Willow biomass ensiling trials

Milestone report for the Productive Riparian Buffer project

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1 Background

Through the Sustainable Farming Fund (SFF) Agreement Number: 405601, the Ministry of Primary Industries (MPI) is funding a project that was co-developed by NIWA and DairyNZ – "Productive Riparian Buffers". The primary objective of the SFF Productive Riparian Buffers (PRB) project is to develop edge-of-field mitigation methods that improve water quality and ecological condition, while maintaining the productive potential of land utilised for this purpose.

The use of PRB poplar and willow biomass on-farm as tree fodder for stock was one of the original objectives of the PRB concept. This scheme aligns closely with the principle of closed loop nutrient recycling – willows and poplars intercept nutrients generated on farm in the riparian buffer before they reach a waterway; these nutrients are in turn recycled back to the agricultural land from which they originated as animal feed. Published information confirmed high growth rates of poplar and willow foliage and suggested that high feed values were possible (Kemp et al. 2001, Oppong et al. 2001, Kemp et al. 2003). This information added to the attractiveness of the PRB concept.

Although the positive aspects of use of poplar and willow in PRBs for the production of tree fodder were described in detail in the PRB literature review (Heubeck et al. 2019), the review also identified that the concept needs to overcome several technical and practical barriers before it can be implemented at large scale throughout New Zealand. These impediments included:

1. Problems associated with residual branch biomass, left behind in coppice blocks or feed out paddocks. Coppice and pollard tree branch biomass remaining in the paddock has been identified as a potential safety hazard for farm staff and stock, and has been associated with drain blockages, while branch heaps have the potential to become centres for weed propagation (Hawke's Bay Regional Council 1996, Charlton et al 2003).

2. Although large volumes of tree fodder biomass can be generated within a short period using powerful machinery, the feed material might not be utilized effectively by the number of stock on-farm. Novel feed compounds must be introduced to a ruminant diet gradually (Kirchgessner 1997). This creates the potential that mechanized harvest of PRB tree fodder will generate large volumes of biomass that cannot be utilized as intended.

3. If the biomass derived from PRBs is to be used efficiently, methods for preserving harvested biomass must be developed, so that it can be stored on-farm and fed to stock gradually over a sufficiently long period.

In New Zealand, Halliwell (1979) saw little merit in silage making from willow and poplar biomass and raised questions as to if it was possible to reliably compact and exclude oxygen from tree fodder silage. More recently, Olsen and Charlton (2003) speculated about the positive potential for ensiling tree fodder biomass from willows and poplars as winter feed for dry-stock farms. There are examples of subsistence farmers in Bhutan, northern India and Tadjikistan successfully ensiling tree fodder as winter feed supplement, primarily sourced from the willow *Salix babylonica* (SAPPLPP 2009); in the latter examples, however, the entire process (harvesting, processing and ensiling) was performed manually.

One of the tasks of the PRB project included on-farm experiments to evaluate the practicality of preserving PRB tree fodder through ensiling. This would enable mechanical harvesting and processing of PRB biomass, making management of PRBs compatible with current operations on intensive NZ livestock farms. The experiments were aimed at harvesting and preserving all available willow and poplar biomass (foliage and branch/stem biomass), with two objectives:

- to streamline PRB harvesting and processing methods, and
- to eliminate problems associated with waste tree fodder branch biomass remaining in paddocks with conventional methods (Hawke's Bay Regional Council 1996, Charlton et al. 2003).

This report summarises the outcomes of on-farm ensiling of willow coppice biomass. This task was undertaken to fulfil the requirement of milestone 8 of the Productive Riparian Buffers project, which required NIWA to:

- "Undertake trials to test the potential to incorporate materials derived from key species into silage, documenting these findings in a written report for DairyNZ."

2 Material and methods

2.1 Coppice willow block

Ensiling of the forage willow trial biomass was undertaken on the Bruce Fawcett Ltd (BFL) family dairy farm near Waharoa, Waikato. This was the site of a previous biomass harvesting trial (Heubeck, 2020), and continued the collaboration with Mr Jim Carle.[1]

The willow trial site at the BFL farm was previously described in detail (Heubeck, 2020). The willow biomass utilised for the ensiling trials was collected from the same stand of coppice willow used in the earlier harvesting trials. These trees of the willow hybrid "Tangoio" (Salix matsudana x Salix alba) were originally planted in 2014. Following coppicing in July 2019, the biomass used for trial work was the uniform regrowth of the willows until March 2020.

2.2 Willow biomass harvesting and preparation

The coppice willow that regrew from July 2019 to March 2020 had a shoot diameter at breast height (DBH) ranging from 4 mm to 18 mm (mean DBH diameter 8 mm). Individual willow plants had 3 to 6 shoots each with shoot height varying from 1.5 m to 3.0 m.

The biomass for the ensiling trials was derived from materials coppiced ~ 15 cm above ground. The coppice willow biomass was harvested on 11 March 2020. Immediately after harvest, the mixed biomass (foliage and stem) was coarsely chipped with a Hansa C21 woodchipper and tractor power unit. The chipper delivered the willow material into a farm feed-out wagon. The harvesting and chipping process provided good mixing of willow biomass grown on different areas of the willow block, as well as good mixing of the leaf and stem fractions of the chipped willow biomass. Materials were recovered for the ensiling trials by filling individual 20 L plastic buckets, which were weighed on a sack scale.

2.3 Experimental ensiling trials

For the ensiling trials, three treatments were replicated. Silage materials were added to six black polyethylene (PE) 200 L drums. The drums had screw lids, which enabled the conditions required for an ensiling trial to be achieved and maintained – control of moisture and minimisation of gas exchange (particularly oxygen ingress). Three pairs of drums were used for the following treatments:

A. Willow only – chipped willow biomass with no additives.

   - This represents the ideal option for ensiling PRB tree fodder biomass at large scale, provided the biomass contains sufficient fermentable sugars to achieve adequate fermentation.

B. Willow + Sugar – chipped willow biomass with an addition of 5 L sugar solution per drum (representing 1 kg sugar (principally sucrose) nett).

   - successful ensiling requires readily fermentable sugars to be available for lactic acid bacteria to produce sufficient fermentation acids to reduce substrate pH and stabilize the silage

[1] Former Chief of Forest Management Service, Forestry Department, FAO of the United Nations, Rome HQ and Secretary, International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC).

- because little is known about the availability of sugars in willow biomass, a sugar solution was added to the willow material to ensure that sugar-availability wasn't a barrier to successful ensiling
- this treatment is common practice with difficult to ensile forages (e.g. lucerne), where molasses is added to ensure fermentation success.

C. Willow + Maize – chipped willow biomass co-ensiled with chipped maize, filled into the drums in alternating layers (bucket by bucket).

   - maize is readily ensiled and co-ensiling with the willow biomass could be another practical method to guarantee fermentation success
   - co-ensiling PRB willow biomass with maize on the same day could potentially provide efficiency gains, because transport and compaction equipment could be utilised for the harvest of both crops.

Each drum of treatment B received a solution of 1.62 kg household molasses (Chelsea Golden Syrup), containing 1.0 kg of fermentable sugar, diluted up to a total volume of 5 L with tap water.

The maize for the two drums of treatment C was sourced from a neighbouring farm. The crop was at the late/hard dough stage and was ready for harvest. Plants were manually harvested with a machete and chipped with the same Hansa C21 woodchipper used to process the willow biomass.

The two drums of treatment A (drums 1&3) were gradually filled with 84 kg FM (fresh matter) and 75 kg FM chipped willow biomass (stems and leaves), respectively (Figure 1). The willow material was manually compacted after every new bucket was added by manual stomping. Once filled, the drums were sealed with a lid and left to ferment at ambient temperature.

The two drums of treatment B (drums 2&4) were filled with 78 kg FM and 75 kg FM chipped willow biomass respectively, and the materials were compacted in the same way. A portion of the 5 L sugar solution was sprinkled on the surface of the compacted willow biomass after every 4th bucket was added. Care was taken to distribute the solution evenly across the surface, and to avoid pooling of the sugar solution.

The two drums of treatment C (drums 5&6) were filled with alternating layers of 2 buckets of chipped willow biomass followed by 2 buckets of chipped maize. Material was compacted by manual stomping in the same manner as for the other treatments. Drum 5 was filled with 36 kg FM willow and 54 kg FM maize, and drum 6 with 38 kg FM willow and 51 kg FM maize, respectively. While these numbers indicate a fresh matter ratio of roughly 1/3 willow to 2/3 maize, because of the bulkier character of the chipped willow the volumetric ratio was approximately equal.

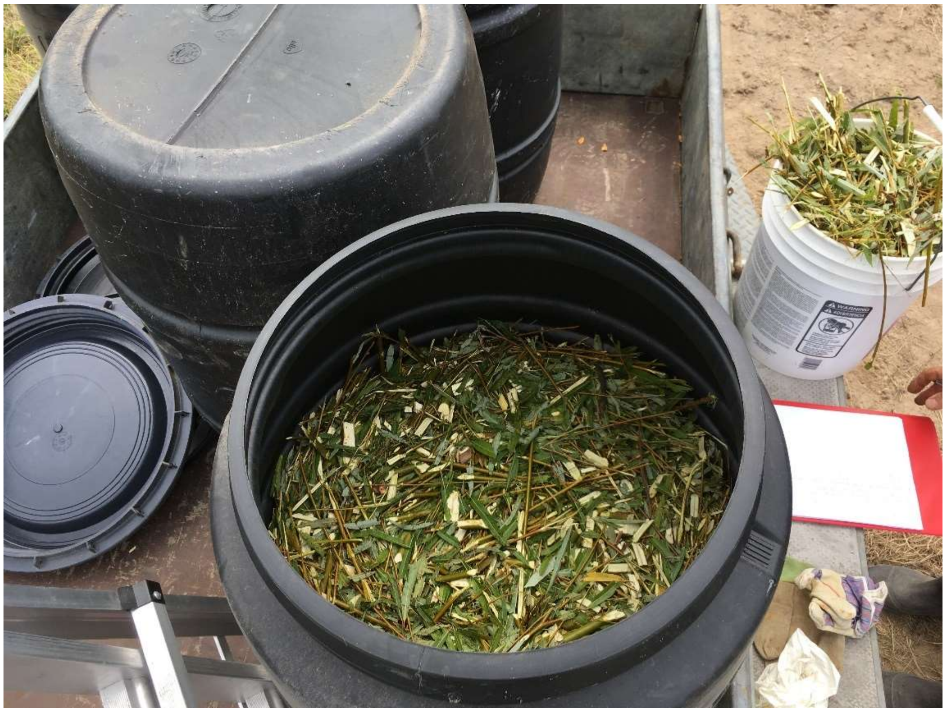

Figure 1: Filling pilot scale silage drums with chipped willow biomass. Materials were filled on 11 March 2020.

3 Results and observations

3.1 Observation of fermentation

Following their initial filling on the 11th of March 2020, the experimental drums were inspected to check the progress of fermentation on the 16th and 20th of March 2020, and on the 19th of May 2020.

Fermentation in all six drums commenced rapidly, and no obvious differences were detected between the three treatments or duplicates. The odour and colour change of the silage (Figure 2) indicated that proper ensiling was occurring, dominated by lactic acid production. From the pleasant odour, we concluded that indicators for sub-standard fermentation (e.g. ethanol fermentation, butyric acid fermentation, acetic acid fermentation, etc.), or anaerobic decomposition – malodours compounds – were largely absent.

The hedonic tone of the willow silages were reminiscent of sauerkraut rather than the generally earthy odour of well-prepared pasture silages. These observations differ from the findings of Smith et al. (2014), who found that acetic acid fermentation was dominant in a trial where coppice willow biomass from *Salix viminalis* was ensiled. One reason for this difference might be the amount of sugars available for fermentation. While Smith et al. (2014) detected 3.5% water soluble carbohydrates (including sugars) in *Salix viminalis* biomass, the biomass from the BFL farm (*Salix matsudana x Salix alba*) used in our trials had an average soluble sugar concentration of 12.2%.

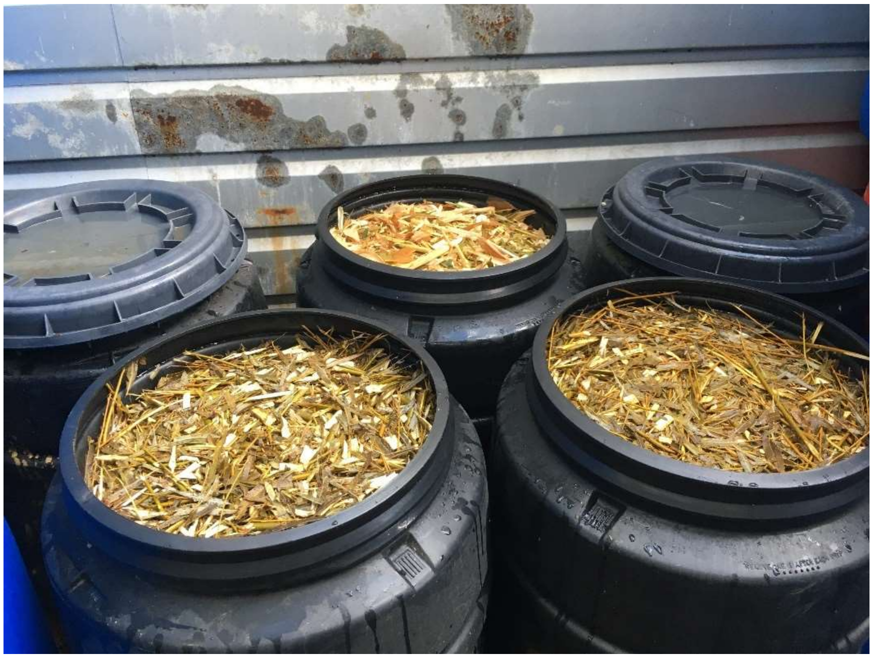

Figure 2: **Appearance of ensiled material during fermentation.** Willow only treatment (left), willow + sugar (right), and willow + maize (background). Photo taken on 20.03.2020, nine days after filling.

When the drums were inspected and sampled for feed value analysis on the 19th May 2020, some surface mould had developed in drum 4 (willow + sugar), and in drum 5 and drum 6 (both willow + maize). On the basis of visual inspection, the occurrence of mould was restricted to the top 10 cm of each drum. We believe the occurrence of mould reflects our use of a partially sealed container (the screw-lid drum) as fermentation vessel, rather than the materials selected for the trial. Solar heating and contraction and expansion of the drum contents and air in the headspace between drum contents and lid during day – night cycles could have introduced oxygen into the drum headspace and into contact with the surface of the silage. The drum had to remain unsealed to allow fermentation gases to escape. This problem does not occur at field scale, where flexible plastic covers allow fermentation gases to escape from the silage stack, while generally excluding oxygen from the silage.

When taking samples for feed value analysis on the 19th May 2020, and during the palatability test on the 28th May 2020, no leachate generation was detected in any of the silage drums.

3.2 Palatability observations

To observe how stock react to ensiled willow biomass (a novel feed), a palatability test was conducted using silage from all six experimental drums. After removing and disposing of silage material with visible mould patches, 1 kg samples were collected for feed value analysis from ~ 30 cm deep in the drums. The drums were brought back to the BFL farm on the 28th May 2020 and the contents were fed to the same herd of 330 Jersey cross cows used for the initial fresh willow biomass palatability test on the 11th of March 2020. The willow silage palatability test was conducted slightly differently to the initial willow palatability test in response to altered circumstances related to farm management.

At the time of the willow silage palatability test the cows were no longer in milk, therefore had a different feed requirement, and different daily routine. There was also less material available for the feed trial, which meant that only a proportion of the herd could consume ensiled willow biomass. The willow silage palatability test was therefore conducted in parallel to the feed out of maize silage (in-paddock feeding with a feed out wagon) and the opening of a new brake feed pasture strip. The 330 cows therefore had an eight-way choice: to consume either fresh pasture, maize silage, or material form any of the six experimental drums (representing three replicate treatments). The latter were placed in six individual heaps in a parallel line adjacent to the newly opened pasture strip and maize silage in-paddock heaps. The behaviour and feeding preference of the cows was then observed from a distance for a period of approximately 1 hour. We observed:

- several dozen of the 330 cows were eager to consume the ensiled willow biomass immediately (Figure 3), despite having access to alternate feeds (fresh pasture or maize silage).
- While the cows appeared to approach the novel feed more cautiously (presumably due to the stalky nature of ensiled willow biomass), and ate willow silage more slowly than maize silage (also presumably due to the stalky nature of the former), no clear pattern of preference between fresh pasture, maize silage and willow silage could be detected.
- It is likely that herd dynamics (hierarchy) probably determined which cows got to consume a specific feed, rather than the overall palatability of the feed in question.
- In addition, the herd did not exhibit an obvious preference or avoidance pattern for ensiled willow biomass derived from any of the three treatments.

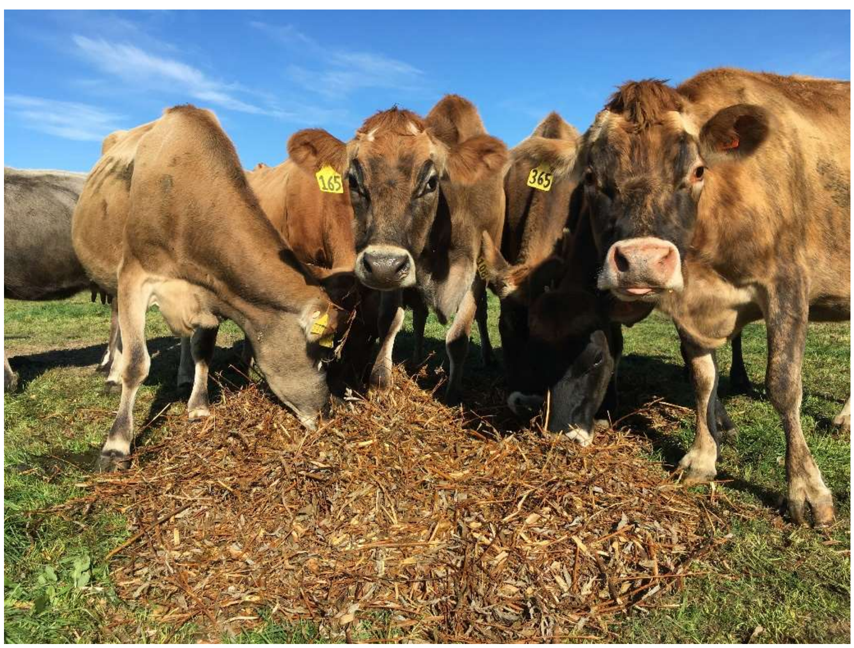

Figure 3: Cows consuming ensiled willow biomass at the BFL farm.

On the 28th of May 2020 all available feed, including willow biomass, was consumed more slowly than consumption of fresh willow biomass on the 11th March 2020. After 1 h of observation, not all of the willow silage heaps (and other feed available to the cows) was consumed. The willow silage heaps derived from the six experimental drums were therefore again inspected at the end of the day (~8hours after initial feed-out). As shown in Figure 4:

- The vast majority of ensiled willow biomass was consumed during the day, and >90% of material from each trial drum was consumed.
- As was the case during the initial palatability test with fresh willow biomass on the 11th March 2020, the left-over feed appears to be primarily composed of long, wire-like willow stem material, rather than the thickest, and most woody, willow stems.
- This indicates that shorter (finer) chipping of the coppice willow biomass could presumably have increased feed utilisation.

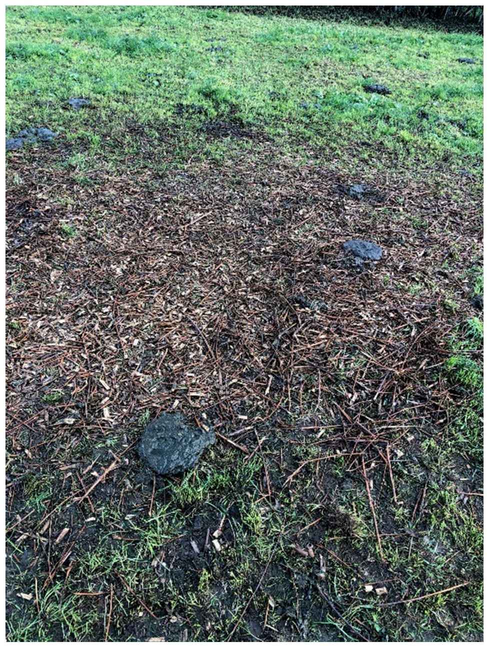

Figure 4: Residue from >70 kg of willow silage after an eight-hour feed-out period.

The wire-like nature of the chipped willow stem material also raises another practical question. We observed that the woody components of the willow biomass can pierce plastic material (e.g. the plastic sampling bags to be sent to the laboratory), even after having been ensiled for weeks. This suggests that chipped fodder biomass harvested from a PRB may pierce the silage plastic cover and allow oxygen and rainwater to penetrate the fermenting biomass. This risk is unlikely to be fully controlled, even if willow biomass is chipped even more finely prior to ensiling. However, if PRB tree fodder biomass were co-ensiled with other forages, such as grass or maize silage, the more problematic tree fodder material could potentially be isolated from the plastic with a layer of conventional forage material, known to not perforate silage plastic covers.

3.3 Feed value analysis

Representative 1 kg willow silage biomass samples were collected from each experimental drum. The six individual samples were sent to an analytical laboratory for standard feed value analysis, similar to the analysis done on the fresh coppice willow biomass samples. Key feed value parameters included: Crude Protein, Acid Detergent Fibre, Neutral Detergent Fibre, Lignin, Organic Matter, Ash, Digestibility of Organic Matter, Metabolizable Energy and Soluble Sugars. Detailed results from the analysis of the original willow biomass and each experimental drum (three treatments in duplicate) are provided in Appendix A, which provides measured values for all variables.

Table 1 provides average results of selected feed value parameters for treatment A, with the input material being mixed willow biomass only and the resultant output ensiled willow biomass only (drums 1 & 3) as sampled on the 19th of May 2020.

In Table 2, providing the key parameters for treatment B, the average input material feed value data was computed by averaging green willow biomass feed value data as sampled on the 11th of March 2020 with literature data of feed sugar (Kirchgessner 1997) on a dry matter ratio basis (3.3% DM sugar). The respective output data is the average of the resultant ensiled willow biomass + sugar solution (drums 2 & 4) as sampled on the 19th of May 2020.

Selected feed value parameters for treatment C are shown in Table 3. The average input material feed value data was computed by averaging green willow biomass feed value data as sampled on the 11th of March 2020 with literature data of dough stage maize (Kirchgessner 1997) on a dry matter ratio basis (36.7% DM willow + 63.3% DM maize), and the respective output data is the average of the resultant willow biomass + maize silage (drums 5 & 6) as sampled on the 19th of May 2020.

The ensiled willow biomass feed value analysis data in Appendix A indicates large differences in the values of some parameters between duplicate drums; for example: a 18% difference in metabolizable energy between drum 1 and drum 3 (both willow only biomass) and a 27% difference in the crude protein concentration between drum 2 and drum 4 (both willow biomass + sugar). It is unlikely that the ensiling process is responsible for such large variabilities, especially since the observation of the fermentation process (see 3.1) indicated a rather uniform, consistent and high quality ensiling process in all 6 drums. It is more probable, that the difficulty of producing a representative and uniform sample from the rather heterogeneous mixture of willow leaf and woody willow material in the experimental drums has contributed to data variability. Furthermore, the very variable soil conditions of the trial plot did lead to some variability of individual willow growth form and biomass yield, features amplified by the non-uniform effect of GWA damage on some of the trail plot willow plants. While it was assumed that chipping biomass from large stretches of the trial block into the feed-out wagon and filling mixed biomass from a large pile into the experimental silage drums would balance out most of this variability, some level of heterogeneity may have persisted.

Table 1: Comparison of selected key feed value parameters for treatment A - mixed green willow biomass and ensiled willow only biomass. (Samples taken 19 May 2020).

Willow only	**Dry Matter %DM**	**Ash Ash %DM**	**Crude Protein CP %DM**	**Neutral Det. Fibre NDF %DM**	**Soluble Sugars SoluSug %DM**	**DM Digestibility DOMD %**	**Metabolizable Energy MJ/kgDM**
Input material Mixed willow biomass	38.57%	7.97%	12.40%	34.50%	12.20%	53.70%	8.57
Output material Silage from D1+D3 (averaged)	47.35%	3.15%	5.10%	63.55%	1.90%	31.80%	5.10
% change	*23%*	*-60%*	*-59%*	*84%*	*-84%*	-41%	*-40%*

Table 2: Comparison of selected key feed value parameters for treatment B - mixed green willow biomass plus sugar and ensiled willow + sugar biomass. (Samples taken 19 May 2020).

Willow + Sugar	Dry Matter %DM	Ash Ash %DM	Crude Protein CP %DM	Neutral Det. Fibre NDF %DM	Soluble Sugars SoluSug %DM	DM Digestibility DOMD %	Metabolizable Energy MJ/kgDM
Input material Mixed willow biomass plus 3.3% DM sugar	37.42%	7.70%	12.00%	33.37%	15.06%	55.09%	8.75%
Output material Silage from D2+D4 (averaged)	46.10%	3.25%	5.20%	58.30%	4.40%	37.15%	5.90%
% change	*23%*	*-58%*	*-57%*	*75%*	*-71%*	*-33%*	*-33%*

Table 3: Comparison of selected key feed value parameters for treatment C - mixed green willow biomass plus maize and ensiled willow + maize biomass. (Samples taken 19 May 2020).

Willow + Maize	Dry Matter %DM	Ash Ash %DM	Crude Protein CP %DM	Neutral Det. Fibre NDF %DM	Soluble Sugars SoluSug %DM	DM Digestibility DOMD %	Metabolizable Energy MJ/kgDM
Input material 36.7% DM mixed willow + 63.3% DM maize	43.46	6.09	9.68	25.19	11.09	66.43	9.93
Output material Silage from D5+D6 (averaged)	39.45	4.8	6.00	57.00	1.9	43.45	6.95
% change	*-9%*	*-21%*	*-38%*	*126%*	*-83%*	*-35%*	*-30%*

Ensiling of any forage crop is a microbiological process, and as such will always be associated with loss of nutritional value (i.e. metabolizable energy, crude protein) and overall amount of dry matter, because the input material is converted to silage and the microbes consume energy while converting some of the plant biomass to microbial biomass. In conventional field-scale silage production, losses of metabolizable energy and dry matter can be higher than 25% (Muck 1988). However, the bulk of high percentage losses are associated with silage leachate losses, and secondary aerobic silage degradation (Muck 1988). Under air-tight conditions, without the generation of silage leachate and with a proper fermentation regime dominated by lactic acid fermentation, losses of key feed value parameters, such as metabolizable energy, dry matter and crude protein are less than 10% (Mayne and Gordon 1986, Muck 1988, Yahaya et al. 2002).

Observation of the experimental silage drums (see 3.1) and the palatability test (see 3.2) both indicated successful ensiling of the willow biomass. This makes it unlikely that the large losses of crude protein and metabolizable energy (input material *versus* silage) listed in Table 1, Table 2 and

Table 3 are entirely due to fermentation losses. In the same way that the large variability between duplicate drums was attributed to difficulty collecting a representative and uniform sample from the heterogeneous mixture of willow leaf and woody willow material, analysis of unrepresentative sub-samples may have contributed to the variable crude protein and metabolizable energy values observed. These difficulties also probably contributed to the differences between the fresh willow biomass and the resulting willow biomass silages (Table 1, Table 2, Table 3).

The crude protein values (ranging from 4.4% to 6.0%), metabolizable energy content (4.6 to 6.1 MJME/kg) and dry matter digestibility (ranging from 29% to 38%) (Appendix A), indicate that coppice willow silage cannot be the main feed component for highly producing dairy cows. The same conclusions were drawn by Smith et al. (2014) for silage prepared from coppice biomass of *Salix viminalis*, with 39% dry matter digestibility and 18% crude protein, respectively.

3.4 Other outcomes from the silage trial

The experiments and observations indicate that properly fermented and stabile silage with a high fibre content, albeit only low to moderate crude protein and metabolizable energy concentration, may readily be produced on-farm from mixed coppice willow biomass, without the need for specialist techniques or additives. Furthermore, the produced coppice willow biomass silage is readily consumed by dairy cows.

This approach also indicates that biomass derived from mechanised harvesting of PRB effectively eliminates the problems associated with residual tree fodder branch material derived from alternate tree fodder management systems observed previously (Hawke's Bay Regional Council 1996, Charlton et al. 2003).

We propose that ensiled coppice willow biomass may best be considered as a minor supplement component of silage, incorporated to balance the product and address limitations of other forage crops. For example, inclusion of ensiled coppice willow biomass may be used to increase the dry matter content of pasture- or brassica silages or boost the mineral concentration of maize silage (Smith et al. 2014). Coppice willow silage may also have niche applications to replace bought high fibre supplements – for example it may be used to replace straw currently used to balance the very low fibre content of diets based on fodder beet or brassicas.

Options exist to improve the nutritional value of mixed coppice willow biomass and its resultant silage through management. Kemp et al. (2003) report a 10%- 20% reduction in crude protein and metabolizable energy concentration of willow foliage between samples collected in December and March, respectively. Harvesting coppice willow biomass earlier in the season, could therefore be a practical tool to increase feed value, although this is likely to be associated with a reduction in overall biomass yield.

It has been established that willow foliage has a higher feed value than either mixed willow biomass or the woody willow stem material (Appendix A, Kemp et al. 2001, Oppong et al. 2001, Kemp et al. 2003). The feed value of mixed willow biomass could therefore be improved by reducing the proportion of thicker stem material. This may be achieved by increasing the planting density of coppice willow plants in a PRB.

It has also been observed that repeated coppicing of willow plants over several years increases the number of finer shoots in subsequent years (pers. com. Jim Carle). Over time, regularly coppiced willows grown on PRB may therefore produce a biomass with a decreasing wood fraction and an increasing feed value.

4 Summary

The key findings of the ensiling trials are:

- Mixed coppice willow biomass can be readily ensiled. To achieve a good fermentation and preservation result, there is no need to separate foliage from stem material, nor does the ensiling success rely on the addition of co-substrates such as molasses (as a sugar source) or maize biomass.
- Dairy cows readily consumed ensiled willow biomass.
  - Cows did not exhibit an obvious feed preference between treatments of ensiled willow only, willow + sugar or willow + maize biomass.
  - Overall feed utilisation was high (>90% observed).
  - Feed residues mainly comprised thin, long stem material, indicating that consumption may potentially be improved by chipping willow biomass finer prior to ensiling.
- The woody fraction of mixed coppice willow biomass was identified as a potential issue for the integrity of plastic silage covers at filed scale.
  - It may be possible to minimize puncturing of silage covers, by co-ensiling coppice willow biomass with other forages, such as maize or grass silage.
- Initial feed value analysis of ensiled mixed coppice willow biomass indicates modest concentrations of key feed value parameters such as crude protein or metabolizable energy.
  - As such, ensiled PRB coppice willow biomass cannot be considered as a main diet component for high producing dairy cows.
  - However, ensiled mixed coppice willow biomass has the potential to compensate and improve deficiencies of other forage silages when incorporated in a co-ensiled product.
- Since practical considerations, like the integrity of plastic silage covers in direct contact with chipped willow biomass or the organisation of on-farm harvesting logistics, also point towards the (co-) use of PRB coppice willow biomass as a silage blending partner, the main application scope for this novel PRB crop may indeed lay in this area, rather than with the stand alone harvest, preparation and use of coppice willow biomass silage.

5 Acknowledgements

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Appendix A Data tables

Table 1: Chemical and feed value analysis results of fresh willow biomass foliage, woody stem and mixed biomass. (Samples taken on 11th of March 2020).

BFL Farm	**Dry Matter**	**Ash**	**Organic Matter**	**Crude Protein**	**Acid Det. Fibre**	**Neutral Det. Fibre**	**Lignin**
11/03/2020	**%**	**Ash %DM**	**OM %DM**	**CP %DM**	**ADF %DM**	**NDF %DM**	**Lig %DM**
Willow Foliage 1	36.0%	10.2%	89.8%	15.2%	17.2%	28.8%	12.8%
Willow Foliage2	35.6%	10.8%	89.2%	16.0%	19.9%	32.0%	14.2%
Willow Foliage 3	36.8%	9.0%	91.0%	14.8%	21.7%	32.5%	16.0%
Willow woody stem	62.3%	-	-	-	-	-	-
Willow Mixed 1	37.1%	8.1%	91.9%	11.7%	24.5%	35.9%	13.0%
Willow Mixed 2	38.0%	8.6%	91.4%	13.1%	25.1%	36.4%	12.7%
Willow Mixed 3	40.6%	7.2%	92.8%	12.4%	21.9%	31.2%	11.0%
BFL Farm	**Crude Fat**	**Soluble Sugars**	**OMD in-vivo**	**DM Digestibility**	**Metabolizable Energy**	**Nitrogen**	**Phosphorus**
11/03/2020	**Cfat %DM**	**SoluSug %DM**	**OMDin-vivo**	**DOMD %**	**MJ/kgDM**	**N %DM**	**P %DM**
Willow Foliage 1	3.0%	16.1%	66.4%	**59.6%**	**9.5**	2.3%	0.20%
Willow Foliage2	3.0%	12.4%	63.3%	**56.5%**	**9.0**	2.4%	0.23%
Willow Foliage 3	2.9%	11.5%	59.9%	**54.5%**	**8.7**	2.3%	0.20%
Willow woody stem	-	-	-	**-**	**-**	0.4%	0.07%
Willow Mixed 1	3.1%	11.4%	56.6%	**52.0%**	**8.3**	1.8%	0.18%
Willow Mixed 2	2.8%	12.4%	57.6%	**52.7%**	**8.4**	2.0%	0.21%
Willow Mixed 3	3.0%	12.8%	60.7%	**56.4%**	**9.0**	1.9%	0.16%

Table 2: Chemical and feed value analysis results of ensiled willow biomass, from 6 pilot scale drums representing 3 different treatments. (Samples taken on 19 of May 2020).

BFL Farm	**Dry Matter**	**Ash**	**Organic Matter**	**Crude Protein**	**Acid Det. Fibre**	**Neutral Det. Fibre**	**Lignin**
19/05/2020	**%**	**Ash %DM**	**OM %DM**	**CP %DM**	**ADF %DM**	**NDF %DM**	**Lig %DM**
Willow only Drum 1	46.3%	3.1%	96.9%	5.3%	46.4%	61.3%	13.2%
Willow only Drum 3	48.4%	3.2%	96.8%	4.9%	50.3%	65.8%	13.0%
Willow + Sugar Drum 2	46.6%	2.9%	97.1%	4.4%	43.8%	57.6%	11.6%
Willow + Sugar Drum 4	45.6%	3.6%	96.4%	6.0%	44.5%	59.0%	13.1%
Willow + Maize Drum 5	39.2%	4.3%	95.7%	5.9%	40.3%	57.1%	9.4%
Willow + Sugar Drum 6	39.7%	5.3%	94.7%	6.1%	37.9%	56.9%	8.5%
BFL Farm	**Crude Fat**	**Soluble Sugars**	**OMD in-vivo**	**DM Digestibility**	**Metabolizable Energy**	**Nitrogen**	
19/05/2020	**Cfat %DM**	**SoluSug %DM**	**OMDin-vivo**	**DOMD %**	**MJ/kgDM**	**N %DM**	
Willow only Drum 1	2.4%	2.0%	36.0%	34.9%	**5.6**	0.8%	
Willow only Drum 3	1.9%	1.8%	29.7%	28.7%	**4.6**	0.8%	
Willow + Sugar Drum 2	2.2%	5.2%	39.6%	38.4%	**6.1**	0.7%	
Willow + Sugar Drum 4	2.1%	3.6%	37.2%	35.9%	**5.7**	0.9%	
Willow + Maize Drum 5	2.2%	2.2%	44.0%	42.1%	**6.7**	0.9%	
Willow + Sugar Drum 6	2.2%	1.6%	47.3%	44.8%	**7.2**	0.9%	