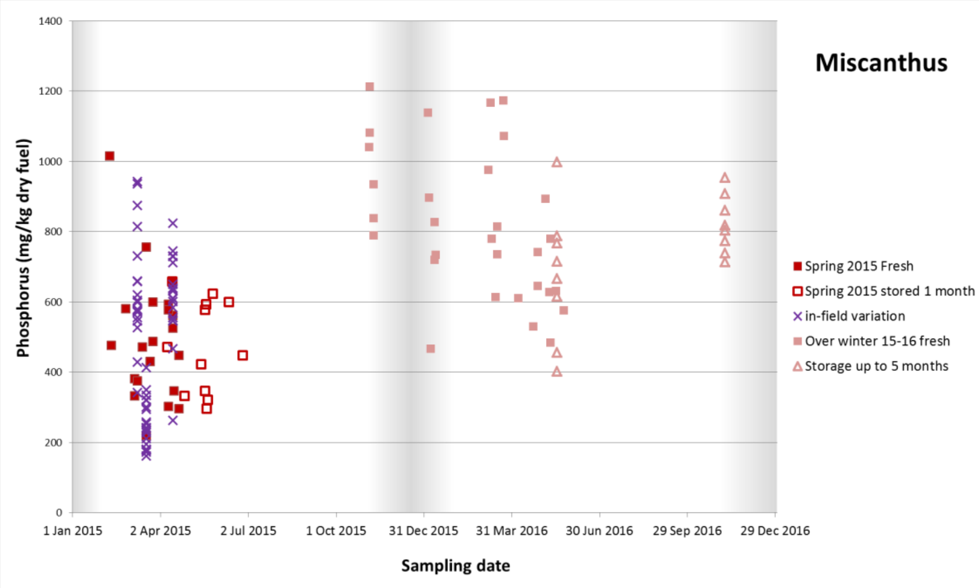

Miscanthus
Sodium (mg/kg dry fuel)
350
300
250
200
150
100
50
0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

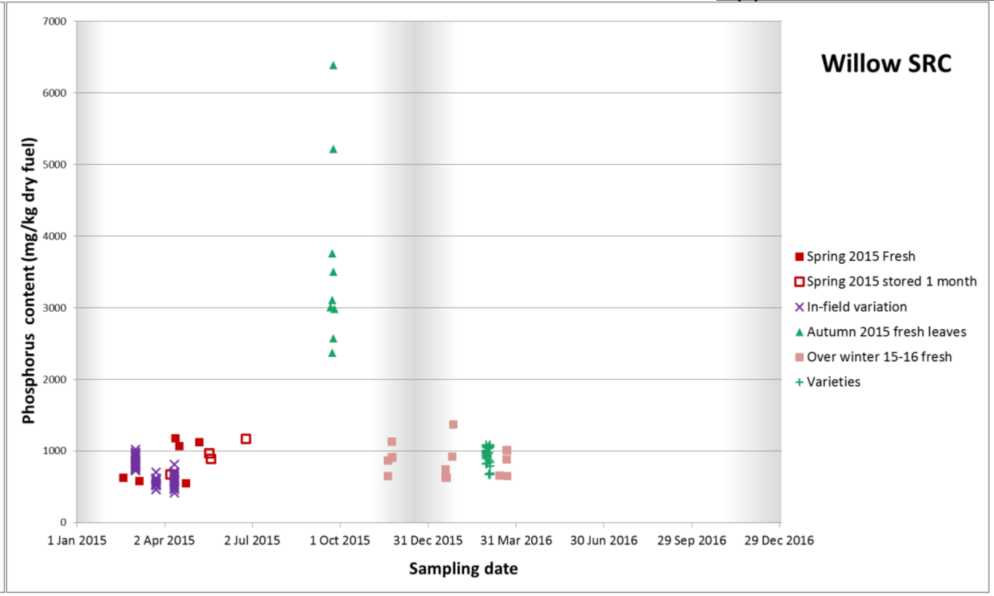

Willow SRC
Sodium content (mg/kg dry fuel)
250
200
150
100
50
0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

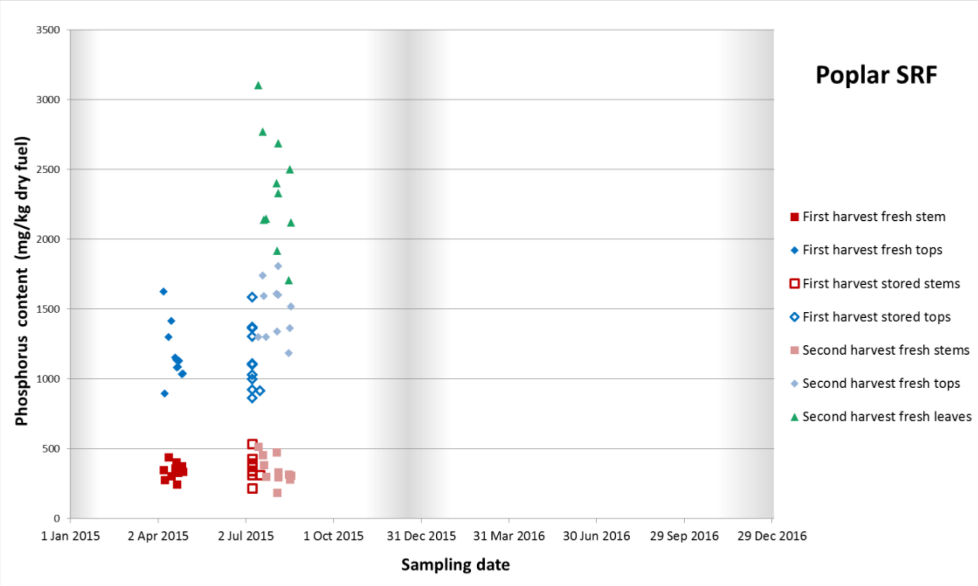

Poplar SRF
Sodium content (mg/kg dry fuel)
300
250
200
150
100
50
0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

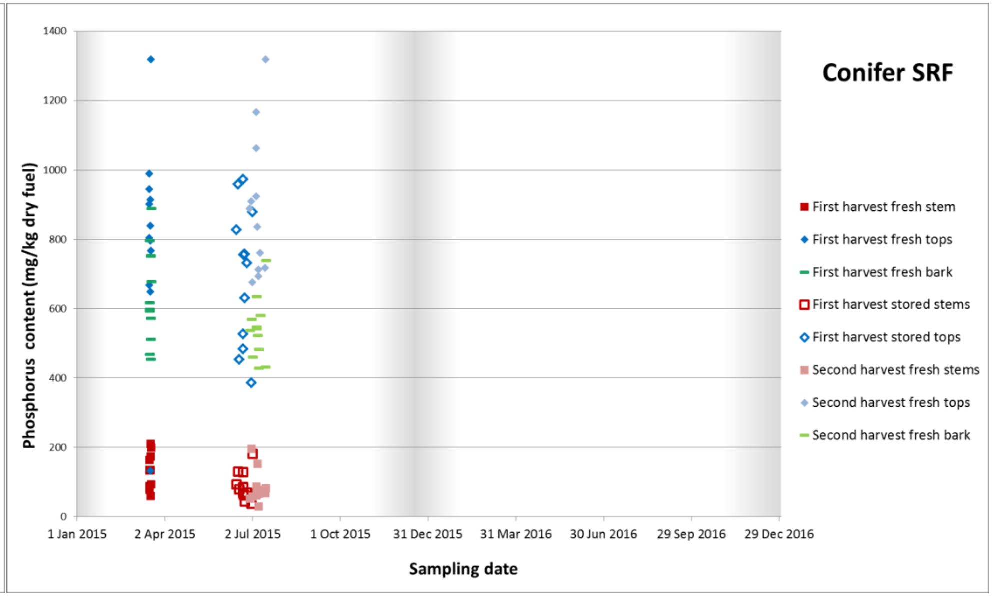

Conifer SRF
Sodium content (mg/kg dry fuel)
350
300
250
200
150
100
50
0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

PHOSPHORUS CONTENT	In units of mg/kg in dry fuel
General	Of the traditionally harvested bioenergy feedstocks, conifer SRF stem wood had the lowest levels of phosphorus (<200), followed by poplar SRF stems (200 – 500), then *Miscanthus* and willow SRC with 300 – 1200. The other plant parts had much greater phosphorus concentrations but all the conifer components were within the range of *Miscanthus* and willow SRC.
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: no significant effect of climate zone Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* light soil type showed significantly lower phosphorus level than medium soil (440 vs 622) Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* long term storage was linked to a significant increase in phosphorus (from 630 to 822) but with no impact of storage method Willow SRC: no significant effect of storage Poplar SRF: no significant effect of storage Conifer SRF: the level of phosphorus in fresh stem samples was higher than stored samples (105 vs 86).
Location within field	*Miscanthus* and willow SRC: for both feedstocks in-field variation was less than the variation between fields
Plant part	Within each of the feedstocks the woodier parts had lower concentrations. In willow SRC, stems < leaves; in poplar SRF, stems < tops < leaves; conifer SRF, stem wood < bark < tops.
Season	*Miscanthus:* in Phase 2, there was a decrease in phosphorus levels from autumn to late spring especially after cutting Willow SRC: no significant effect of harvesting time Poplar SRF: tops samples harvested in spring had lower phosphorus level than those from summer (1156 vs 1486), though this is unlikely to have operational impact. Conifer SRF: The level of phosphorus in bark samples was significantly higher in spring than summer (641 vs 540).
Variety (willow SRC)	Varietal differences were not significant.

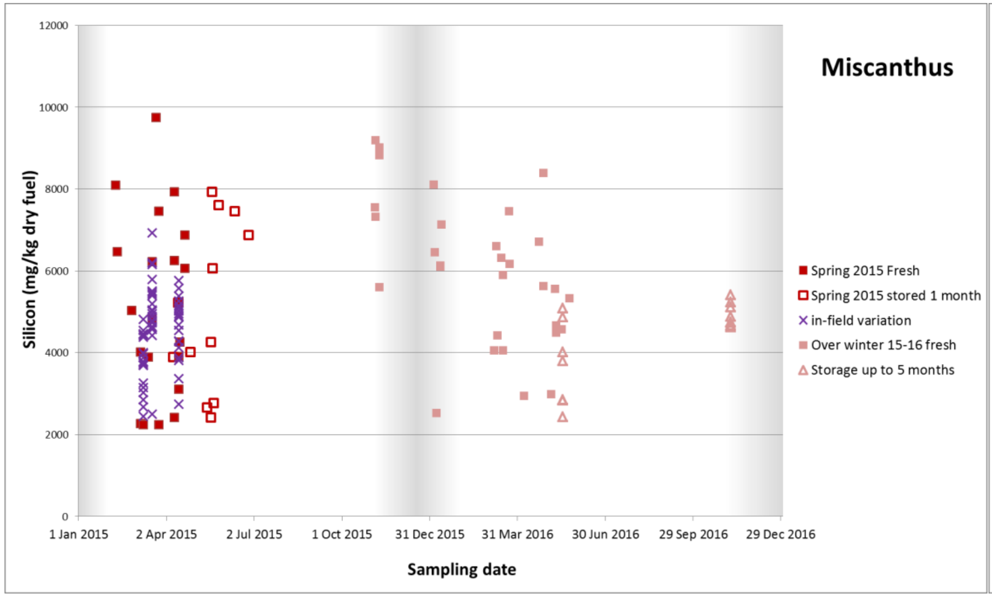

Miscanthus
Phosphorus (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

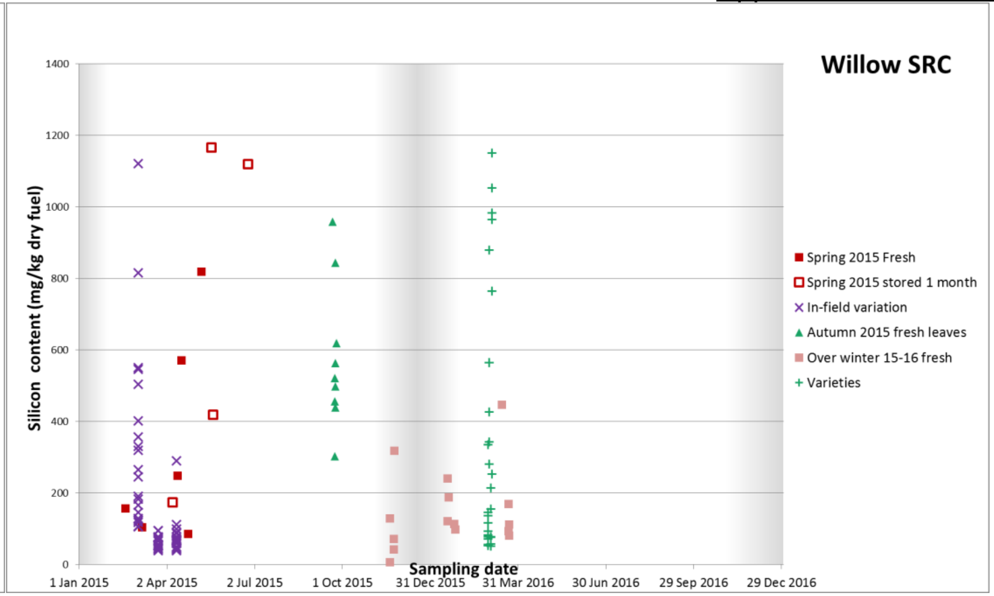

Willow SRC
Phosphorus content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

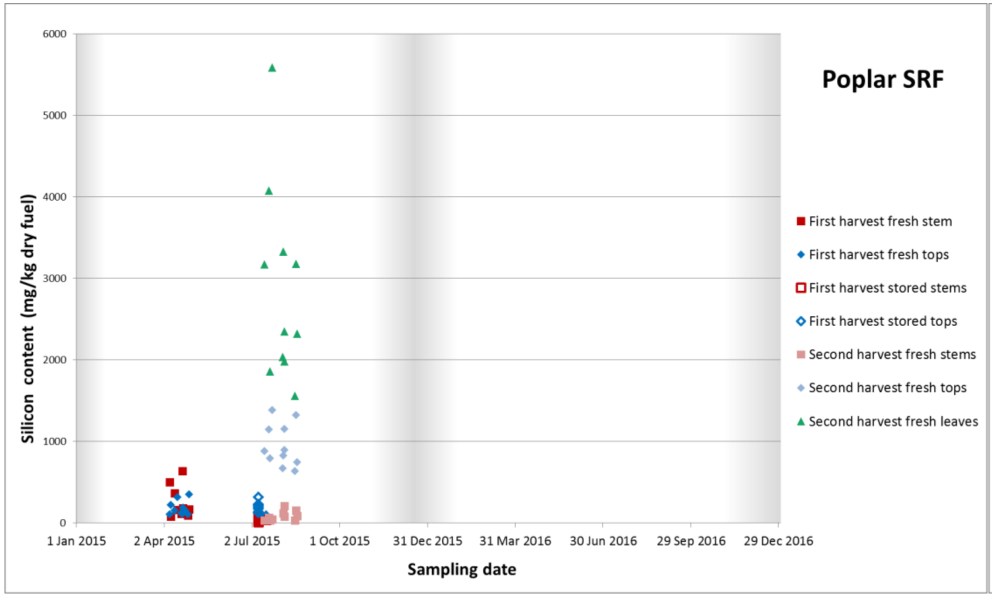

Poplar SRF
Phosphorus content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

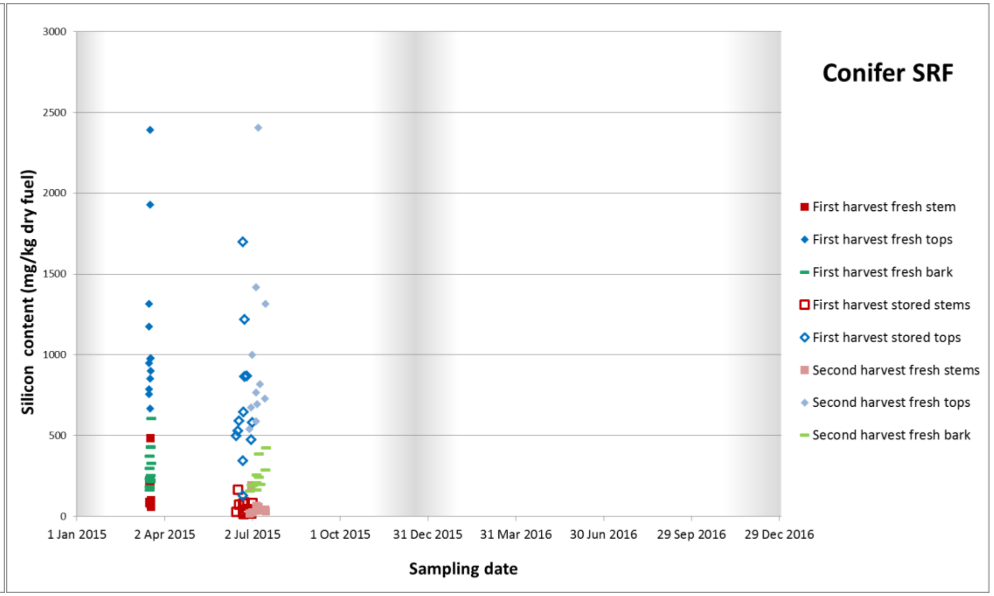

Conifer SRF
Phosphorus content (mg/kg dry fuel)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

SILICON CONTENT	In units of mg/kg in dry fuel
General	There were major differences between feedstocks with *Miscanthus* having the highest silicon contents (2,000 – 9,000) whereas willow SRC stem concentrations were < 1,200, poplar SRF stems were < 500 and conifer SRF stem wood was < 200. The other plant components had definitely higher silicon contents with willow SRC leaves reaching 400 – 1000; poplar SRF tops reaching approx. 1500 and leaves up to 4000; and lastly conifer bark at < 400 and tops up to 1500.
Source of variation	
Climate zone	*Miscanthus:* samples from warm/dry climate zone showed significantly higher levels of Si compared to those from warm/moist climate zone (5446 vs 3014) Willow SRC: no significant effect of climate zone Poplar SRF: no significant effect of climate zone Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* long term storage was linked to a significant increase in silicon (from 3591 to 4927) but with no impact of storage method Willow SRC: no significant effect of storage Poplar SRF: the level of silicon in stored stem samples fell significantly in storage from 176 to 42. Conifer SRF: the level of silicon in fresh stem wood and tops samples was significantly higher than stored samples (135 vs 56 for stem; 1127 vs 703 for tops). The decrease associated with storage was especially large in warm/moist climate zones where the fresh value was 1333 and the means of the other climate zones (cold/wet) and storage combinations were all < 921
Location within field	*Miscanthus* and willow SRC: for both feedstocks, in-field variation was similar to the variation between fields
Plant part	In willow SRC, stems < leaves; in poplar SRF, there was no difference between stems and tops in spring but in summer stems < tops < leaves; in conifer SRF, stem wood < bark < tops.
Season	*Miscanthus:* in Phase 2, there was a decrease in phosphorus levels from autumn to late spring Willow SRC: no significant effect of harvesting time Poplar SRF: the level of silicon in tops samples in spring was significantly lower than in summer (177 vs 948). Conifer SRF: the level of silicon in stem wood samples in spring was higher than in summer (136 vs 54 for stems). This decreasing trend was also evident in bark (313 vs 244) but this is unlikely to have operational impact. The impact of harvest time on levels in the tops was influenced by climate zone with the increase being especially large in moist/wet as opposed to cold/wet climate zones
Variety (willow SRC)	Varietal differences were not significant although the range across the sites and varieties was large.

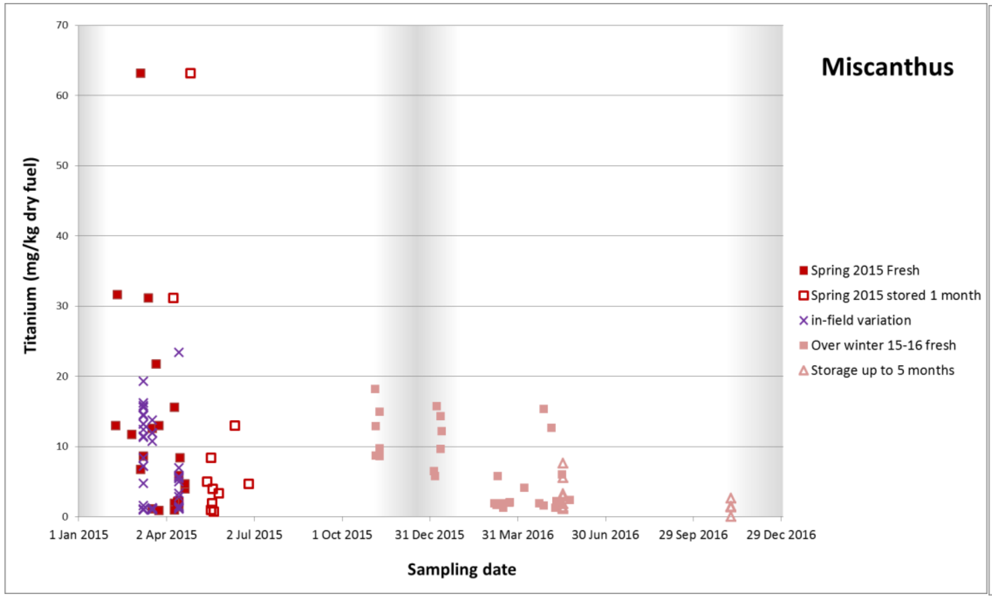

Miscanthus
Silicon (mg/kg dry fuel)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

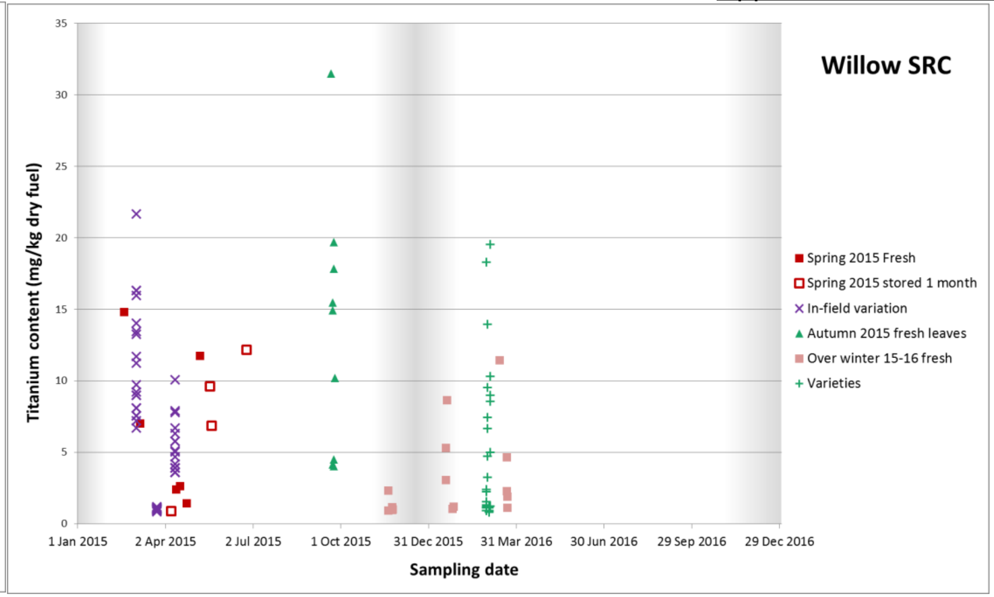

Willow SRC
Silicon content (mg/kg dry fuel)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

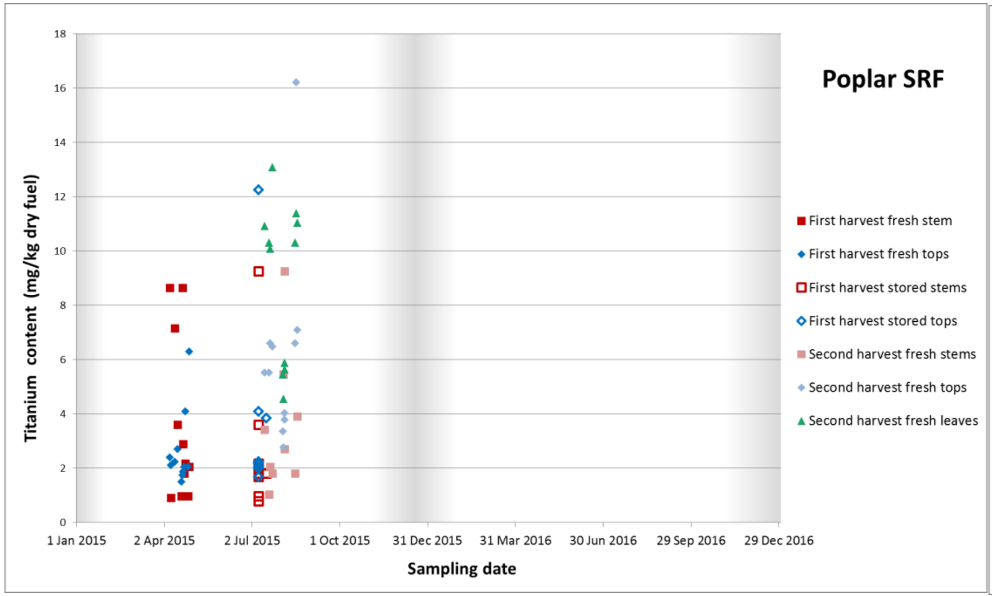

Poplar SRF
Silicon content (mg/kg dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

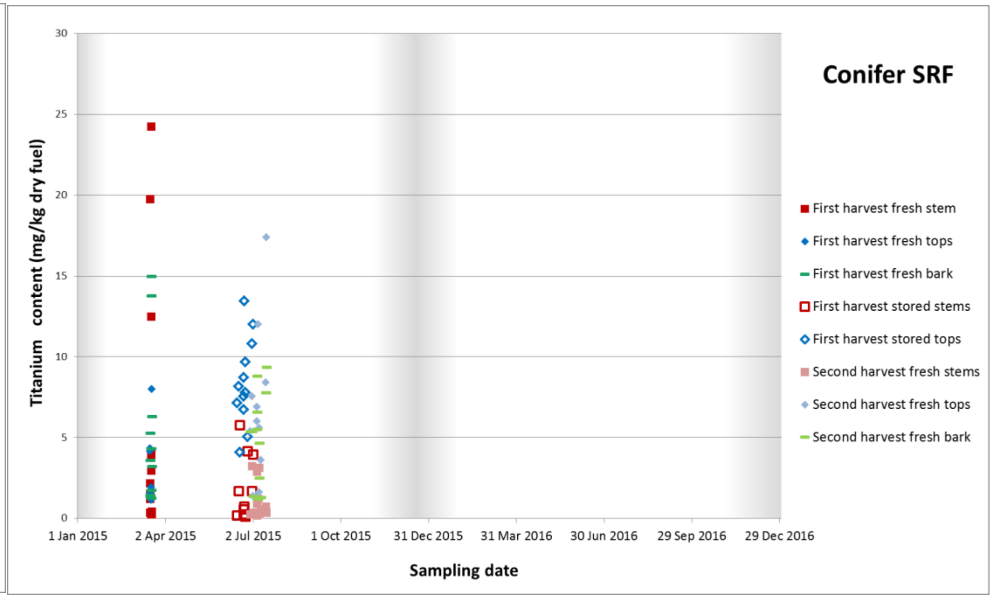

Conifer SRF
Silicon content (mg/kg dry fuel)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

TITANIUM CONTENT	**In units of mg/kg in dry fuel**
General	Generally < 20 for all feedstocks.
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: the level of titanium in leaf samples from warm/dry climate zone was significantly higher than from warm/moist climate zone (10 vs 5) but this is unlikely to have an operational impact. Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* no significant effect of storage or method Willow SRC: no significant effect of storage Poplar SRF: no significant effect of storage Conifer SRF: the level of titanium in the tops samples was lower in the fresh samples than those stored (5 vs 8) though this is unlikely to have operational impact.
Location within field	*Miscanthus* and willow SRC: for both feedstocks the in-field variation was greater than the variation between fields
Plant part	Stems < leaves for the broadleaved species but no difference in conifer SRF
Season	*Miscanthus:* in Phase 2, concentrations decreased over winter but there was an indication of an increase again at baling Willow SRC: no significant effect of soil type Poplar SRF: the level of titanium in tops samples in spring were lower than in summer (3 vs 6), though this is unlikely to have operational impact. Conifer SRF: no significant effect of soil type
Variety (willow SRC)	Varietal differences were not significant

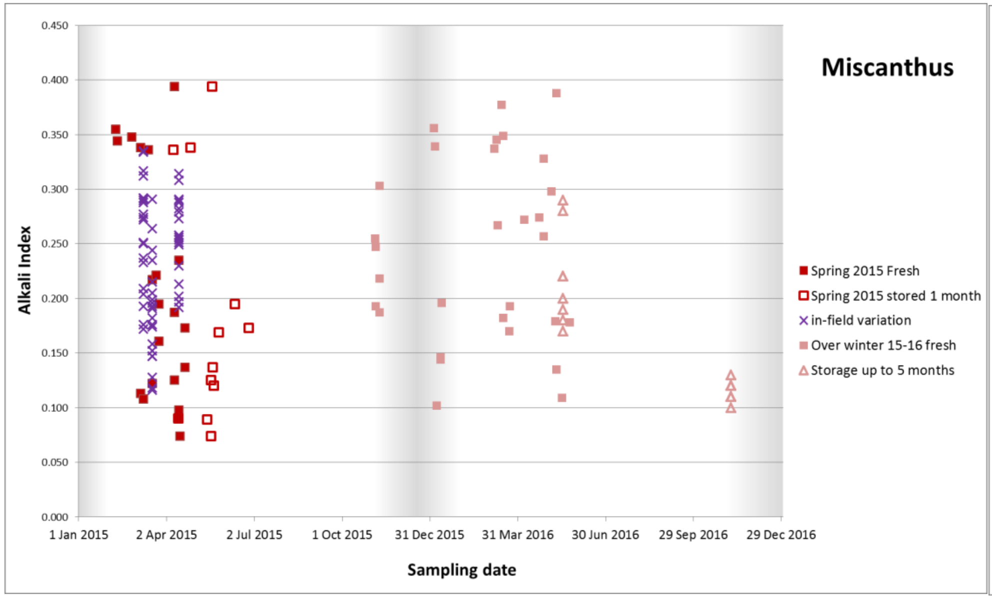

Miscanthus
Titanium (mg/kg dry fuel)
Sampling date
0
10
20
30
40
50
60
70
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

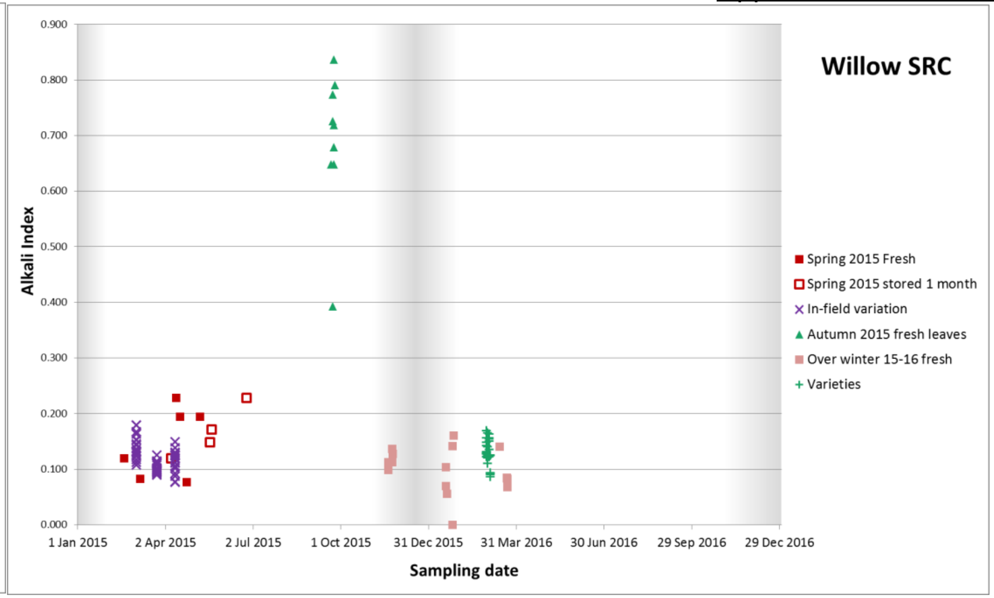

Willow SRC
Titanium content (mg/kg dry fuel)
Sampling date
0
5
10
15
20
25
30
35
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

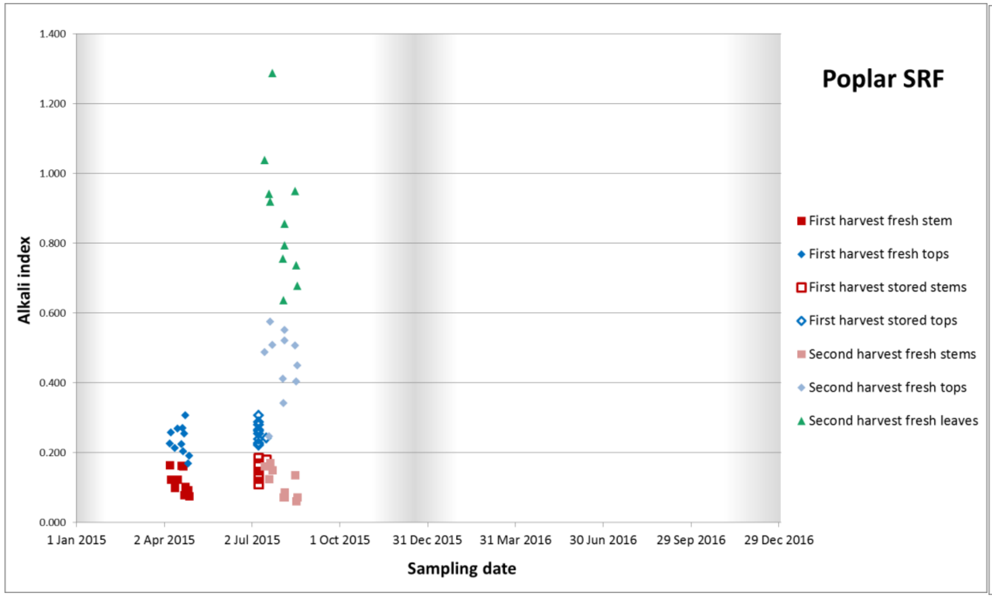

Poplar SRF
Titanium content (mg/kg dry fuel)
Sampling date
0
2
4
6
8
10
12
14
16
18
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

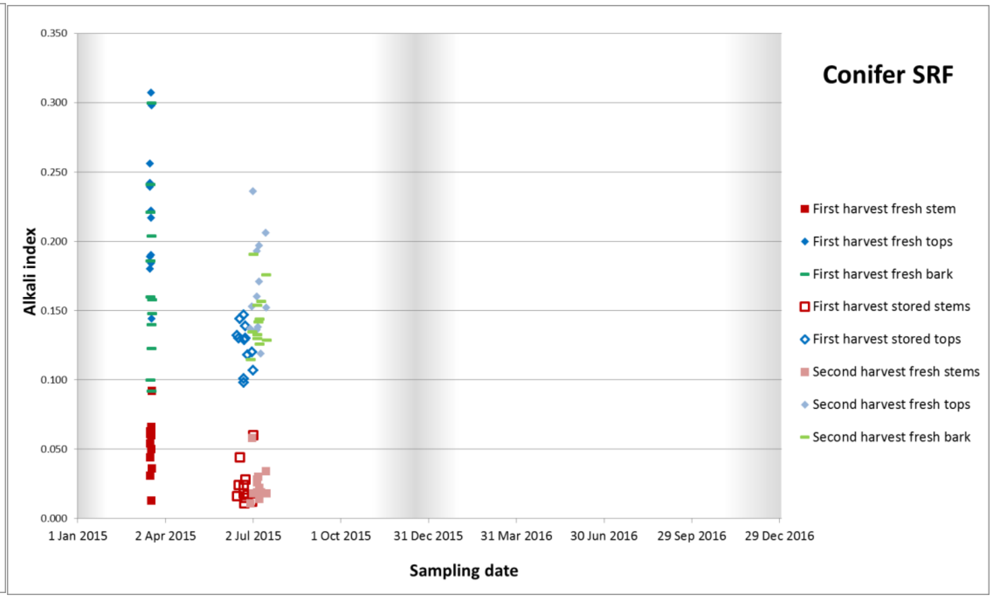

Conifer SRF
Titanium content (mg/kg dry fuel)
Sampling date
0
5
10
15
20
25
30
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

ALKALI INDEX	Kg (Na_2O+K_2O)/GJ GCV
General	There were clear differences between feedstock and plant parts. Comparing the more traditional bioenergy feedstocks, *Miscanthus* had the highest index (0.06 – 0.35) with both willow SRC and Poplar SRF having a range of approx. 0.06 – 0.20. Stem wood of conifer SRF had the lowest index (< 0.06) with bark ranging up to 0.25 and tops up to 0.30. The tops and leaves of willow SRC and poplar SRF had indices above those of *Miscanthus.*
Source of variation	
Climate zone	*Miscanthus:* samples from warm/dry climate zone showed significantly higher alkali index compared to those from warm/moist climate zones (0.21 vs 0.1) Willow SRC: no significant effect of climate zone Poplar SRF: poplar SRF stems harvested in summer had particularly low index in warm/moist climate zones (0.08) whereas the other combinations of harvest time and climate zone had values >0.12 Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* in Phase 2, long term storage was linked to a significant decrease in index (from 0.22 to 0.12) but with no impact of storage method Willow SRC: no significant effect of storage Poplar SRF: the alkali index increased in storage in stem samples from 0.11 to 0.15 as a result of the increase in potassium content. Conifer SRF: the alkali index in stem and tops samples decreased in storage: 0.04 to 0.02 in stems; 0.19 to 0.13 in tops owing to the fall in potassium content.
Location within field	*Miscanthus* and willow SRC: in-field variation was similar to the variation between fields.
Plant part	In willow SRC, stems < leaves; in poplar SRF, stems < tops < leaves; in conifer SRF, stem wood < bark and tops.
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: the alkali index in the spring stem samples was lower than the summer samples (0.25 vs 0.46), owing to the lower potassium content. Conifer SRF: the alkali index in the spring stem samples was higher than the summer samples (0.04 vs 0.03), owing to the higher potassium content
Variety (willow SRC)	Varietal differences were small and were not significant

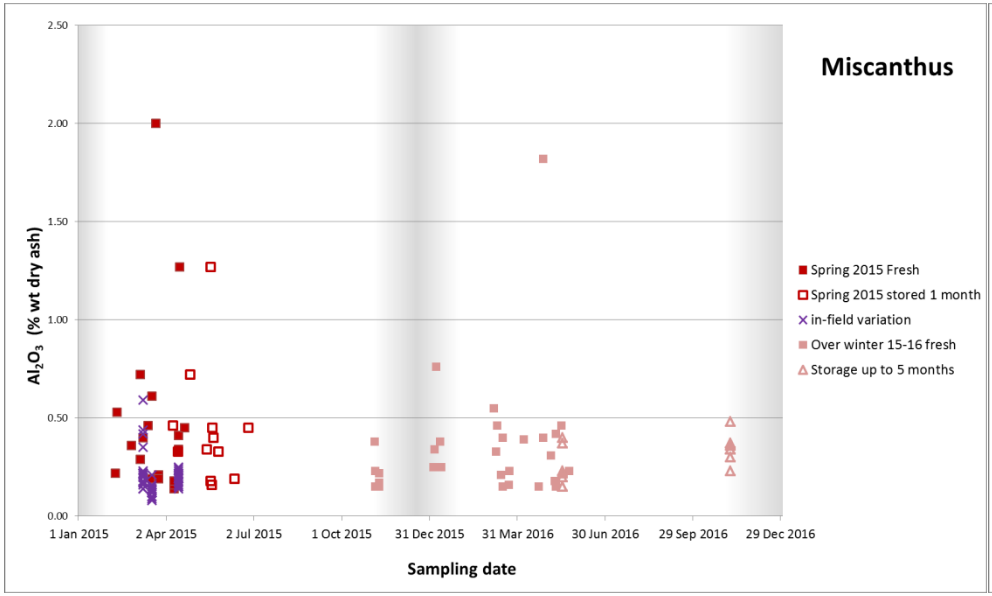

Miscanthus
Alkali Index
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

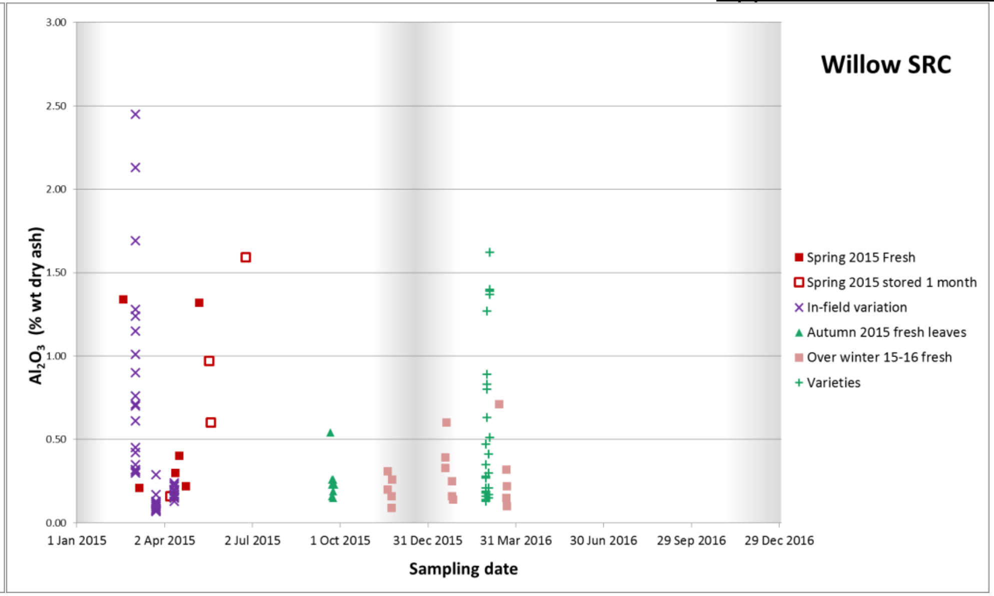

Willow SRC
Alkali Index
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

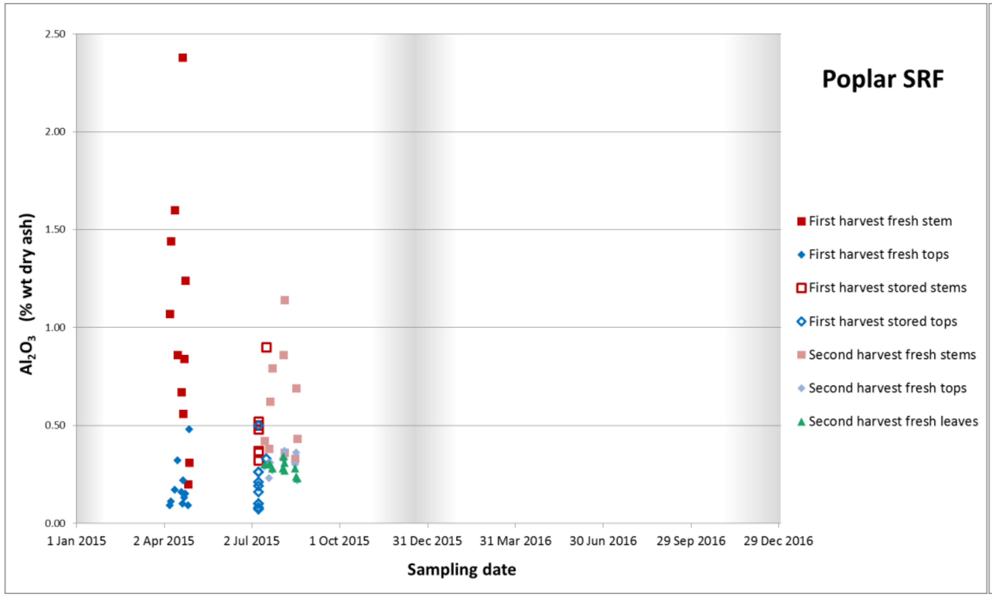

Poplar SRF
Alkali index
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

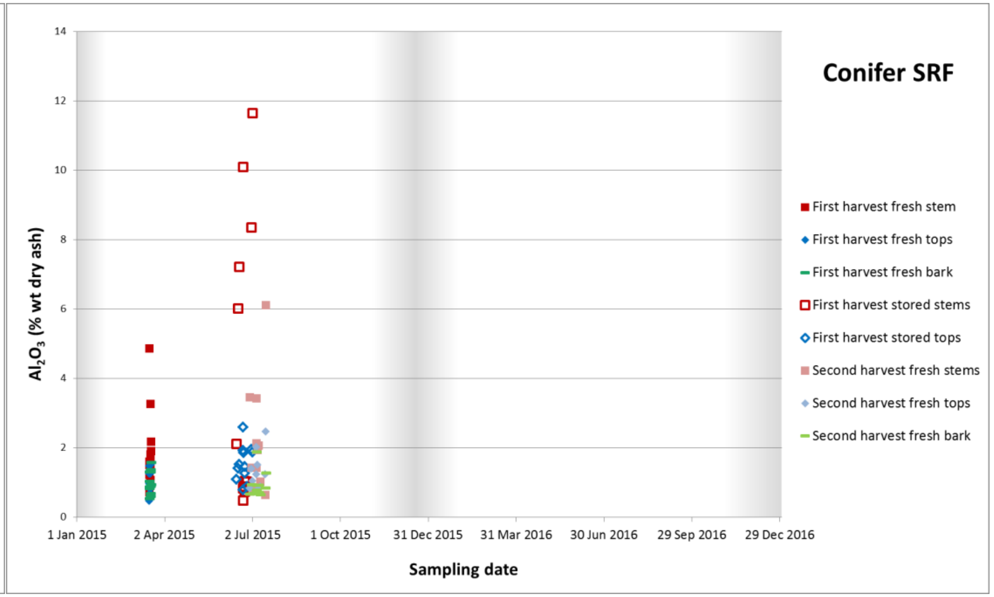

Conifer SRF
Alkali index
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

ALUMINIUM OXIDE	In units of mg/kg in dry ash
General	One of the minor ash components in all feedstocks. It was generally low (<0.05 percentage of the total ash weight) for *Miscanthus;* willow SRC and poplar SRF tops and leaves were generally < 0.1. Poplar stems were up to about 1.5 and conifer SRF values were the highest with stem wood have values between 4 and 6.
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: There was a 3-way interaction of climate zone, soil type and harvest time on the concentrations in poplar SRF tops but the differences are unlikely to have an operational impact. Conifer SRF: There was a 3-way interaction of climate zone, soil type and storage on the concentrations in conifer SRF stems but the differences, though relevant, were very difficult to clarify. Similarly the 2-way interaction between climate zone and soil type on the concentrations in tops though relevant were not possible to interpret. There was a 3-way interaction of climate zone, soil type and harvest time on the concentrations in bark but the differences though relevant were not possible to interpret. In all cases the number of sites falling within the combinations of climate zone and soil type were not uniform, e.g. there were no mineral soils in the cold/wet climate zone, which made interpretation of these interactions unreliable.
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: The percentage of Al_2O_3 in the ash from leaf samples from light soils were lower than from medium soils (0.2 vs 0.3), but this is unlikely to have operational impact. Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* long term storage was linked to a small but statistically significant increase in aluminium oxide (from 0.2 to 0.4) but with no impact of storage method Willow SRC: no significant effect of storage Poplar SRF: no significant effect of storage Conifer SRF: no significant effect of storage
Location within field	*Miscanthus* and willow SRC: in-field variation was similar to the variation between fields.
Plant part	Tops and bark < leaves < stems
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: no significant effect of harvesting time Conifer SRF: no significant effect of harvesting time
Variety (willow SRC)	Varietal differences were not significant

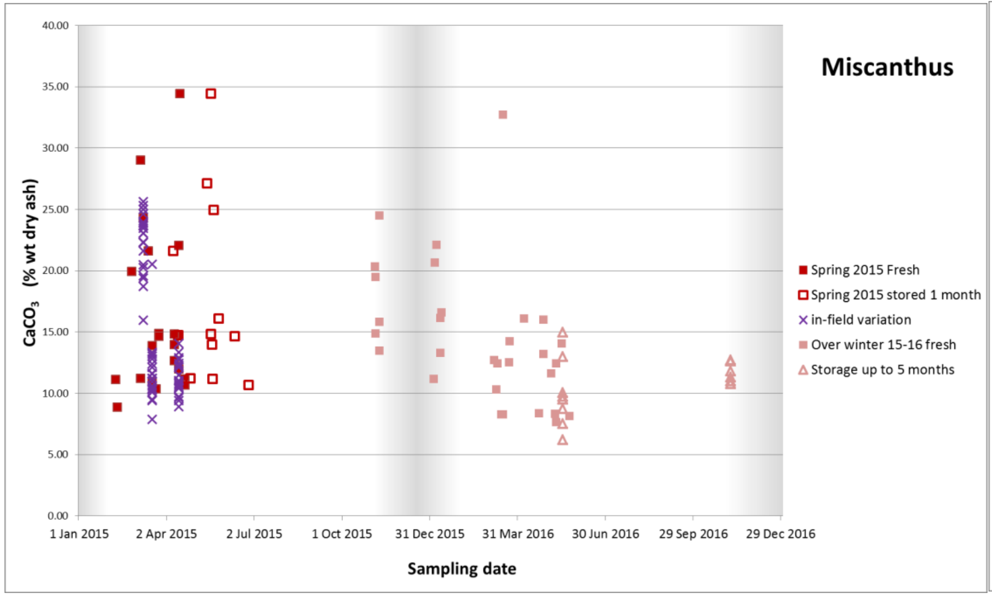

Miscanthus
Al2O3 (% wt dry ash)
2.50
2.00
1.50
1.00
0.50
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

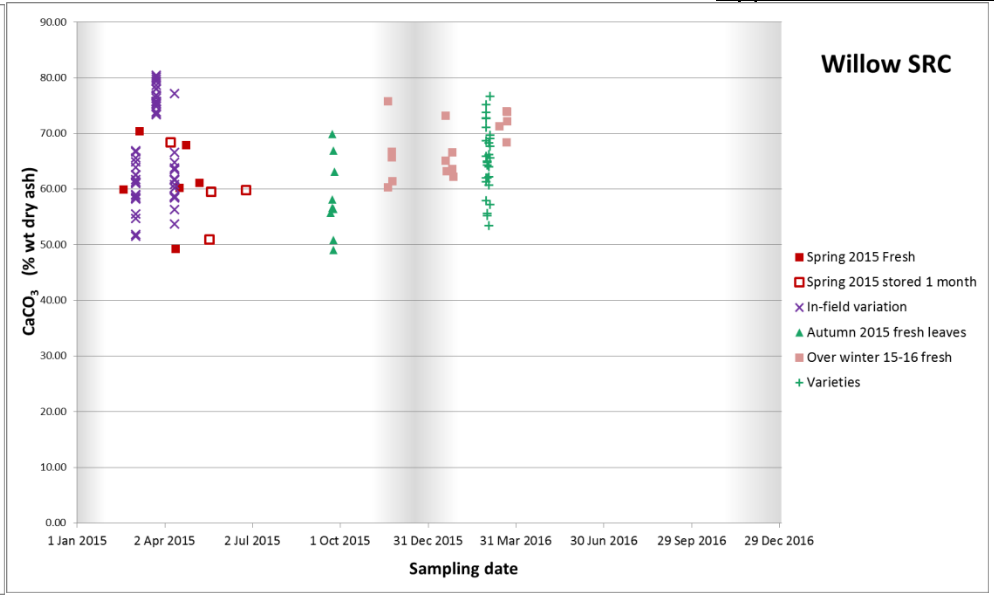

Willow SRC
Al2O3 (% wt dry ash)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

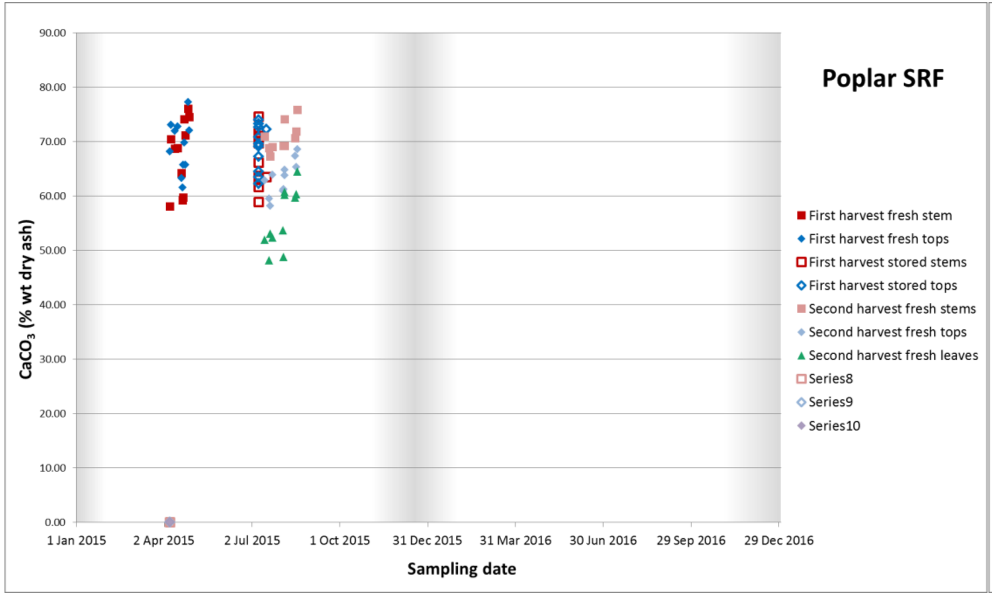

Poplar SRF
Al2O3 (% wt dry ash)
2.50
2.00
1.50
1.00
0.50
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

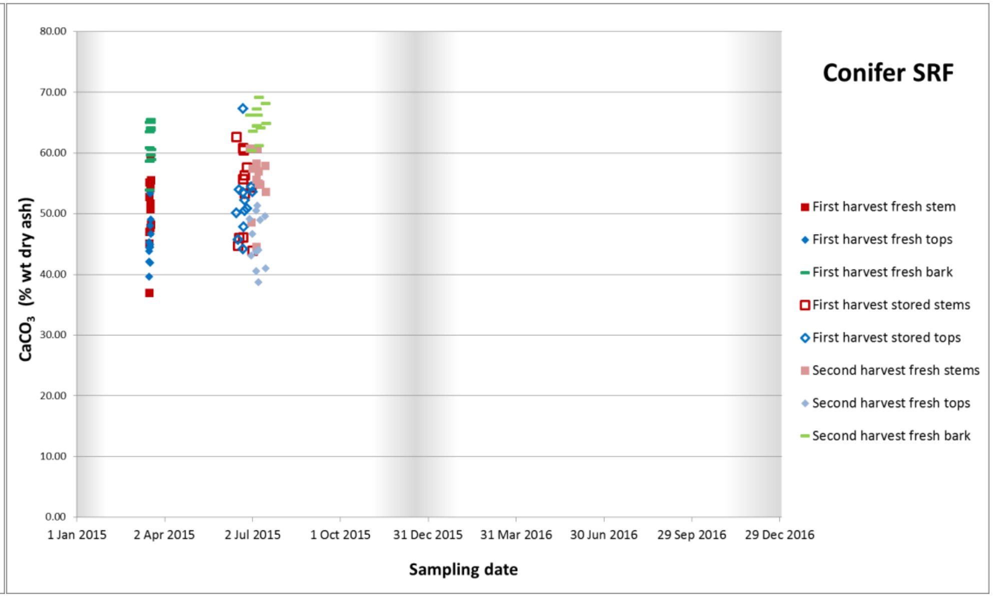

Conifer SRF
Al2O3 (% wt dry ash)
14
12
10
8
6
4
2
0
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

CALCIUM CARBONATE	In units of mg/kg in dry ash
General	This is a major component of the ash for the woody species (50-70 percentage of the total ash weight for willow SRC and poplar SRF; 40-75 for conifer SRF) but was much lower for *Miscanthus* (7-30)
Source of variation	
Climate zone	*Miscanthus:* the percentage of $CaCO_3$ in the ash from a warm/dry climate zone was significantly lower than in those from the warm moist climate zone (14 vs 27) Willow SRC: no significant effect of climate zone Poplar SRF: no significant effect of climate zone Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* long term storage was linked to a small but statistically significant increase in calcium carbonate (from 9 to 12) but with no impact of storage method Willow SRC: no significant effect of storage Poplar SRF: no significant effect of storage Conifer SRF: the percentage of $CaCO_3$ in the ash rose in the tops samples (45 to 52)
Location within field	*Miscanthus* and willow SRC: For both feedstocks, the variation within fields was much lower than the variation between fields
Plant part	Depended on species: for willow SRC leaves and stems were similar; for poplar SRF leaves < tops < stems; for conifer SRF tops < stem wood < bark
Season	*Miscanthus:* values decreased during autumn, winter and spring and then stabilised in late spring after cutting Willow SRC: values were stable in autumn and increased in spring. Poplar SRF: the percentage of $CaCO_3$ in the ash was slightly lower in the spring stem samples than the summer (67 vs 69). In the tops sample, however, the percentage was slightly higher in the spring samples (69 vs 63). Neither change is likely to have operational impact. Conifer SRF: the percentage of $CaCO_3$ in the ash was higher in the spring samples for the tops (48 vs 46), but lower in the spring samples for bark (62 vs 65), though the latter is unlikely to have operational impact.
Variety (willow SRC)	Varietal differences were significant with Resolution had consistently the lowest levels, followed by Sven. The other varieties had more variable rankings depending on the site and each had the highest level of calcium carbonate at one site.

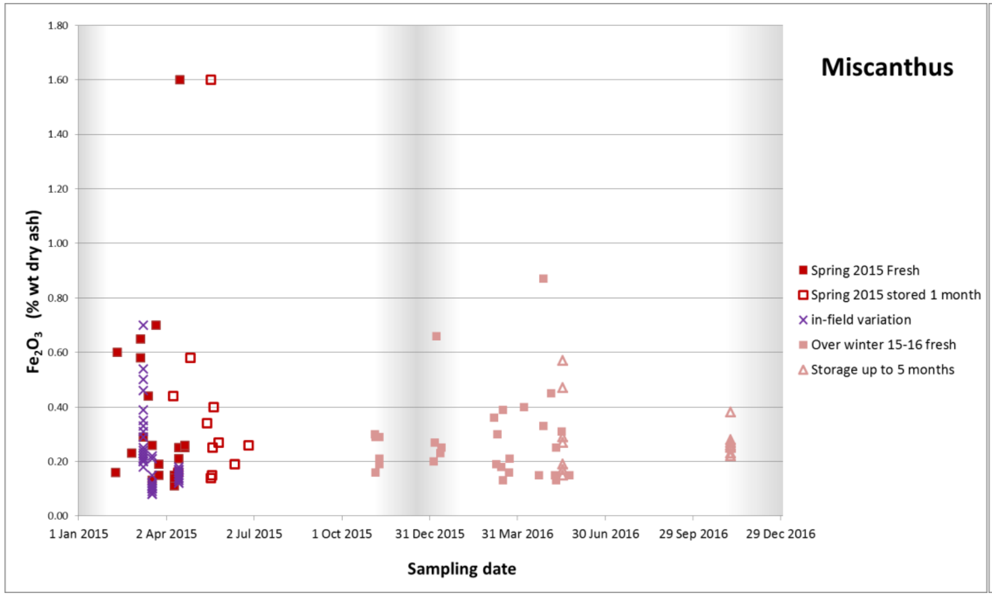

Miscanthus
CaCO3 (% wt dry ash)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016

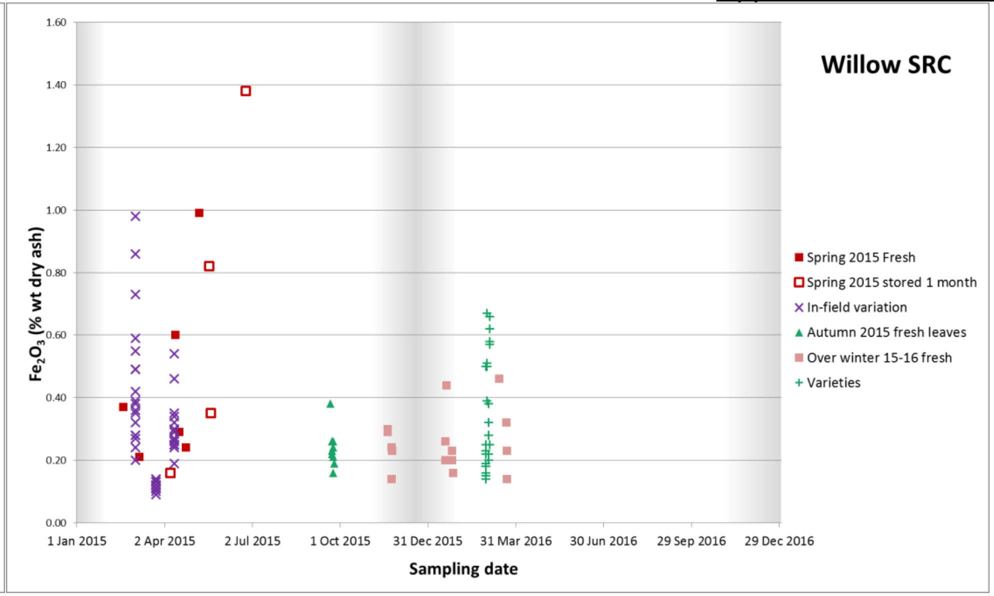

Willow SRC
CaCO3 (% wt dry ash)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

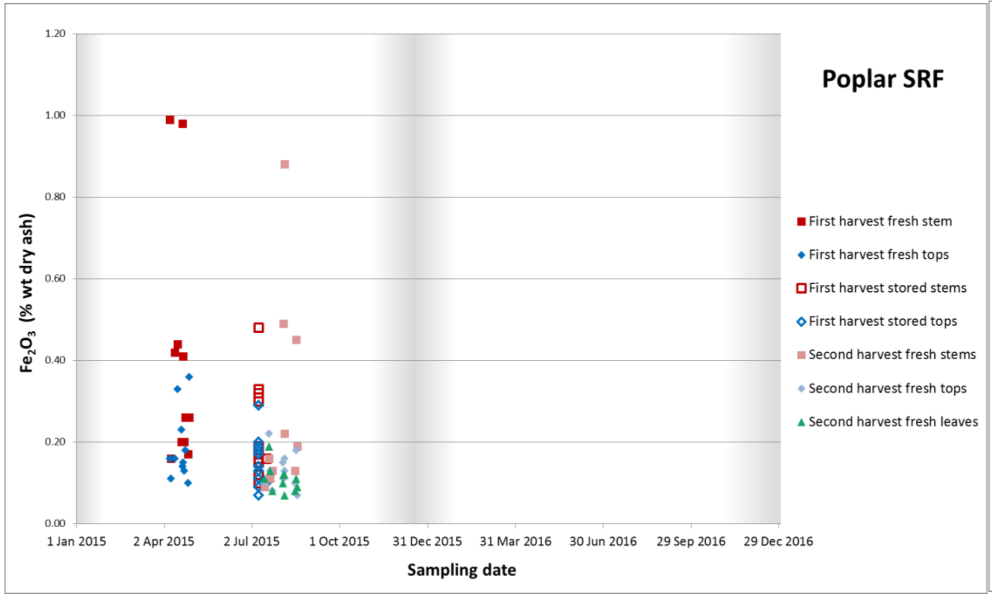

Poplar SRF
CaCO3 (% wt dry ash)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves
Series8
Series9
Series10

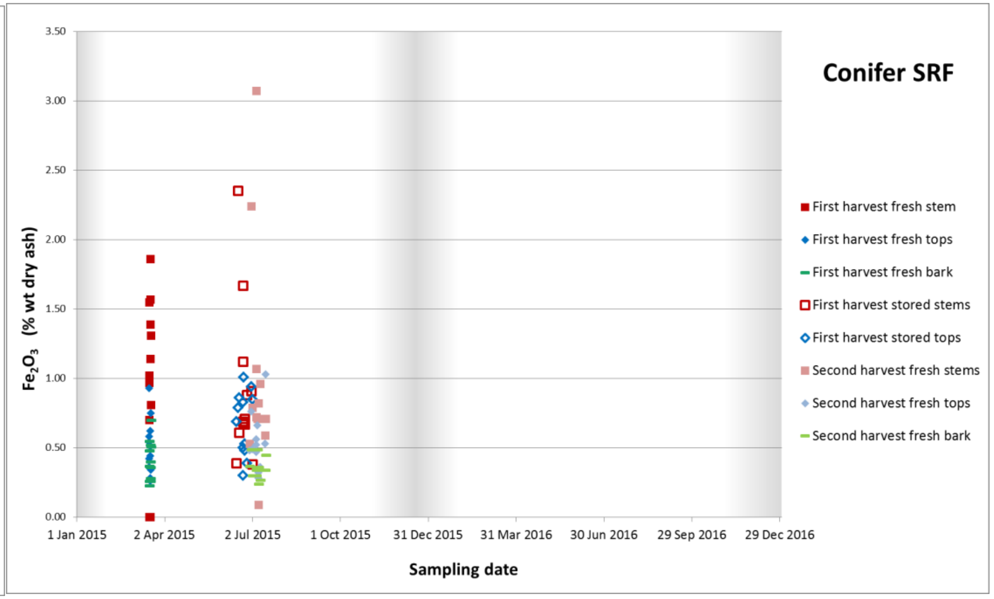

Conifer SRF
CaCO3 (% wt dry ash)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

IRON (III) OXIDE	In units of mg/kg in dry ash
General	This is a minor component but was slightly higher for conifer SRF (up to 1.5 percentage of the total ash weight) than for the other feedstocks
Source of variation	
Climate zone	*Miscanthus:* the percentage of Fe_2O_3 in the ash from the warm/dry climate zone was significantly lower than from the warm/moist climate zone (0.3 vs 0.7) though it is unlikely to have operational impact Willow SRC: no significant effect of climate zone Poplar SRF: there was a two-way interaction between climate zone and harvest time on stem levels – stems harvested in summer in warm/moist climate zones had much higher levels (0.5) than the other combinations where levels were all < 0.3 Conifer SRF: there was a two-way interaction between climate zone and harvest time on stem wood levels – stems harvested in summer in warm/moist climate zones had much lower levels (0.6) than the other combinations where levels were all > 1.2
Soil type	*Miscanthus:* the percentage of Fe_2O_3 in the ash from the light soil type was significantly higher than from the medium soil (0.4 vs 0.3) though it is unlikely to have operational impact Willow SRC: there was an interaction between soil type and storage but this is unlikely to have operational impact. Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* no significant effect of storage or method Willow SRC: there was an interaction between soil type and storage but this is unlikely to have operational impact. Poplar SRF: the percentage of Fe_2O_3 in the ash was higher in the fresh stem samples than the stored samples (0.4 vs 0.2) Conifer SRF: the percentage of Fe_2O_3 in the ash fell in storage for the stem samples (1.2 to 0.9), but rose slightly in storage for the tops samples (0.5 to 0.7), though the latter is unlikely to have operational impact.
Location within field	*Miscanthus* and willow SRC: for both feedstocks, the variation within fields was much greater than the variation between fields
Plant part	Depended on species: for willow SRC leaves and stems were similar; for poplar SRF leaves < tops < stems; for conifer SRF bark < tops < stem wood
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: there was a two-way interaction between climate zone and harvest time on stem levels – stems harvested in summer in warm/moist climate zones had much higher levels (0.5) than the other combinations where levels were all < 0.3. Also the percentage of Fe_2O_3 in the ash was slightly higher in the spring tops samples than summer (0.2 vs 0.1) but this is unlikely to have operational impact. Conifer SRF: there was a two-way interaction between climate zone and harvest time on stem wood levels – stems harvested in summer in warm/moist climate zones had much lower levels (0.6) than the other combinations where levels were all > 1.2
Variety (willow SRC)	Varietal differences were not significant

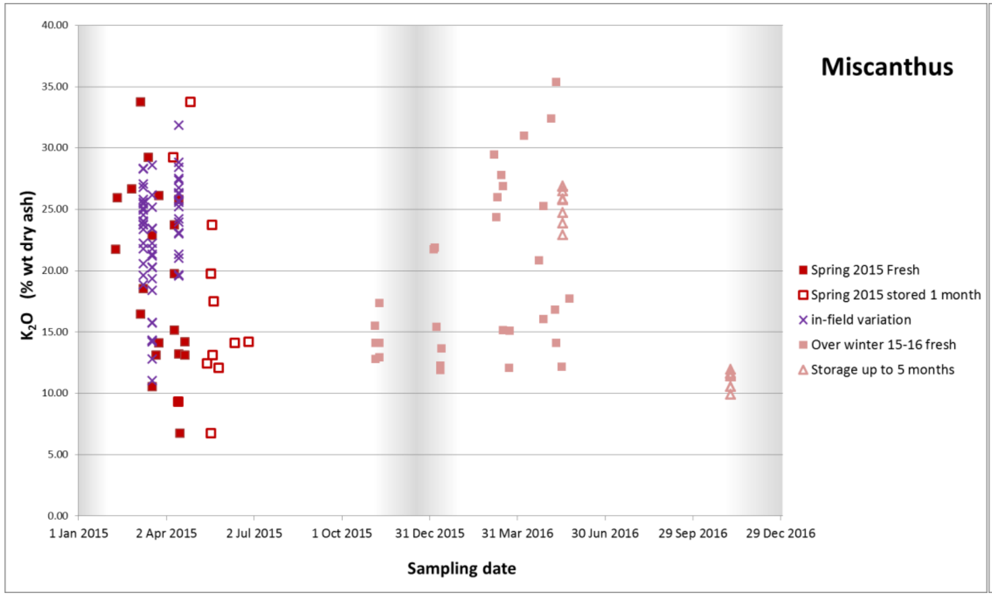

Miscanthus
Fe2O3 (% wt dry ash)
Sampling date
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

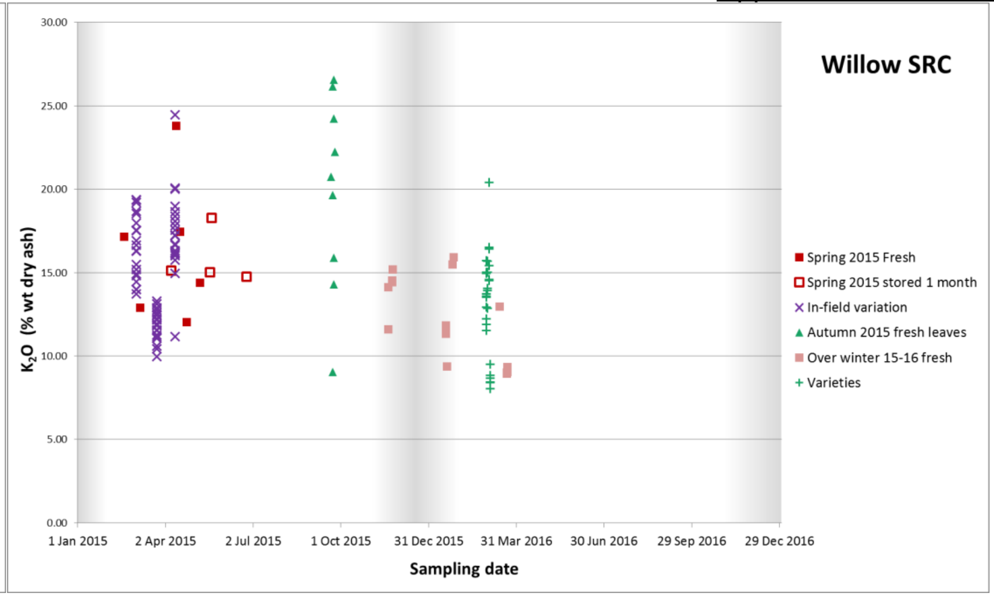

Willow SRC
Fe2O3 (% wt dry ash)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

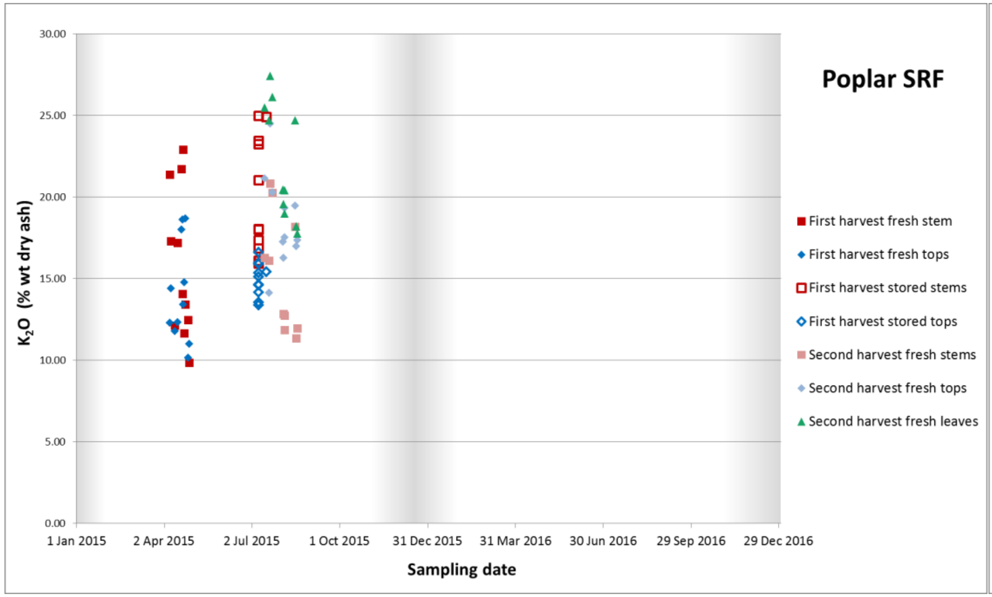

Poplar SRF
Fe2O3 (% wt dry ash)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

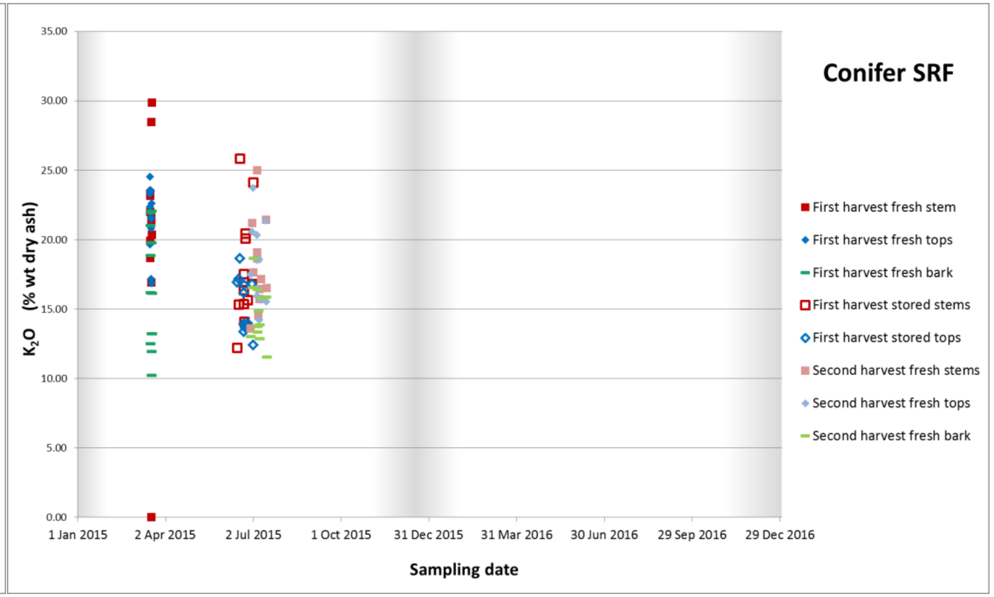

Conifer SRF
Fe2O3 (% wt dry ash)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

POTASSIUM OXIDE	In units of mg/kg in dry ash
General	This is a small but important component of the ash representing 10-25 percentage of the total ash weight
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: stem concentrations decreased from spring to summer but more so in the warm/moist climate zone than the warm/dry zone Conifer SRF: Bark samples from the cold/wet climate zone had a higher percentage of K_2O in the ash than from warm/moist climate zone (16.4 vs 14.7), though this is unlikely to have operational impact.
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* in Phase 2 there was a very large decrease during long term storage but there was no impact of storage method. Willow SRC: no significant effect of storage Poplar SRF: The percentage of K_2O in the ash was lower in the fresh stem samples than the stored samples (15.3 vs 20). Conifer SRF: The percentage of K_2O in the ash fell in storage for the stem and tops samples (20.1 to 17.8 for the stems; 19.8 to 15.3 for the tops), though the former is unlikely to have operational impact.
Location within field	*Miscanthus* and willow SRC: In *Miscanthus* the variation within and between fields was similar but for willow SRC, the variation between fields exceeded in-field variation
Plant part	For willow SRC stems tended to have lower concentrations than leaves; for poplar SRF stems < tops < leaves; for conifer SRF there was no clear differentiation
Season	*Miscanthus:* levels increased over autumn and winter but in late spring values became increasingly variable Willow SRC: levels decreased between autumn and spring Poplar SRF: The percentage of K_2O in the ash was lower in the spring tops samples than in the summer samples (14.6 vs 18.6). Conifer SRF: no significant effect of harvesting time
Variety (willow SRC)	Varietal differences were significant – Resolution had high values whereas Terra Nova generally had the lowest levels

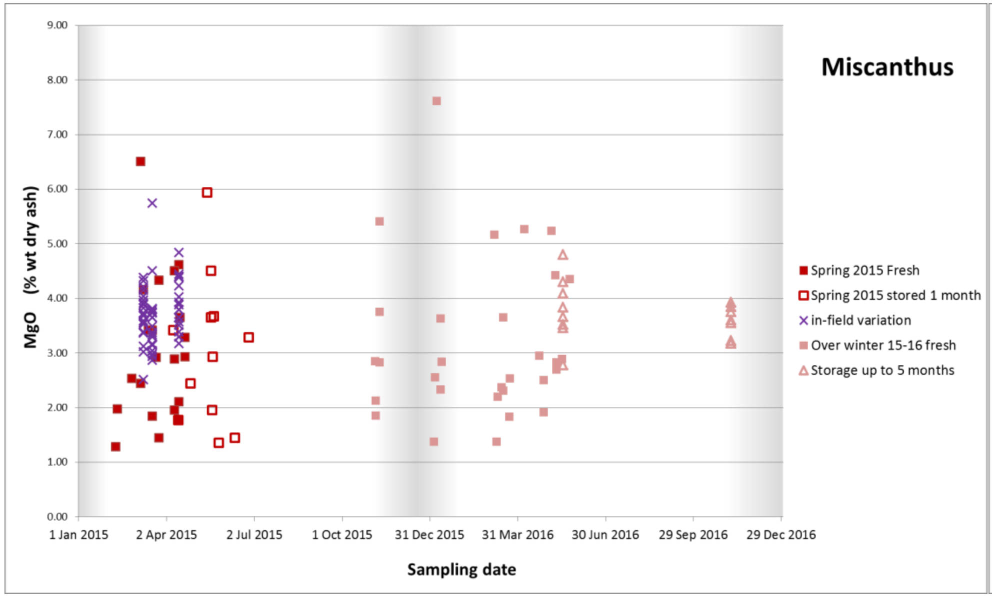

Miscanthus
K2O (% wt dry ash)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

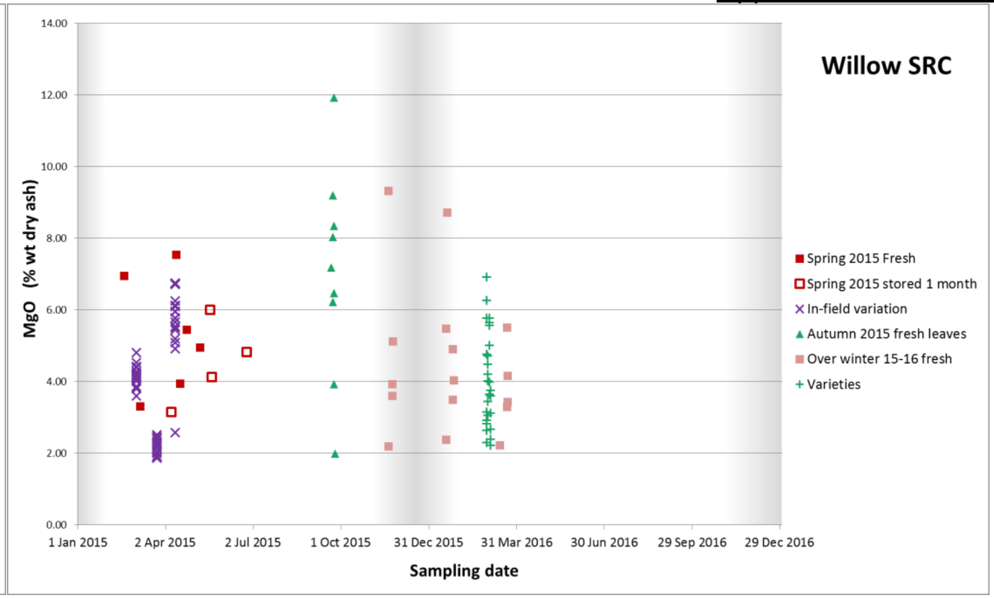

Willow SRC
K2O (% wt dry ash)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

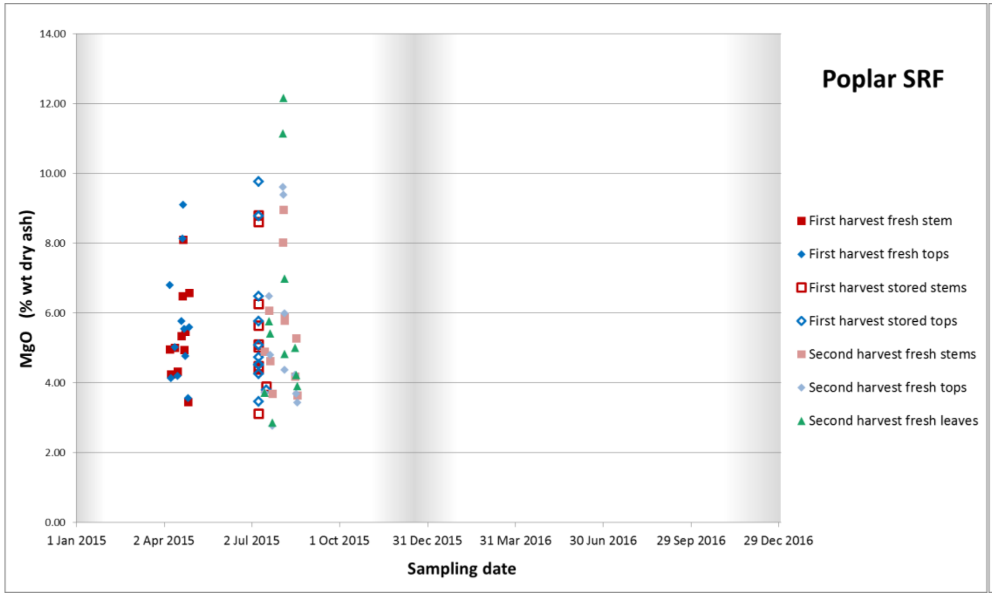

Poplar SRF
K2O (% wt dry ash)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

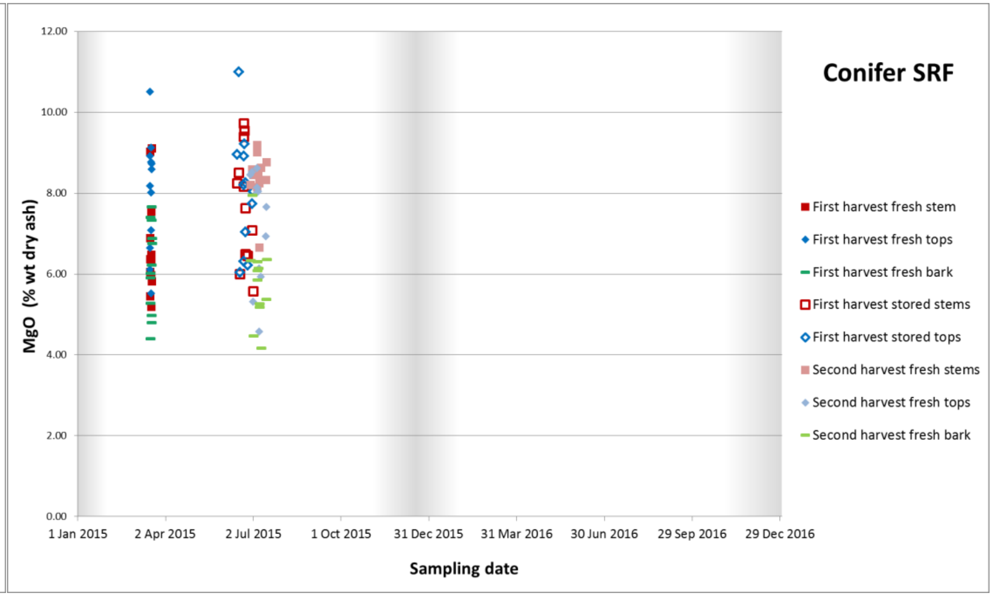

Conifer SRF
K2O (% wt dry ash)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

MAGNESIUM OXIDE	**In units of mg/kg in dry ash**
General	This was a small component of the ash accounting for 1 – 6 percentage of the total ash weight in *Miscanthus* and 3-10 percentage of the total ash weight in the other species
Source of variation	
Climate zone	*Miscanthus:* the percentage of MgO in the ash from warm/dry climate zone was significantly lower than from warm/moist climate zone (2.8 vs 4.4) Willow SRC: no significant effect of climate zone Poplar SRF: no significant effect of climate zone Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* the percentage of MgO in the ash from light soil type was significantly higher than from medium soil (3.5 vs 2.1) Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of climate zone Conifer SRF: no significant effect of climate zone
Storage	*Miscanthus:* no significant effect of storage or method Willow SRC: no significant effect of storage Poplar SRF: no significant effect of storage Conifer SRF: the percentage of MgO in the ash from stem samples rose slightly in storage (7.5 to 7.7)
Location within field	*Miscanthus* and willow SRC: for *Miscanthus* in-field variation was greater than the variation among fields but the reverse was true for willow SRC where the variation within field was less than the variation among fields
Plant part	There was no obvious distinction between plant parts in willow SRC and poplar SRF but in conifer SRF, bark < tops and stem wood
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: no significant effect of harvesting time Conifer SRF: the percentage of MgO in the ash from stem samples was lower in spring than summer (7.2 vs 8.4) but higher in the tops samples in spring (8.0 vs 7.2).
Variety (willow SRC)	Varietal differences were significant. Resolution and Endurance had the highest levels across the six sites.

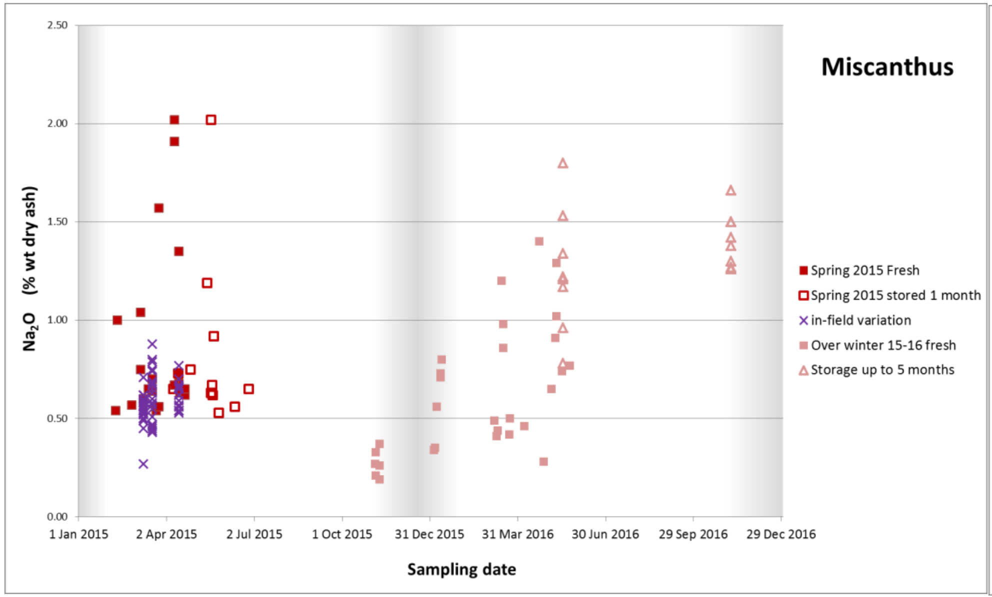

Miscanthus
MgO (% wt dry ash)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

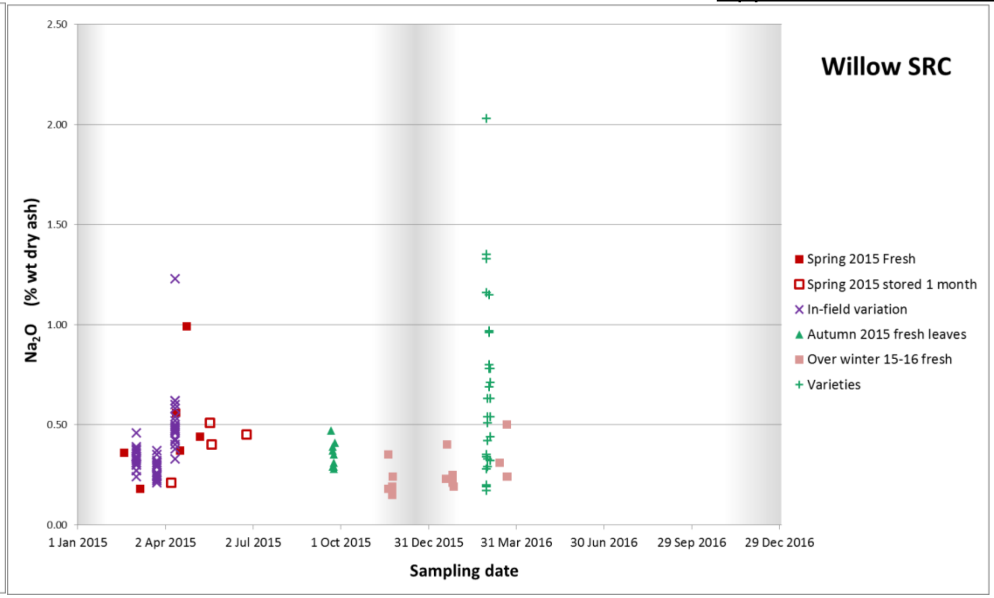

Willow SRC
MgO (% wt dry ash)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

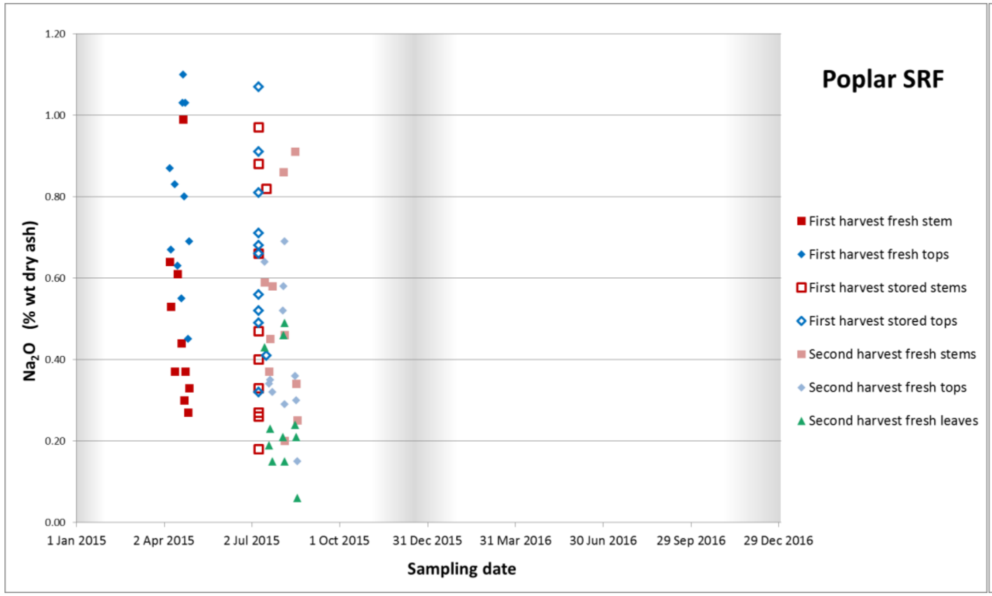

Poplar SRF
MgO (% wt dry ash)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

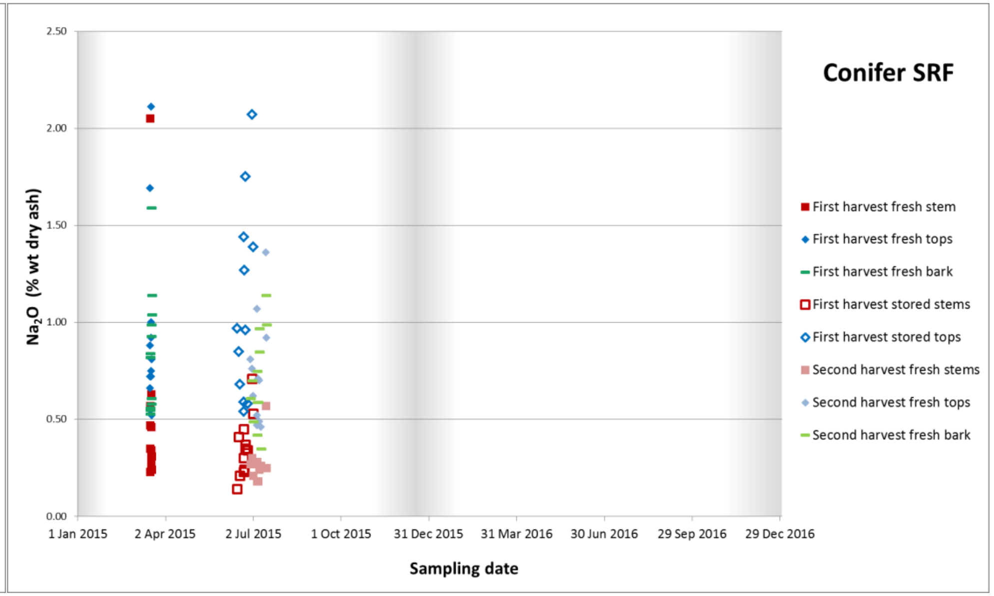

Conifer SRF
MgO (% wt dry ash)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

SODIUM OXIDE	In units of mg/kg in dry ash
General	This was a minor ash component with a range of 0.2 to 1.5 percentage of the total ash weight in all feedstocks however it is included in the calculation of Alkali Index
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: The percentage of Na_2O in the ash was lower in the tops samples and leaf samples from the warn/dry climate zone than warm/moist (0.6 vs 0.8 for tops; 0.2 vs 0.4 for leaves). Conifer SRF: The percentage of Na_2O in the ash from bark samples was higher from the cold/wet climate zone than the warm/moist climate zone (0.9 vs 0.7).
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: The percentage of Na_2O in the ash from leaf samples from light soils was lower than from medium soils (0.3 vs 0.4), but this is unlikely to have operational impact. Poplar SRF: The percentage of Na_2O in the ash was significantly higher in the tops samples and leaf samples from light soils than medium soil (0.7 vs 0.5 for tops; 0.3 vs 0.2 for leaves). Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* no significant effect of storage or method Willow SRC: no significant effect of storage Poplar SRF: There was a slight rise in the percentage of Na_2O in the ash from the tops samples in storage (0.6 vs 0.7) but it is unlikely to have operational significance. Conifer SRF: no significant effect of storage
Location within field	*Miscanthus* and willow SRC: for *Miscanthus* in-field variation dominated but there was no difference found for willow SRC; for both feedstocks the range within fields was 0.3 – 0.5
Plant part	For willow SRC leaves and stems were generally similar; in poplar SRF the relative order changed with season - in spring levels in the stem tended to be less than those of the leaves whereas in summer leaves had the lowest levels and there seemed little difference between stems and tops; for conifer SRF stem wood < bark and tops.
Season	*Miscanthus:* levels increased over autumn, winter and spring Willow SRC: no significant effect of harvesting time Poplar SRF: The percentage of Na_2O in the ash was significantly higher in the spring tops samples than summer samples (0.7 vs 0.4), though this is unlikely to have operational impact. Conifer SRF: The percentage of Na_2O in the ash was higher in the spring stem, tops and bark samples than summer samples (0.4 vs 0.3 for stems; 1.0 vs 0.7 for tops; 0.9 vs 0.7 for bark), though the bark result is unlikely to have operational impact.
Variety (willow SRC)	Varietal differences were significant with Resolution having the highest level of sodium oxide in the ash across the six sites.

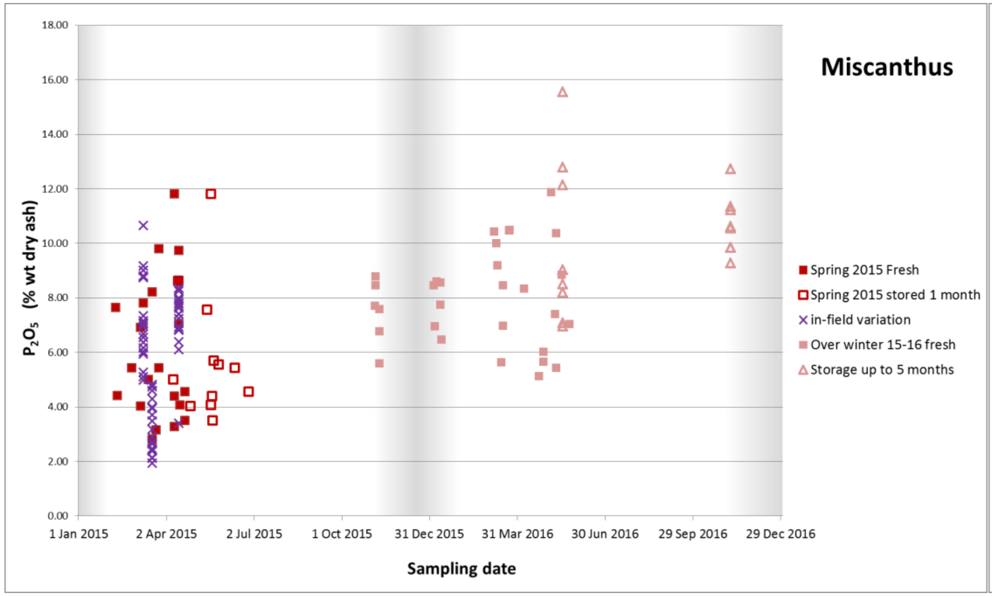

Miscanthus
Na2O (% wt dry ash)
2.50
2.00
1.50
1.00
0.50
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months

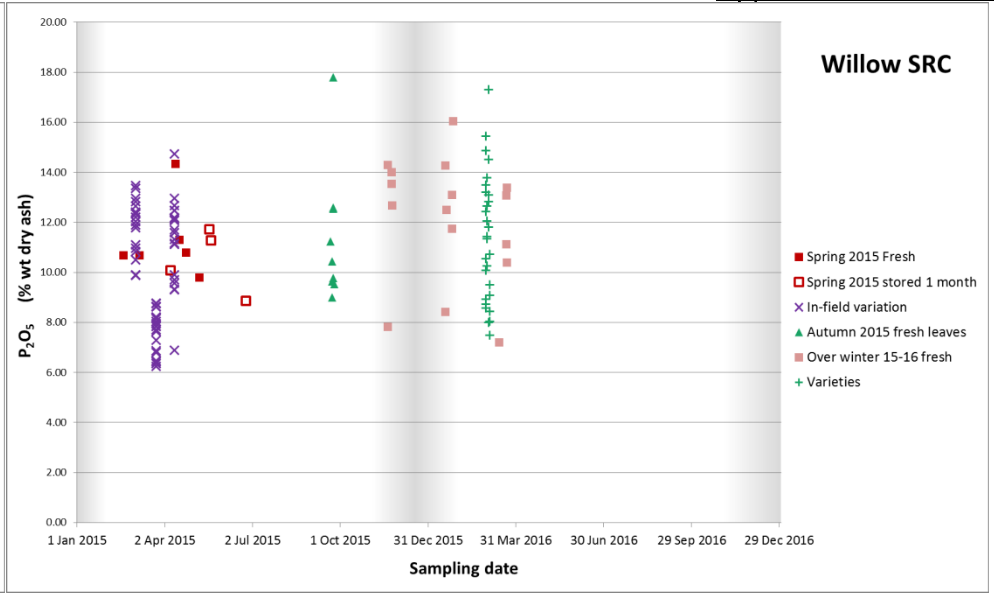

Willow SRC
Na2O (% wt dry ash)
2.50
2.00
1.50
1.00
0.50
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

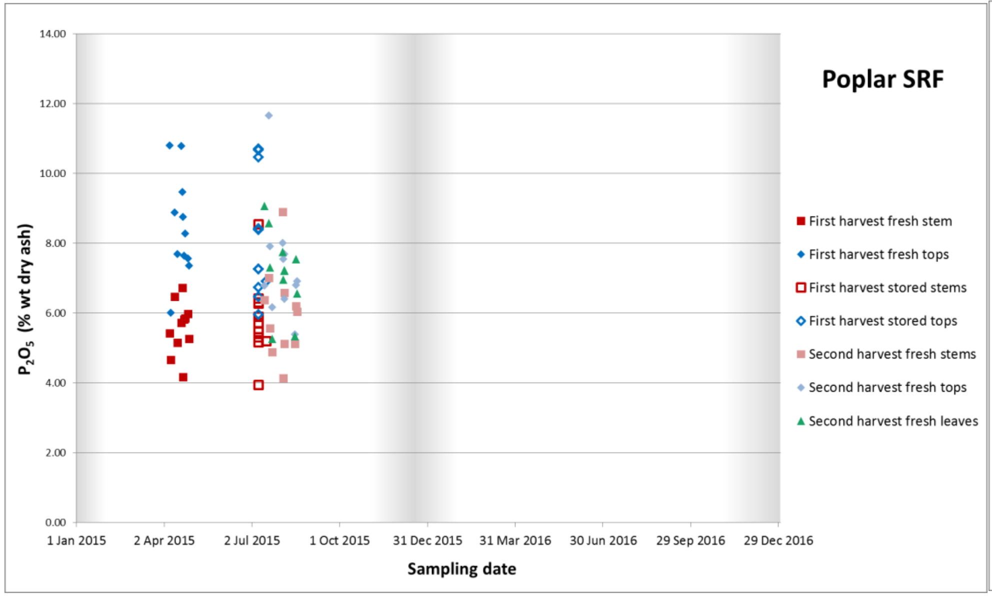

Poplar SRF
Na2O (% wt dry ash)
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

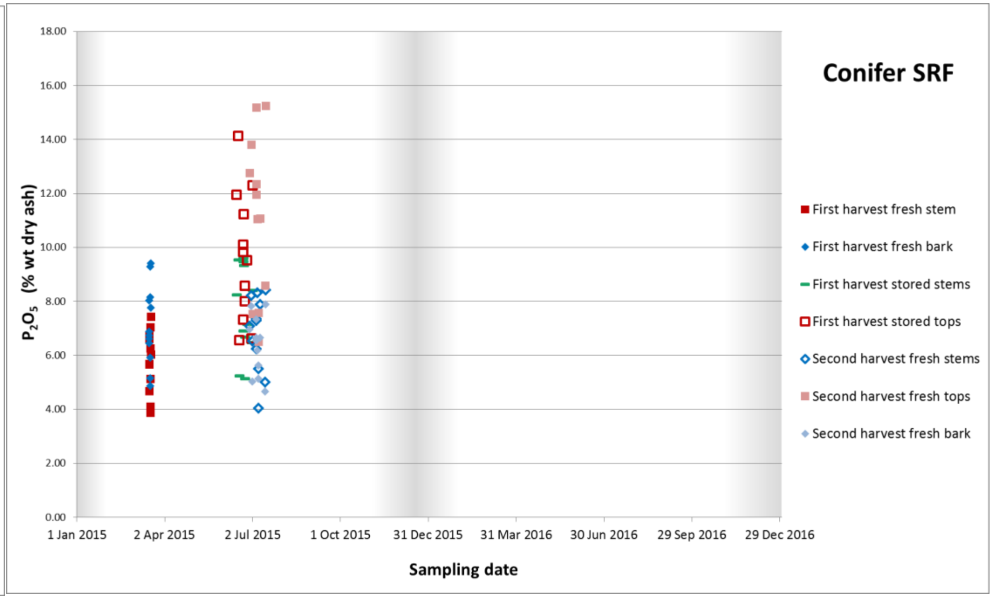

Conifer SRF
Na2O (% wt dry ash)
2.50
2.00
1.50
1.00
0.50
0.00
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

PHOSPHORUS OXIDE	In units of mg/kg in dry ash
General	This was a small component of the ash in all feedstocks comprising 4 – 12 % of the total ash weight
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: no significant effect of climate zone Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: The percentage of P_2O_5 in the ash was highest in the bark samples from peat soils (7.3), lower from the organic soils (6.6, and lowest from the mineral soils (5.1).
Storage	*Miscanthus:* no significant effect of storage or method Willow SRC: levels decreased slightly from winter to spring Poplar SRF: no significant effect of storage Conifer SRF: The percentage of P_2O_5 in the ash increased in stem wood stored from spring for 3 months from 6.3 to 7.7
Location within field	*Miscanthus* and willow SRC:
Plant part	For willow SRC leaves and stems were generally similar; in poplar SRF levels in the stem tended to be less than those of the tops and leaves; for conifer SRF stem wood and bark < tops.
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: The percentage of P_2O_5 in the ash was significantly higher in the spring tops samples than summer samples (8.3 vs 7.4), though this is unlikely to have operational impact. Conifer SRF: The percentage of P_2O_5 in the ash was lower in the spring tops samples than the summer samples (9.6 vs 11.1), but higher in the spring bark samples (7.1 vs 6.4).
Variety (willow SRC)	Varietal differences were not significant

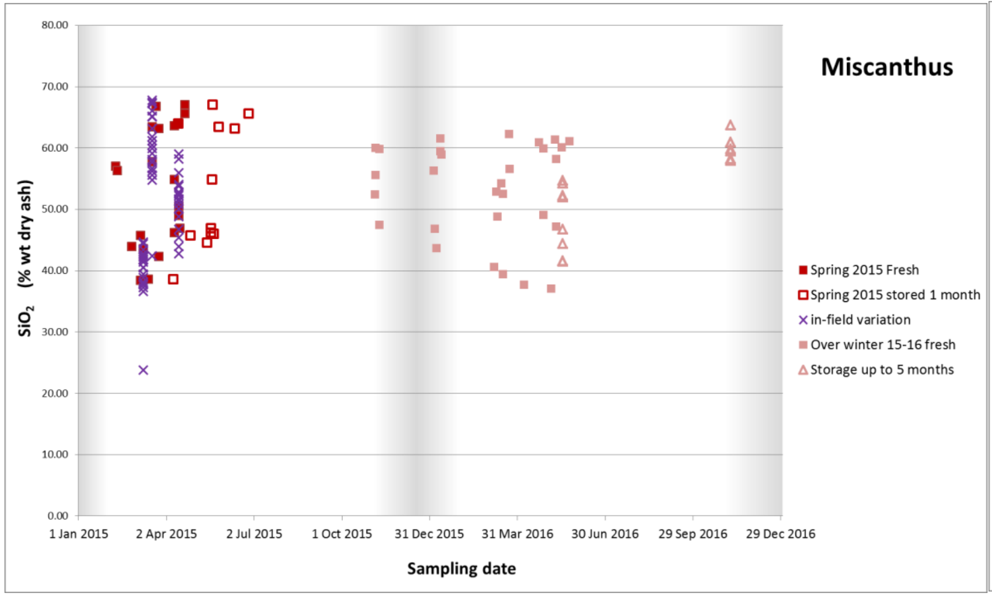

Miscanthus
P2O5 (% wt dry ash)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016

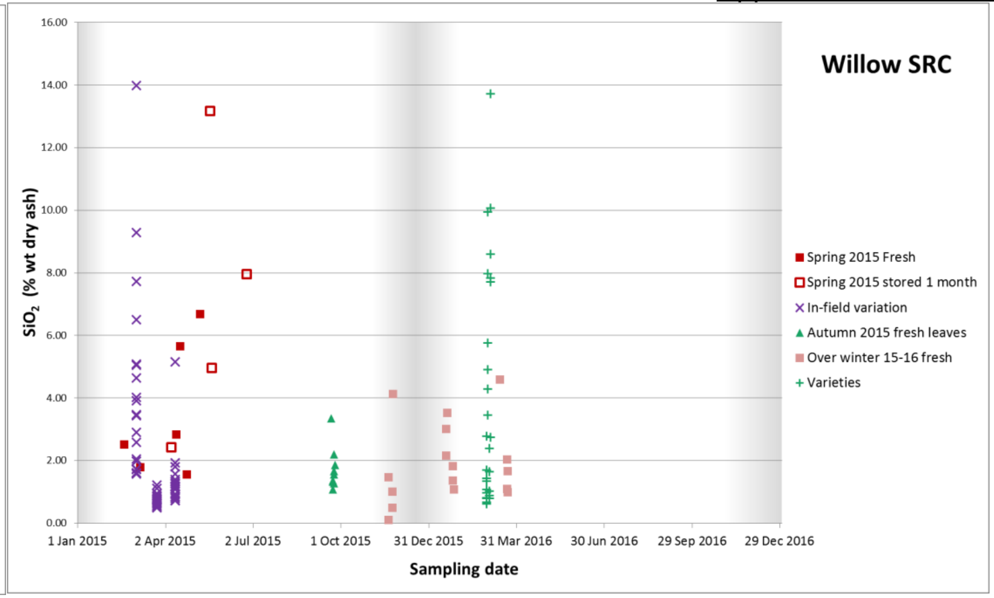

Willow SRC
P2O5 (% wt dry ash)
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties

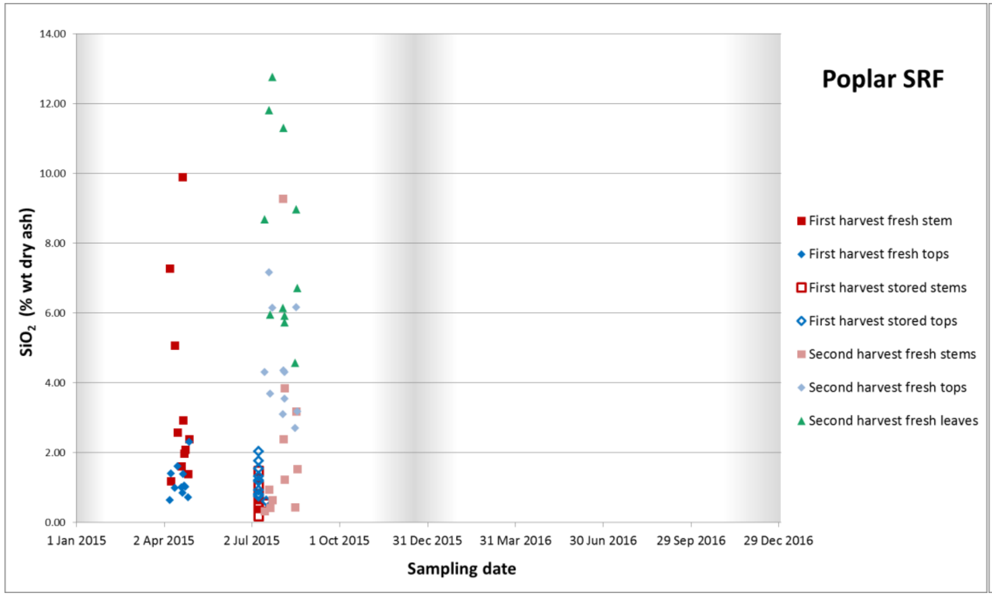

Poplar SRF
P2O5 (% wt dry ash)
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves


Conifer SRF
P2O5 (% wt dry ash)
Sampling date
First harvest fresh stem
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

SILICON OXIDE	**In units of mg/kg in dry ash**
General	There was a marked difference between feedstocks with *Miscanthus* having the highest concentration (40 – 65 percentage of the total ash weight), followed by conifer SRF (2 – 15), poplar SRF (1 -12) and willow SRC (1 -10)
Source of variation	
Climate zone	*Miscanthus:* no significant effect of climate zone Willow SRC: no significant effect of climate zone Poplar SRF: no significant effect of climate zone Conifer SRF: no significant effect of climate zone
Soil type	*Miscanthus:* no significant effect of soil type Willow SRC: no significant effect of soil type Poplar SRF: no significant effect of soil type Conifer SRF: no significant effect of soil type
Storage	*Miscanthus:* there was a large increase in levels during the storage period (48 to 60) but there was no difference with storage method Willow SRC: no significant effect of storage Poplar SRF: The percentage of SiO_2 in the ash from fresh stem samples was significantly higher than in stored samples (2.8 vs 0.6) Conifer SRF: The percentage of SiO_2 in the ash from fresh stem wood was significantly higher in the fresh than stored samples (5.9 vs 4.5); levels in tops samples were significantly higher than in stored samples (11.2 vs 8.7).
Location within field	*Miscanthus* and willow SRC: for Miscanthus in-field variation dominated whereas for willow SRC the variation within and between fields was similar
Plant part	For willow SRC leaves and stems were generally similar; in poplar SRF the relative order changed with season - in spring levels in the stem tended to be greater than those of the tops whereas in summer stems < tops < leaves; for conifer SRF stem wood and bark < tops.
Season	*Miscanthus:* no significant effect of harvesting time Willow SRC: no significant effect of harvesting time Poplar SRF: The percentage of SiO_2 in the ash was significantly lower in the spring tops samples than summer samples (1.2 vs 4.4). Conifer SRF: The percentage of SiO_2 in the ash was significantly higher in the spring stem samples than summer samples (6.1 vs), but lower in the spring tops samples (9.9 vs 11.2).
Variety (willow SRC)	Varietal differences seemed to be large but were not analysed because all varieties had fewer than three sites with complete data.


Miscanthus
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
SiO2 (% wt dry ash)
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
in-field variation
Over winter 15-16 fresh
Storage up to 5 months


Willow SRC
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
SiO2 (% wt dry ash)
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
Spring 2015 Fresh
Spring 2015 stored 1 month
In-field variation
Autumn 2015 fresh leaves
Over winter 15-16 fresh
Varieties


Poplar SRF
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
SiO2 (% wt dry ash)
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh tops
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh leaves

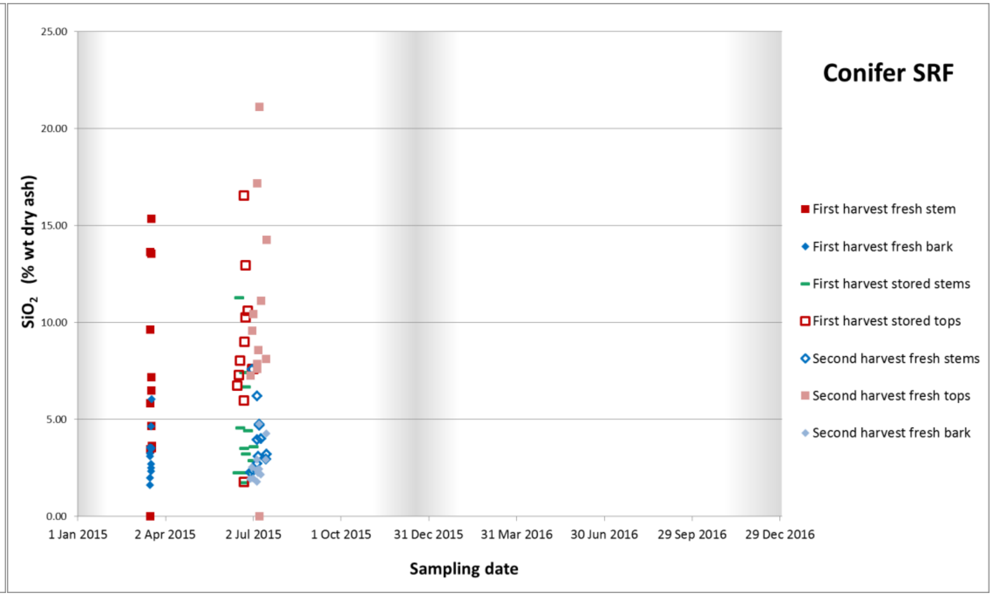

Conifer SRF
25.00
20.00
15.00
10.00
5.00
0.00
SiO2 (% wt dry ash)
1 Jan 2015
2 Apr 2015
2 Jul 2015
1 Oct 2015
31 Dec 2015
31 Mar 2016
30 Jun 2016
29 Sep 2016
29 Dec 2016
Sampling date
First harvest fresh stem
First harvest fresh bark
First harvest stored stems
First harvest stored tops
Second harvest fresh stems
Second harvest fresh tops
Second harvest fresh bark

Figure 9-1: Map showing the location of *Miscanthus* sites used in Study 5 (marked with a X) and Study 8 (marked with a +) in Phase 2 in relation to the sites used in Phase 1

Misc. = *Miscanthus;* WD = Warm/dry climate zone; WM = Warm/moist climate zone; IFV = in-field variation from Phase 1; V1 = Study 5; V4 = Study 8 from Phase 2.

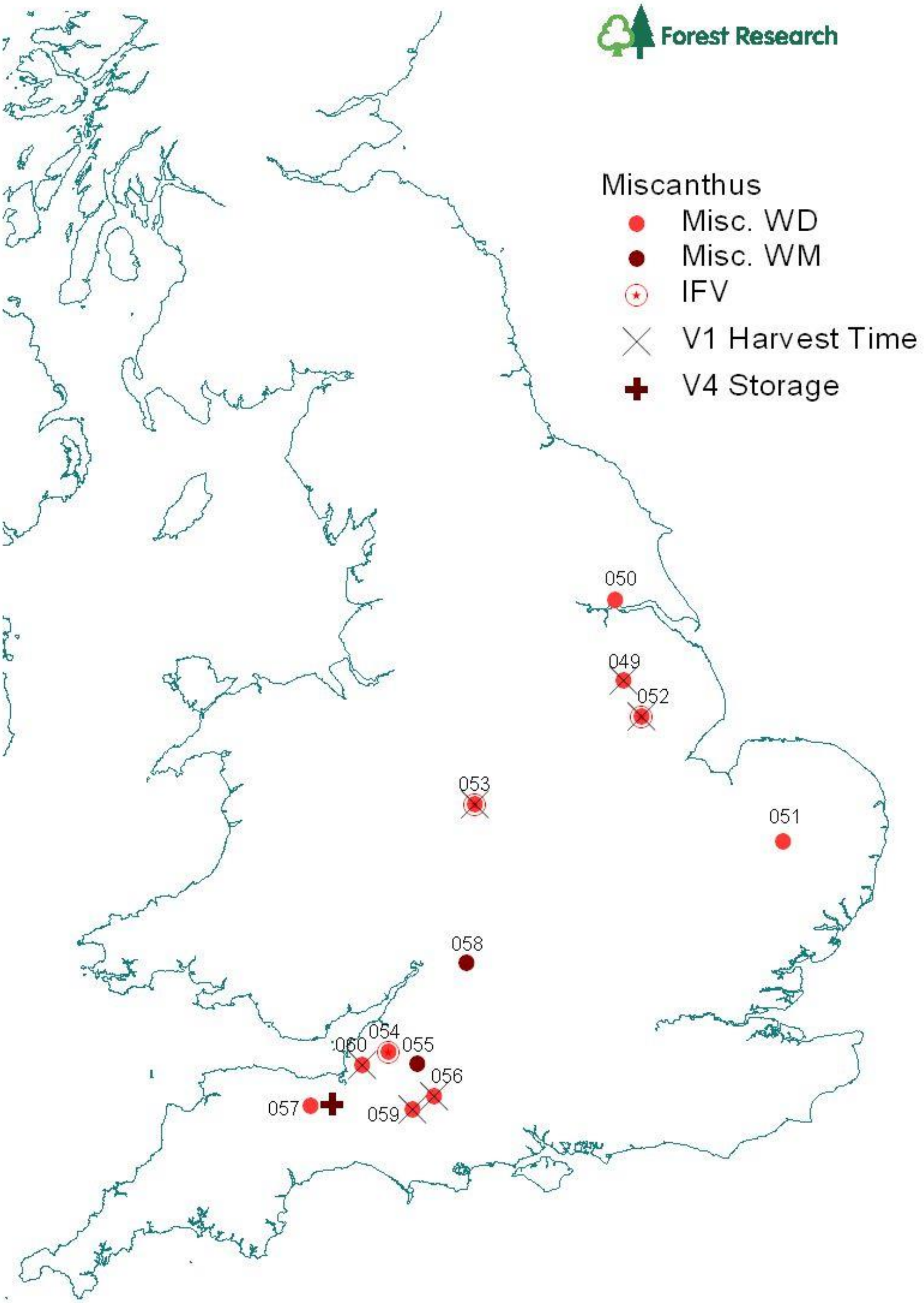


Figure 9-2: Map showing the location of willow SRC sites used in Study 6 (marked with a X) and Study 7 (marked with a *) in Phase 2 in relation to the sites used in Phase 1

Note that at Sites 13 and 16 the location of the field used is accurately located making the symbols appear slightly off centre. IFV = in-field variation; SRC-W- WD = Willow SRC Warm/dry climate zone; SRC-W- WM = Willow SRC Warm/moist climate zone; LEAF = leaf samples from Phase 1; V2 = Study 6; V3 = Study 7 from Phase 2.

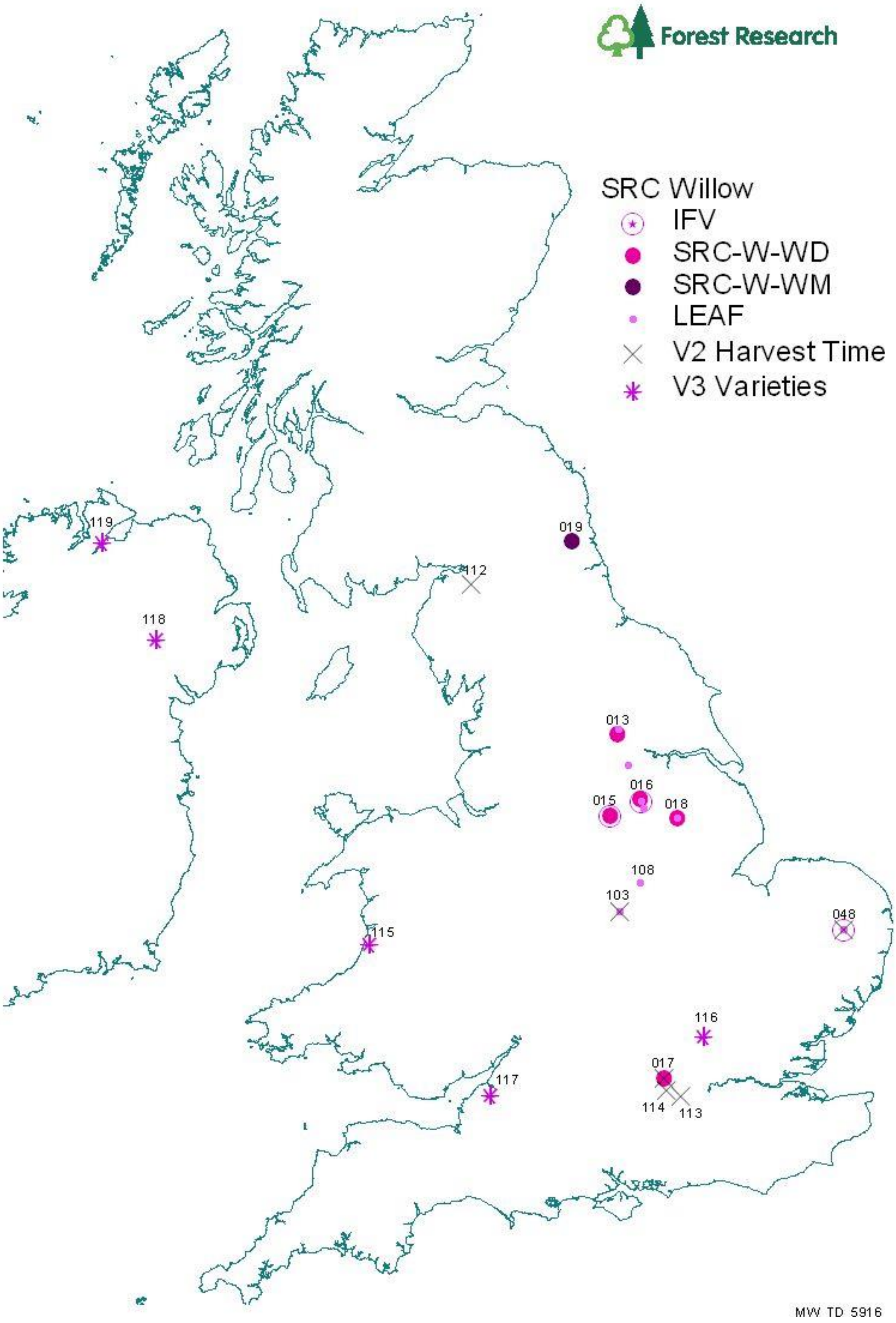


Figure 9-3: Sampling locations for poplar SRF

(WD = warm/dry climate; WM = warm/moist climate).WD = Warm/dry climate zone, WM = Warm/moist climate zone.

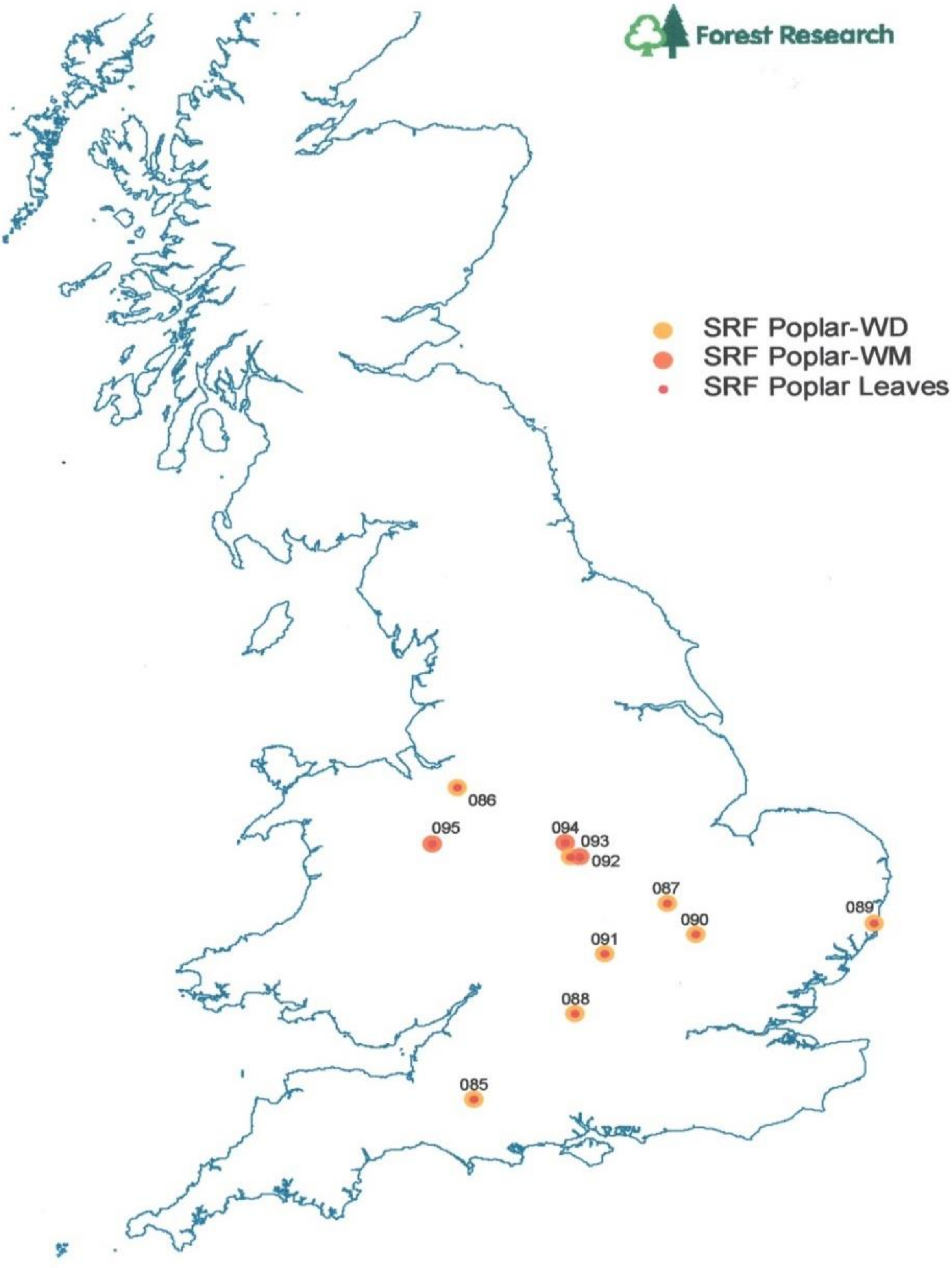


Figure 9-4: Location of Conifer SRF sampling sites, indicating site numbers used in Study 1