Harvest of PRB biomass

Milestone report for the Productive Riparian Buffer project

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Executive summary

This short report summarizes the results of field trials of Totara biomass for essential oil extraction in Northland and coppice willow biomass for the production of tree fodder supplement in Waikato, conducted as part of the DairyNZ – NIWA "Productive Riparian Buffers (PRB)" investigation, funded through the Ministry of Primary Industries as project MPI SFF40560. This report summarises project milestone 6, and specifically describes trials undertaken to test a range of harvesting methods. These results will be supplemented with other reports that describe the results of experiments regarding the preservation of tree fodder for ruminants through ensiling, and more detailed feed nutrient analysis.

Totara biomass for essential oil extraction was harvested from a sapling plot and a dense pole stand during normal silvicultural management of these tree stands (thinning, pruning). Material was also obtained from the crown of a mature Totara tree, simulating biomass recovery likely to occur in parallel with conventional timber harvest.

Manual and mechanical-manual harvesting methods were employed. Harvest productivities, expressed as mass per labour unit minute for the Totara stands were recorded as follows:

- 0.875 kg/minute (fresh matter, FM) – sapling plot,
- 0.641 kg/ minute (FM) – pole stand, and
- 0.663 kg/ minute (FM) – mature tree.

These values were measured in terms of recovery of biomass suitable for essential oil extraction.

A mixed Totara foliage biomass sample was used in a pilot scale experiment to extract essential oil using standard saturated steam distillation technology. A yield of 0.1% essential oil (FM) was obtained in a distillation time of ~ one hour. These results indicate that Totara foliage is an average substrate in terms of yield and ease of distillation. The composition of the Totara essential oil indicates unusual characteristics and the potential for use in high value applications.

Coppice willow biomass was harvested from a trial planting established in 2014. The 9-month old coppice regrowth was harvested mechanically-manually with a productivity of 3.214 kg (FM) per labour unit minute, and yielded 22.5 t/ha fresh matter, equivalent to 8.7 tDM/ha mixed biomass. A simple palatability test using chipped willow biomass showed that dairy cows readily consumed coppice willow, similar to more traditional feed supplements, including stem material. This indicates that there is no need to separate leaves from stem material if coppice willow biomass is to be used in ruminant nutrition. Feed value analysis of mixed coppice willow biomass indicated a relatively high feed value, including ~ 12% crude protein and 8.6 MJ/kg metabolizable energy.

Chemical analysis showed that coppice willows have a great potential for fixing nitrogen and phosphorus from riparian zones; they are able to retain approximately 174kg N and 17 kg P per hectare per year. These values are about one order of magnitude higher than the respective numbers for Totara biomass for essential oil extraction. Use of the biomass as feed will allow these nutrients to be recycled back into the farming system.

Overall the harvesting trials indicated that candidate PRB crops have different strengths and weaknesses. Coppice willow biomass has a great nutrient recycling potential, is easy to integrate with existing farming practices, and shows potential for future mechanisation and automation of harvest.

Totara biomass for essential oil productions is aimed at the production of a higher value product, that will require market development. This intended use is likely to be best integrated with the production of other Totara products such as general purpose or speciality timber.

These trials also confirmed that no PRB utilisation pathway can be successful in terms of ecological and financial value and benefit with a minimum amount of maintenance and care. The trials also indicate that PRBs may be tailored to many different biophysical conditions and a wide range of farming systems. This versatility should enable the concept of PRBs to be adapted and integrated to the vast majority of farming situations in NZ.

1 Introduction

This report summarises the findings of a Productive Riparian Buffers (PRB) project, funded by the Ministry of Primary Industries (MPI) through the Sustainable Farming Fund (SFF). The project was co-developed by NIWA and DairyNZ, with DairyNZ holding the main contract with MPI (Agreement Number: 405601 Productive Riparian Buffers).

The primary objective of the SFF Productive Riparian Buffers 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 – this creates the potential for a win-win in terms of economic and environmental sustainability.

This report summarizes the results of biomass harvest trials conducted as part of project milestone 6 of the PRB project.

An earlier PRB literature review (Heubeck et al 2019) identified a range of vegetation covers and utilisation pathways that could be implemented to deliver the overall project goal of reconciling environmental protection with financial yield and sustainability on the same area of riparian margin. These PRB utilization pathways included a wide range of products:

- traditional products such as timber intended for general purpose use,
- novel products such as honey produced from cultivated Rewarewa,
- native and culturally important plants such as Harakeke as well as newly introduced species such as Miscanthus, and
- from short term yielding crops such as cut and carry pasture grass filter strips to very long-term projects such as the production of hardwood timbers.

However, one common theme emerged from the literature review – for the majority of PRB products and utilisation pathways, there were open questions around the most appropriate harvesting techniques and technologies recovering these materials from the sensitive riparian environment, without compromising the overarching environmental goals of PRB. This was one of the key topics of discussion among the project stake holder group – farmers and consultants – who considered the problem to be a knowledge as well as a technology gap. A similar nexus was evident in the international literature that we surveyed.

The key purpose of the harvest trials and this report is therefore to help address this knowledge and technology gap, and provide farmers, consultants, catchment managers and researchers with better information around this complex topic. Having access to this information will be critical to widespread adoption of productive riparian buffers specifically, and the implementation of riparian buffers more generally. Recent work by NIWA and DairyNZ has established guidelines regarding the performance of riparian buffer zones for nutrient management purposes – one of the factors identified likely to impeded adoption of nutrient mitigation tools is inadequate information (McKergow et al., 2020). There is therefore a requirement for increased knowledge about riparian buffers and how they may be used to achieve multiple objectives.

Sites for field trials were identified in Northland and Waikato where different PRB products were selected for PRB biomass harvesting:

In Northland, the trials focused on the harvest of Totara biomass for essential oil extraction. This trial provides an example involving cultivation and harvest of PRB biomass for the production of a novel product for an immature market. While the trial identifies methods that may potentially be used to harvest Totara biomass at commercial scale, this utilisation pathway will remain in "pioneering" status for some time to come. It is representative of many novel and less proven PRB utilisation options and products identified through the PRB literature review (Heubeck et al 2019). Many of these PRB utilisation options and products tended to fall into the category of high value and low volume products.

The second field trials were undertaken in the Waikato. They involved the harvest of coppice willow biomass for feed supplement production. This product and utilization pathway represents a large volume, lower value PRB use option that could be adopted almost immediately by many farmers throughout NZ at scale. Uptake of these kinds of PRB uses will be facilitated by several factors:

- they may be integrated into existing farming practices with minimal effort,
- they require limited development of technology
- there is little requirement to develop a new market , and
- they are generally amenable to mechanisation and automation using equipment already available on-farm.

2 Harvest of Totara biomass for essential oil extraction

2.1 Background

The PRB literature review identified Totara as a highly versatile and potentially profitable native plant for productive use on riparian buffers, with potential to be used for general timber (section 5.4.1), essential oil extraction (section 5.8.2), pharmaceutical extracts (section 5.8.4), as well as more generally for bio-energy (section 5.2) (Heubeck et al. 2019). As a consequence of this versatility, Totara can also be considered for use in a production "cascade" – i.e. processes where the by-product / waste of one utilisation pathway becomes the input for another utilisation pathway.

In order to better evaluate Totara as a productive species on PRB, it is important to better understand the time and resource requirements for silviculture (pruning / thinning) required to produce either general purpose or speciality timber from Totara trees in PRB. Following the cascade use principle, it was also the aim of the first trial harvest to estimate labour requirements and foliage yield and recovery during pruning/ thinning, and to estimate biomass production per area that could be used as input for modelling the economics of essential oil extraction.

The Bramley dairy farm (Waiare Rd, Kaeo, Northland) has extensive stands of Totara on riparian margins and similarly sloping land. The rolling pastures and slopes dotted with stands of Totara are a landscape typical of many Northland dairy farms; similar characteristics exist on farms across New Zealand. Totara stands comprising trees of all age groups are present on the Bramley farm, including dense, young sapling stands (up to 10 year tree age), dense pole stands (with trees >100 mm at breast height (~1.5 m)), and semi mature trees, 35 – 50 years of age (representing the very earliest stages for commercial Totara timber harvesting). These stands are dominated by Totara, which in some cases are a monoculture. They will therefore very closely represent a managed Totara timber plantation established as a PRB. The dominance of Totara in these settings is partially due to grazing pressures on riparian vegetation during the 1970's and 1980's. The prickly Totara vegetation was least likely to be browsed by stock (Bergin 2003). Another factor is Totara's high tolerance for Metsulfuron herbicides, often leading to dense Totara regrowth on land where gorse has been successfully eradicated.

2.2 Test plots

Three distinct test plots were marked out in Totara stands on the Bramley farm:

1) A 0.01 ha circular, south sloping area with young Totara saplings up to 10 years of age and up to 3.5 m tall. The sapling density of this test plot was 2,300 stems/ha (a density at the higher end of a recommended range for establishing Totara wood lots on open sites (Bergin 2003)), and all saplings were due for their initial form prune; this would include total removal of saplings where spacing was inadequate.

2) A 0.01 ha circular, south sloping area with Totara poles with an average diameter at breast height (DBH) of 14.3 cm. This trial plot had an extremely high density (3,600 stems/ha), which was marked out to be thinned down to 1,200 stems/ha. This silviculture treatment simulates final thinning ~30 years prior to the first (~50%) commercial part harvest of Totara timber under a continuous cover forestry regime.

3) To cross compare the Totara foliage harvesting efficiency for essential oil extraction, a single 38 year old edge tree was felled to simulate Totara foliage harvest being carried out in association with Totara timber harvest, one manifestation of dual use (production "cascade") of Totara grown as PRB.

Pruning and thinning work was undertaken as follows:

- Form pruning of the sapling test plot was carried out manually, using tree sheers, hand clippers and a forestry ladder for easy access.
- Thinning of the pole stand and harvesting of the mature tree was carried out using chain saws and appropriate manual aids, such as forestry access ladders.
- Work time was determined with a stopwatch.

All pruning and thinning work (including all chainsaw work) was carried out by Mr Paul Quinlan, a landscape architect and coordinator of the Northland Tōtara Working Group (which is convened by Tane's Tree Trust). Mr Quinlan is skilled and experienced in these areas of forestry work. Area and labour hour productivities recorded during the trial harvest are therefore generally representative of manual and motor-manual pruning and thinning operations, carried out by a skilled operator in a riparian buffer setting.

Several hundred kg of Totara foliage from the sapling prunings, pole thinings and mature tree were recovered for subsequent trial essential oil extraction. Suitable foliage was selected and cut manually with garden shears, then weighted on a sack scale and packed for transport by two unskilled labour units. This part of the trial harvest was not representative of a commercial operation, where foliage suitable for essential oil extraction would likely be recovered much more efficiently using chain saws and tractor mounted chippers.

2.3 Trial harvest results and observations

2.3.1 Sapling plot

Initial form pruning of the sapling plot stocked at 2,300 stems/ha was carried out manually in exactly 1 hour (**Figure 1**). For the essential oil extraction trial, 105 kg fresh matter (FM) – high-quality foliage – was recovered from the sapling stand and packed for off-site processing. This represented ~ 50% of the total biomass generated by pruning. All of the pruned biomass was of high quality (no dry branches, no moss or lichen growth which could reduce the quality of essential oil extracted from the biomass) and was therefore suitable for essential oil extraction without further sorting. In a commercial setting this would allow for on-site chipping and the use of a more efficient combination of machinery and unskilled labour.

Extrapolating these numbers to larger scale, commercial PBR utilisation, it is indicated that the initial form pruning of a Totara sapling stand of 1ha area (e.g. a Totara PRB 7m wide and 1,429m long) at 5-10 years of age would require ~100 h of skilled labour. High-quality Totara biomass for essential oil extraction would be made available at a rate of approximately 20t/ha (fresh matter), which would require ~10h of additional unskilled labour to be recovered for essential oil extraction using motor-manual methods.

Figure 1: The 0.01 ha sapling plot before and after pruning. Note: The blue marker pole indicates the plot centre. Branch pile in the foreground represents biomass harvested prior to packing and shipping for essential oil extraction.

2.3.2 Pole stand

The marked out, 0.01 ha extent Totara pole stand was motor-manually thinned from 3,600 stems/ha to 1,200 stems/ha in 2.5 hours (**Figure 2**). However, it is noted that the experimental nature of the harvest did slow down the pace of work. We consider that thinning is likely to be faster in a commercial setting. Thinning the smaller trees changed the mean tree DBH from 14.3 cm to 16.7 cm, and the remaining trees had an average height of 12.8 m.

Recovery of Totara biomass for essential oil extraction from the thinned pole stand was more complex and difficult than from the sapling plot. Branch material from the dense pole stand has a higher proportion of dry branches and twigs with relatively few green leaves. In addition, many branches were overgrown with lichen and moss. Overall approximately half of the branch material from the pole stand was deemed suitable for essential oil extraction – recovering this material required labour-intensive sorting of material within the stand. The large volumes of spent branch and pole material that remained after thinning further complicated removal of biomass, particularly on sloping ground typical of riparian zones. Overall 109 kg of suitable Totara foliage biomass was recovered from the pole stand for essential oil extraction in 85 minutes using two unskilled labour units.

Figure 2: The 0.01ha pole stand after thinning, part way through Totara foliage biomass recovery. Note the large volume of dry and substandard foliage requiring careful selection and land amount of prunings on the ground, complicating manual biomass recovery.

There appear to be few options for improving biomass harvesting efficiency from the pole stand. The use of mechanical aids like winches or hydraulic booms to remove the biomass may not be practical, since there is a high risk that heavy machinery can damage trees selected for future harvest as timber products. Mechanical aids are only likely to improve the speed of biomass removal – the most labour intensive and time-consuming task (sorting high quality Totara foliage from lower quality foliage unfit for essential oil extraction) would still have to be done manually. It may be more appropriate to utilize all the biomass generated during pole stand thinning for other applications, such as bioenergy production.

2.3.3 Mature tree

To simulate Totara foliage biomass harvest from a mature stand, a 38-year-old edge tree was felled (the age was estimated from a ring count). This tree was part of a larger stand of Totara of similar age, but had poor growth form, but with a voluminous and large crown. Harvest of the foliage was carried out by hand, using tools that included tree clippers, loppers and a hand saw. When compared to material from the pole stand, the crown of the mature tree contained almost no dead branches, and twigs were thickly covered in green leaves, which were softer and less needle-like than those on the younger trees. However (most likely related to the age of the tree), the foliage from the mature tree was contaminated with lichen and moss, which necessitated careful manual separation of clean foliage fit for essential oil extraction. Despite the crown of the felled tree being accessible from three sides, selection of useable material was not straight forward and took considerable time. In total 126 kg (FM) of foliage suitable for essential oil extraction was recovered within 95 minutes. While this mass represented all foliage usable for essential oil extraction, it was only a small fraction (estimated as less than a fifth) of the total crown foliage and branch material by weight.

2.4 Comparison of harvest methods

Despite being sourced from Totara trees of different growth stages and production regimes, the recovery of high-quality Totara foliage for essential oil extraction by manual or motor-manual methods were similar in terms of labour and time requirements. Calculated per labour unit minute, 0.875kg (FM) from the sapling plot, 0.641kg (FM) from the pole stand and 0.663 kg (FM) from the mature tree crown were recovered.

It is possible to recover Totara foliage for essential oil extraction from several silvicultural activities related to forest management - thinning, pruning, final harvest. These activities occur at different growth stages in the production cycle. This indicates that it is not necessary to plant Totara as PRBs as a crop exclusively intended for the production of essential oil. Rather, the production of Totara essential oil can be an add-on activity arising from the management of Totara trees for a wide range of uses, including speciality and general timber production.

The scope for greater mechanisation of foliage recovery from pole stands and mature tree crowns appear limited, because the limiting step is manual sorting of good and bad branches and twigs. The likelihood of productivity gains is therefore also limited. Increased efficiency in recovery of Totara biomass from pruning saplings is more likely. The harvested biomass seems to be usable as-is, without requiring additional sorting. This provides scope for greater use of machinery in the field, promising substantial productivity gains at larger scale.

An additional field observation was the surprisingly wide range of appearances and colours of Totara foliage recovered from different trees, and from different branches of the same tree. Foliage from lower branches was very dark green, with pointy and stiff needle leaves, whereas foliage form upper branches was lighter green, softer, and with a more distinct pine aroma when freshly cut (**Figure 3**).

Figure 3: An example of the wide range of foliage colours, textures and structures observed on Totara trees grown in close proximity.

Sapling foliage was different again, with very long, sharp pointed leaves, of a more yellow-greenish colour. When freshly cut, sapling biomass also had a distinct citrus aroma note, in addition to the pine smells.

These observations suggest that different essential oil composition and distillation yields may be expected of Totara foliage recovered from trees of different growth stages. However, since the scope of this current project is limited to an initial investigation, it was decided to prepare only one mixed batch of Totara foliage as a general indicator for trial distillation. The batch comprised 105 kg (FM) from the sapling plot, 109 kg (FM) from the pole stand and 126 kg (FM) from the mature tree. The total of 340 kg (FM) Totara foliage was packed into a 1m^3 steel mesh crate, carefully compacted, and shipped to an essential oil extraction facility near Queenstown.

2.5 Essential oil extraction

The facility in Queenstown uses saturated steam (~100°C) distillation to extract essential oil from biomass. This is the same process used for extraction of Lavender essential oil or manuka and kanuka essential oil (Crop and Food 2000). The Totara foliage was chipped, and batch distilled (**Figure 4**), to determine overall distillation yield and yield evolution versus distillation time (i.e. ease of distillation).

Figure 4: Chipped Totara foliage loaded into the batch still, ready for essential oil extraction.

hree replicate distillation runs were conducted. The overall total essential oil yield of the Totara biomass was 1 g/kg FM (0.1%). This is lower than for Manuka essential oil (0.2- 0.6%, Essien et al. 2019) and Kanuka essential oil (0.3 – 2.1%, Crop and Food 2000). Distillation of the Totara biomass over 3 hours indicated that 90% of the distillation yield was achieved after 1 hour. This is slightly longer than typical distillation times required for Kanuka (20 – 40 minutes), but shorter than the time required for Manuka essential oil distillation (2 – 6 hours) (Crop and Food 2000). The key distillation parameters – yield and distillation time – indicate that Totara foliage is likely to be an average substrate, being neither very difficult or time consuming to work with, nor particularly high yielding and therefore cheap to produce.

To better determine the likely uses and value of Totara foliage essential oil, more research is required. However, positive characteristics of the Totara essential oil include a relatively clear and bright appearance (**Figure 5**), a fresh pine – citrus aroma, and good physical blending properties. An initial gas chromatograph analysis (propriety information) of the Totara essential oil furthermore indicates an unusual and potentially beneficial make up – a high concentration of Betacaryophyllene provides an interesting prospect for future applications in the health and beauty industry.

Figure 5: A sample of freshly distilled Totara essential oil separating from the water phase.

2.6 Summary

The key findings of the Totara harvesting trials are:

- Recovery of Totara foliage from several silvicultural management steps (thinning, pruning, final harvest) and growth stages for essential oil extraction is possible.
- For manual and motor-manual harvesting operations of Totara stands of different ages and structure, harvest productivity for essential oil extraction is similar: 0.875 kg (FM), 0.641 kg (FM) and 0.663 kg (FM) per labour unit minute for biomass from sapling plots, pole stands and felled mature trees, respectively.
- Although options for increased mechanisation of the harvest appear limited due to the requirement for manually sorting good foliage from contaminated biomass, biomass recovery from sapling plots offers some scope for further mechanisation.
- Totara essential oil yield of 0.1% (FM), recoverable within 1 hour, put Totara biomass in a mid-field position, being neither very difficult to work with, nor very high yielding.
- The market scope and potential value of Totara essential oil requires research; early indications of a unique essential oil composition suggests that potential as a high value oil exists.

3 Harvest of coppice willow biomass for tree fodder

3.1 Background

The use of poplar and willow for the production of tree fodder on PRB is discussed at length in the PRB literature review (Heubeck et al. 2019). In fact it was the initial starting point for the entire concept of PRB, since it almost perfectly adheres to the principle of closed loop nutrient recycling – willows and poplars intercept nutrients on the riparian buffer before they reach the waterway, and are in turn recycled back to the agricultural land from which they originated after use as animal feed. The high feed value of poplar and willow foliage and their high growth rates (Kemp et al. 2001, Oppong et al. 2001, Kemp et al. 2003) add to the attractiveness of this concept, as does the option of using the tree fodder from PRB strategically as emergency feed during drought years or other times of feed shortage (Hawke's Bay Regional Council 1996). In addition, willows and poplars have long been valued for erosion control and stream bank stabilisation (McIvor 2013).

The project team was very fortunate to be able to collaborate with Mr Jim Carle, 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). Mr Carle remains on the Executive Committee of the IPC. Since 2014, Mr Carle has established several forage willow trial plots on the Bruce Fawcett Ltd (BFL) family dairy farm near Waharoa, Waikato, and has allowed the PRB project team to use these for various willow harvesting trials and tree fodder tests.

The willow trial site at the BFL farm is a low-lying paddock bordering the Waitoa River, which in wet years is subject to frequent and sustained flooding. The initial aim of the willow trial plantings was to test the suitability of coppice willow as a fodder alternative for dairy cows, with the aim of establishing a productive riparian buffer along the Waitoa River, while also converting several hectares of low-lying and flood prone pasture into willow forage paddocks. The low-lying trial site is characterised by a highly variable soil structure, with light, pumice-derived soil patches alternating with heavier clay soils, while iron pans are present in parts of the sub-soil (gley soil). This complex soil structure results in varying rooting depth, and consequently different water availability during summer dry conditions on parts of the trial site only meters apart.

3.2 Coppice willow block

The coppice willow block on the BFL farm was originally established in August 2014. Site preparation included deep soil ripping (65-70 cm) at 1 m spacing. One thousand willow wands of the hybrid "Tangoio" (*Salix matsudana x Salix alba*) were hand-planted into the ripped furrows at 1 m spacing. Initial rooting and growth of the 1 m willow wands was excellent and shoot growth up to 3 m could be observed within 6 months.

Subsequently however the newly established willows suffered repeatedly from attack by the Giant Willow Aphid *Tuberolachnus salignus* (GWA, a new pest for NZ), as well as physical damage caused by cows breaking through a fence and browsing and trampling the willow plot. In July 2019, the growth of the 2018/2019 season was manually harvested to produce willow wands that were planted to expand the willow area on the farm. This resulted in the established willows being uniformly cut back to ~ 15 cm above ground level. The willow biomass for the PRB harvest trials on 11 March 2020 therefore represent the uniform regrowth of the 2014 "Tangoio" willows since July

2019. All trial harvest work and biomass trials were conducted with this coppice crop from the July 2019 regrowth.

3.3 Trial harvest results and observations

3.3.1 Total willow biomass and harvest time trial

In order to determine the coppice willow biomass yield, a representative 10 m by 2 m (= 20 m^2 nett area) sampling plot was defined within the larger trial plot of "Tangoio" willow. The sampling plot consisted of 2 parallel willow rows, four rows in from the northern edge of the planting. Even over the 10 m length of the sampling plot the willow plants showed a considerable variability in growth form and height, presumably due to different soil structure and water availability. On the 10 m by 2 m sampling plot, 28 individual surviving willow plants were counted, which had developed 3 to 6 shoots each since last cut in July 2019. The shoot diameter at breast height (DBH) varied considerably from 4 mm to 18 mm (mean DBH diameter 8 mm). Shoot height varied from 1.5 m to 3.0 m. Using the definition of Kemp et al. (2001), that willow foliage includes leaves and green stems up to 5 mm in diameter, the mean shoot DBH of only 8 mm indicates that a small fraction of the coppice biomass will be defined as woody stem biomass.

Many shoots bore evidence of previous GWA damage (scarred bark), while live GWA could be found in patches on many plants of the trial plot.

All willows harvested on the day were coppiced ~ 15 cm above ground with a chain saw (**Figure 6**). After all plants of the sampling plot were coppiced, the cut biomass (leave and shoots) were packed into a large plastic crate and weighted on a sack scale. The time required to harvest the trial plot was determined with a stopwatch. The total biomass yield was 45.0 kg (FM) from 20 m^2, equating to 22.5 t fresh matter (FM) per hectare (ha). Subsequent laboratory analysis (**Table 1**) indicated that the dry matter (DM) content of the willow biomass was on average 38.6%, resulting in a dry matter yield of 8.7 tDM/ha. This yield is considerably higher than the biomass yields of 4.32 t DM/ha/y and 7.48 t DM/ha/y for *Salix matsudana x alba* willow fodder blocks on flat and fertile land reported by Douglas et al. (1996) and Oppong et al. (2001), respectively.

The willow biomass on the 20 m^2 sampling plot was harvested with 2 labour units within 7 minutes (one person cutting and one person removing/processing the biomass), resulting in a productivity of 3.214 kg (FM) per labour unit minute. However, these numbers appear to represent the upper productivity limit, as the sampling plot was well prepared (good access) and located on flat terrain.

Figure 6: **Mechanical-manual harvest of the coppice willow trial plot.**

3.3.2 Palatability observations

Coppiced willow and other potential tree fodder crops are not widely used in NZ, particularly for dairy cow nutrition. While cattle have evolved to digest stalky, high fibre material, including shrub and tree biomass (Kirchgessner 1997), the concept of utilising PRB for tree fodder production on a dairy farm would be made unattractive if dairy cows would not find the alternative feed palatable, or would only utilise it after a lengthy adaptation period. The literature indicates that willows can contain high concentrations of potentially antinutritive or unusual-tasting compounds such as tannins and salicin (Oppong et al. 2001, Kemp et al. 2001, Kemp et al. 2003) – this knowledge is likely to raise questions about the ease of feeding coppice willow biomass to dairy cows.

To provide initial answers to these questions, as simple observation test with coppice willow biomass was conducted at the BFL farm. The biomass (stems and leaves) of ~ 450 coppice willows from the trial site (~720 kg FM) was coarsely chipped with a Hansa C21 woodchipper and tractor power unit, loaded into a silage feed out wagon and fed to a herd of 330 Jersey cross cows. This was done as “in paddock feeding” at the same time of day and in the same manner as grass and maize silage had been fed out as supplement feed in previous days (**Figure 7**). The reaction of the cows to the new supplement feed was then observed from a distance.

Figure 7: Chipped willow biomass being feed out to dairy cows from a feed out wagon on the BFL dairy farm.

It was observed that the majority of cows (~ 80%) started to consume the willow biomass vigorously and without delay. The majority of the remaining cows approached the novel feed more carefully, but after a few minutes of sniffing and trying, also started to feed on the material. Overall it is estimated that fewer than 10 cows out of the entire herd did not consume any willow biomass at all. Their reluctance to eat this material may have been primarily due to these animals trying to avoid the noise around the feed out wagon, and the other cows wrangling and pushing around the feed piles.

About 1.5 h later the cows were removed from the paddock, and the residual feed wastage was inspected. Overall the feed wastage appeared similar to the wastage that would be expected when feeding out other supplements such as grass silage. It is estimated that more than 90% of the willow biomass was consumed by the dairy herd. Interestingly, even the thicker willow stems (up to 18 mm diameter) were almost completely consumed, since the chipper was reliably cutting them to less than ~ 35 mm length. However, some of the thinner shoot tips managed to find a way around the chipper blades and ended up in the feed as longer pieces up to 150 mm long and of wire like consistency. These thin, long stem pieces were left behind by the cows (**Figure 8**), which indicates that the palatability of willow biomass for dairy cows could potentially be improved through finer and more accurate chipping.

Figure 8: Residual feed wastage of chipped willow biomass left behind by the dairy herd, around 1.5 hours after feed-out.

3.3.3 Ensiling test

For willow (and poplar) tree fodder from PRB to become widely adopted by NZ farmers, it will be important to mechanise and automate biomass harvesting. Specialised and powerful harvesting machinery offered to farmers through agricultural or landscaping contractors could provide a convenient and practical option for farmers to adopt PRB with requirement for investment, and little additional demand on already stretched labour budgets. However, harvesting large stretches of PRB by contractors with powerful machinery would result in a very large volume of tree fodder becoming available on the farm all at once. To make good use of this resource, the tree fodder would have to be preserved and fed to the animals in smaller amounts over time.

The most practical and cost- effective method for preserving large quantities of tree fodder would be ensiling it, either on its own, or in combination with maize or grass silage. Technology for handling silage is already available on most farms. However, during review of the PRB literature (Heubeck et al. 2019), no information about the requirements for or the ease of ensiling willow, poplar or any other tree fodder biomass was found. One of the goals of the coppice willow harvesting trials at the BFL farm was to test the ensiling properties of willow biomass at pilot scale.

For the ensiling trials, six black PE plastic drums with screw lids of 200 L volume were sourced. These were gradually filled with 80 - 90 kg each of chipped willow biomass (stems and leaves) and strongly compacted by manual stomping (**Figure 9**), sealed with a lid and left to ferment at ambient temperatures. A separate field report will provide details about the willow biomass ensiling experiment, the different treatments simulated in each drum, along with details regarding the feed value of the ensiled material. The latter was determined though standard feed value laboratory analysis.

One key piece of information that can be provided immediately is that chipped willow biomass can be readily ensiled on its own, without the need for a blending substrate, secondary sugar source such as molasses, and without requirement for a specific bacterial inoculum. It may be inferred that the relatively high concentrations of soluble sugars (~ 12% in the mixed biomass, see **Table 1**), measured in the willow biomass from the BFL farm, are key to this positive result. These sugars provide an easily fermentable sugar source for lactic acid bacteria, that in turn can reduce the pH and stabilize the ensiled willow substrate rapidly.

This information provides an early indication that large scale cultivation of coppice willow on PRB for the production of tree fodder, and mechanical harvesting with powerful machinery, could be relatively easily integrated with existing on-farm practices such as winter feed preparation and supplement feed out.

Figure 9: Filling pilot scale silage drums with chipped willow biomass.

3.4 Chemical and feed value analysis of willow biomass

3.4.1 Coppice willow feed value

Representative 1 kg willow biomass samples of foliage only (according to the definition of Kemp et al. (2001)), stem only, and mixed total biomass were taken from the trial plot. These were sent to an analytical laboratory for chemical analysis, primarily nitrogen (N) and phosphorus (P), to determine the nutrient recovery potential of coppice willows grown as PRBs. Standard feed value analysis was also conducted on these samples to determine key feed parameters listed in **Table 1** and **Table 2**.

Table 1: Chemical and feed value analysis results of willow biomass samples.

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 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%
Willow woody stem	62.3%	-	-	-	-	-	-

Table 2: Chemical and feed value analysis results of willow biomass samples.

BFL Farm	**Crude Fat**	**Soluble Sugars**	**OMD in-vivo**	**DM Digestibility**	**Metabolisable 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 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%
Willow woody stem	-	-	-	**-**	-	0.4%	0.07%

Kemp et al. (2001) report for summer harvested "Tangoio" willow foliage, values of 11.7% crude protein, 8.7 MJ/kg ME and 57.9% DM digestibility. These value are very much in line with the values for "Tangoio" foliage from the BFL farm reported in **Table 1**, and compare favourably with the feed value of autumn pasture or the feed value of emergency feeds such as barley straw (55% DM digestibility, 6.8MJ/kg ME, Kirchgessner 1997). However, the really interesting aspect of the feed value analysis results are the relatively small differences in key feed value metrics between willow foliage and mixed total biomass. For the parameters most important for ruminant nutrition, crude protein, DM digestibility and metabolizable energy (Kirchgessner 1997), the mixed biomass values are generally less than 20% of those of foliage-only, while the values for metabolizable energy are even more similar and high, considering the fibrous nature of these materials.

The high feed values of the mixed total biomass grown on the trial site from July 2019 to March 2020 is an important finding. It indicates that feeding of willow biomass does not require separation of foliage and stem biomass, either manually, mechanically or through selective browsing, to provide ruminants with a relatively nutritious feed supplement. Rather, foliage and stem biomass (up to 9 months old for these trials) can be harvested together without substantially reducing the feed value of coppice willow biomass. This provides considerable opportunity to mechanise coppice willow harvest, and by extension willow tree fodder grown as PRB. For PRB with a very wide Zone 3 (see Heubeck et al 2019) – 10 m width or more, it is conceivable that maize forage harvesters could be used for the harvest of coppice willow tree fodder, in the same way such machinery is currently used for harvesting short rotation energy coppice in Europe. The use of more specialised equipment, such as tree shears may allow for similar results to be achieved on narrower PRB or in riparian buffers with a steeper berm slope. When combined with the initial results from the ensiling tests (see 3.3.3), these findings suggest a high potential for mechanisation of coppice willow tree fodder produced as PRBs.

3.4.2 Coppice willow nutrient removal potential

Analysis of mixed coppice willow biomass from the BFL farm indicated a dry matter content of ~ 2.0% nitrogen and 0.2% phosphorus (**Table 1**). These values are in line with reported NZ willow literature data (Oppong et al. 2001, Kemp et al. 2001, Kemp et al. 2003), and are approximately twice as high as N and P concentrations of eight candidate native PRB plants analysed as part of this project. For example, mixed Totara branch biomass sampled on the BFL farm from the riparian zone of the Waitoa River with a dry matter content of 54% contained only 1.0% N and 0.09% P in the dry matter.

Extrapolating from the coppice willow harvest yield of 45.0 kg FM (=17.4 kg DM) from 20 m^2 (=8.7 tDM/ha) reported in section 3.3.1, approximately 174 kg N and 17 kg P per hectare were fixed during the nine month growth season and recycled with the coppice willow biomass at the BFL farm. We can obtain roughly comparable estimates of N and P for Totara sapling form pruning biomass by multiplying the 20 t/ha FM obtained over ~7 years of growth (see 2.3.1) with the Totara dry matter, nitrogen and phosphorus values mentioned above. This calculation indicates an annual fixation and removal of 15.4 kg N and 1.4 kg P. These values suggest that the nutrient removal and mitigation potential of coppice willow established as PRBs may be up to one order of magnitude greater than that of slower growing native vegetation.

3.5 Summary

The key findings of the coppice willow harvesting trials are:

- Coppice willows have a high biomass production potential. The 2020 trials indicated a DM yield of 8.7t/ha from a plot impacted by GWA damage and dry summer conditions.
- The feed value of coppice willow is relatively high, and consistent between foliage only and total willow biomass. The latter contained ~12% crude protein and ~8.6MJ metabolizable energy, with a dry matter digestibility of 54%.
- An initial palatability test showed that the majority of cows in a large dairy herd readily fed on chipped willow biomass and consumed the feed without undue feed wastage.
- Test ensiling of willow biomass at pilot scale indicates that the material can be readily ensiled and preserved with existing on-farm methods and technology.

- Mechanical-manual harvesting of a small trial plot showed a harvest productivity of 3.214 kg (FM) per labour unit minute. Considerable potential for mechanisation and automation of coppice willow harvest on PRB exists.

- The nitrogen and phosphorus removal potential of coppice willows established as PRBs was high, making willows a prime tool for inclusion in PRBs primarily aimed at intercepting nutrient inputs into farm streams.

3.6 Coppice willow future outlook

Since being established in 2014, the coppice willow block at the BFL farm suffered repeatedly from attack by the Giant Willow Aphid *Tuberolachnus salignus*, and it is likely that GWA impact observed on the harvested willow shoots may have reduced willow regrowth and possibly reduced coppice willow biomass yields. While concerns about GWA impact may currently deter farmers from establishing willow plantings as PRBs, the GWA problem is likely to become more manageable. In December 2019, Crown Research Institute Scion gain approval from the Environmental Protection Authority (EPA) for the importation and release of the parasitoid wasp *Pauesia nigrovaria* as a biological control agent for GWA. The BFL farm was one of the initial release sites for the biocontrol agent in March 2020. This occurred in a coppice willow block established in 2019, directly adjacent to the Tangoio coppice willow plot used for the harvesting experiments. If successful, the release of the parasitoid wasp should suppress GWA numbers and reduce the deleterious effect of GWA on willow growth on the BFL farm. This should subsequently occur throughout NZ. In the long term, successful biocontrol of GWA using *Pauesia nigrovaria* should increase the attractiveness of willows for use as PRBs, as well as generally increasing their use as farm trees.

4 Conclusions

Harvest trials were conducted on two different types of riparian buffer vegetation at test locations in Northland and Waikato. The different types of PRB candidate species broadly represent two extremes of a wide spectrum containing high value, low volume products such as Totara essential oil, and lower value, higher volume products such as coppice willow tree fodder.

The harvest trials confirmed that both PRB crops can be successfully harvested by manual and mechanical-manual methods, for which labour unit productivities were determined. While the potentially high value of Totara essential oil could provide an economic justification of manual and/or motor manual harvest, this is less clear for the lower value coppice willow tree fodder product.

However, the harvest trials indicate greater potential for mechanisation and automation of coppice willow used as PRB. Furthermore, uptake of coppice willow as a PRB crop is more attractive because simple, readily available technology is required, no market development is necessary, and the process could be mechanised using equipment already available on many NZ dairy farms. Dairy cows readily consume chipped mixed coppice willow biomass without requiring adaption. Feed value analysis showed that mixed coppice willow biomass has relatively high nutritional value for ruminants, and that it may be ensiled using standard methods without requirement for specialist bacterial inoculum or blending substrates. These factors suggest that coppice willow biomass produced as PRBs could be adopted by the NZ farming community at scale.

Experiments with Totara biomass indicate that production for essential oil extraction is best accomplished as an add-on to the management of Totara trees for a wide range of other primary uses, including speciality and general timber production. Based on this assumption it is also indicated that Totara biomass for essential oil extraction may not be the most attractive crop in situations where yields can be maximised, or production costs minimised, but Totara may be most attractive for those farmers able to tap into a lot of collaboration potential, not only with other farmers, but also other Totara focused initiatives and projects around New Zealand.

The different harvesting trials indicate that selection of PRB candidate species should consider factors other than just products and production pathways. For example, these trials indicate that:

- coppice willows used for tree fodder production provide approximately one order of magnitude greater potential to fix and remove nitrogen and phosphorus from the riparian zone than Totara biomass for essential oil extraction
- However, the nutrient removal potential of Totara biomass for essential oil extraction is still greater than for the largely passive PRB utilisation pathways Rewarewa honey production or carbon credit farming discussed in the PRB literature review (Heubeck et al 2019).
- In turn, PRB utilisation pathways utilizing native species are likely to provide greater biodiversity and habitat benefits.

Finding a balance between these and other factors or criteria was beyond the scope of this project, but should be addressed in future research to ensure that farmers, regulators and the community have a balanced view before investment decisions are made. This would include consideration of the requirements of the National Policy Statement for Freshwater Management (NZ Government, 2019)

The experimental work has also indicated that successful and sustainable PRBs require some maintenance and care. This is illustrated by the Totara pole stand described in section 2.2, and shown in Figure 2. The photograph shows how an excessively dense pole stand has essentially supressed all understorey vegetation, exposing bare ground. On sloping land this exposed ground will always be at risk of erosion, and therefore represents a potential risk for downstream water quality during storm events. The thinning exercise conducted as part of these trials illustrated how:

- Totara biomass may be harvested for essential oil extraction, while
- providing the remaining trees the conditions required to grow into valuable timber producers, and
- enabling sufficient light to reach the ground to enable the re-establishment of an understorey.

The understorey will help to cover and protect the bare ground and minimize the erosion risk from this patch of Totara trees.

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