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The Potential for Temporary Stand-Off Pads Integrated With Poplar and Willow Silvopastoral Systems for Managing Nitrogen Leaching

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Intensive pastoral farming has been linked to adverse environmental effects such as soil degradation and increased fluxes of nitrogen, phosphorus, sediments, and pathogens into waterways, resulting in their degradation. Stand-off pads are engineered structures covered with bedding materials, available for occupation by stock to minimise those adverse effects to soil and water bodies. Wood chips are ideal for bedding due to their low cost, high water holding capacity, and stock preference as resting areas. While they reduce the mobility of both nutrients and pathogens, their effectiveness depends on the type of wood, size of the chips, pH, pad design, and feeding management used. Dissolved organic carbon, present in wood residue, may slow nitrogen mineralisation thereby decreasing loss *via* leachate. This effect depends on plant tannins and nutrients already stored within the plant tissue. Poplar and willow have high concentrations of tannins in leaves and bark with potential nitrification-inhibiting properties. When grown on-farm, these deep-rooted trees also reduce nitrogen leaching and prevent soil erosion. This review addresses the use of temporary stand-off pads within poplar or willow silvopastoral systems. Harvested trees can provide suitable wood chips for constructing the stand-off pad, while the deep rooting systems of the trees will reduce the moisture content of the pad, preventing waterlogging. A key objective is to discuss the feasibility and establishment of multiple temporary stand-off pads that allow for stock rotation from pad to pad, and subsequent on-site composting of wood-wastes into fertiliser, reducing both nutrient inputs and losses in agricultural systems. The review highlights the potential suitability of poplar and willow tree species for such a system.

Keywords: stand-off pad, woodchips, wood waste, nitrogen absorption, tannins, dissolved organic carbon

NUTRIENT LEACHING FROM FARM SYSTEMS

Growing concern around the environmental sustainability of the dairy and beef industries has attracted scientific as well as public interest, with worldwide media coverage around impacts on water quality and the pollution of waterways (Gmür, 2015; Van der Zee, 2018; Cardello, 2019; Praveen, 2019). In particular, the leaching of nitrate (NO_3^-) into ground- and surface water is receiving increasing attention because of its adverse effects on drinking water, rivers and streams (Fenton, 2012). The majority of the nitrogen (N) input is derived from stock urine, which is rapidly converted from ammonia (NH_4^+) into nitrate (NO_3^-), once infiltrated into the soil. NO_3^- has a high potential for leaching as it does not bind onto negatively charged soil colloids due to its negative charge (Latifah et al., 2017).

Nitrogen leaching into waterways is a topic of major interest in New Zealand (Ausseil and Manderson, 2018), and due to ongoing population growth and intensifying agriculture an issue of international relevance (Mahmud et al., 2021). Whereas parts of this review focus on agricultural systems in New Zealand, similar systems may be adapted for other countries to overcome nitrogen leaching problems and high nutrient loads in waterways and groundwater. Literature around the use of woodchips in "stand-off" pads or "corrals" has been published in the last decade, however the wood species and the properties of phytochemicals within the chipped material has attracted only minor interest.

This review hence aims to focus on timber species with plant phytochemicals that may play a role in nitrification inhibition pathways, and their potential inclusion into sustainable farming systems in New Zealand, with international interest. Sections Stand-off Pads in Agricultural Systems and Wood Residues in Stand-off Pads provide an overview of the use of woodchips in current stand-off pad designs and their role in management of nitrogen leaching. Sections Poplars and Willows in NZ Farming Systems and A Silvopastoral System Producing Woodchips for Temporary Stand-off Pads discuss the establishment of poplar and willows in farming systems to potentially mitigate nitrogen loss and generate organic material for application as fertiliser.

Literature has been reviewed using various databases with keywords "woodchips" in "stand-off pad", "corral" and "agricultural systems", and focus on "plant secondary metabolites" and "phytochemicals" in "poplar" and "willow" species, including "biological nitrification inhibition" compounds.

STAND-OFF PADS IN AGRICULTURAL SYSTEMS

Leaching of NO_3^- in agricultural systems is especially high during winter months due to increased soil water content and limited vegetation cover and growth. In those months, soil damage is also significantly greater due to increased pugging, which results from soil trampling (Arends, 2016). Moving stock out of open pastures onto separate areas, so-called stand-off pads, out-wintering pads or corrals, can reduce soil damage and NO_3^- leaching from farm systems (Luo et al., 2004) without compromising animal performance, health, or welfare. Using engineered stand-off pads (**Figure 1**), the farmer can control the amount of animal effluent deposited onto the soil and return the collected effluent onto fields over at a rate that maximises pasture growth and minimises NO_3^- leaching (Luo et al., 2004). The surface area of stand-off pads is often covered with different types of bedding (Ferreira Ponciano Ferraz et al., 2020), including wood materials, such as wood chips, bark chips or sawdust. The bedding material in stand-off pads has to be regularly replaced as cows avoid resting in wet or waterlogged material (Longhurst et al., 2013). Coarser material suffers less compaction over time, thus resulting in better drainage and lower moisture content, which is preferred by stock (Longhurst et al., 2013). To trap animal excreta and liquid wastes, the surface layer is commonly built over an artificially-drained system, allowing effluent to be collected and separated into solid and liquid wastes (Augustenborg et al., 2008).

To avoid or mitigate adverse environmental effects and meet animal welfare criteria, such engineered stand-off pads need to meet legal requirements and have to be properly designed and engineered, which can be associated with high costs. Such requirements vary between regions, regulatory authorities and countries, but often include: recommendations for the minimum area (e.g., 4.0–12.0 m^2/cow), setbacks from dwellings (e.g., 200 m distance from dwelling not located in the same landholding), setbacks from watercourses and water abstraction points (e.g., not located within 100 m of a water abstraction point), overflow and stormwater regulations, and design requirements such as impermeable lining material and thickness of padding material (Dairy NZ, 2017; Environment Southland, 2018). In addition, for medium to long-term use of a stand-off pad, building consents may be required, highlighting the need for further research to remove ambiguities (Ryan, 2009; Smith et al., 2010; AHDB, 2011; Dairy NZ, 2017). Waterlogging in the pad leads to negative impacts on stock health, and thus good maintenance of drainage is essential in such systems (Stewart et al., 2002). Therefore, engineered stand-off structures can require infrastructure that may not be present in all areas of a farm or paddock.

As an alternative, short-term solutions have been investigated where an adsorbent surface material overlies free-draining soil, with no engineered structure to collect leachate (Vinten et al., 2006; Smith et al., 2010; Christianson et al., 2017). Although these "short-term" or "temporary" pads can reduce costs and offer animal welfare and environmental benefits (such as reduced soil pugging or the on-site "treatment" of organic wastes), care has to be taken to avoid groundwater pollution (CREH, 2005). "Short-term" pads are unlikely to pose environmental risks if they are small, lightly stocked and at some distance from wells and waterways. However, they will still be subject to environmental regulation. Besides stocking density and distance from waterways, many other factors such as rainfall, slope, soil type, or surface material determine the leachate NO_3^- load and volume (CREH, 2005). Lysimeter and field studies in this context can further investigate different bedding materials, their performance for animal welfare, and their potential for absorbing nutrients and contaminants, hence reducing pollution of waterways and groundwater. Lysimeter

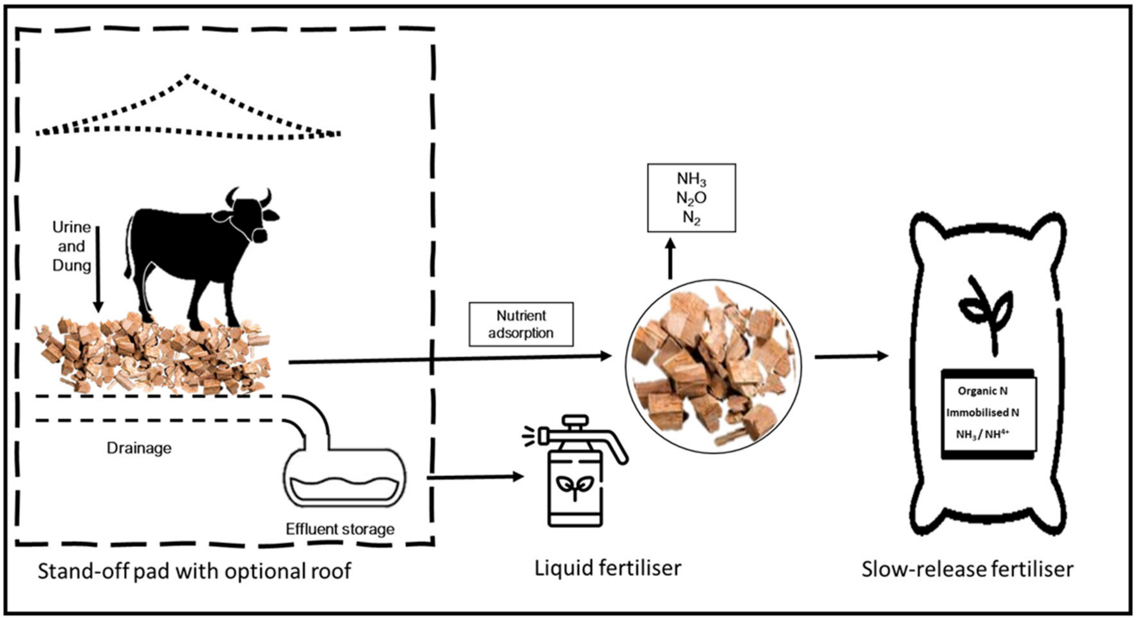

FIGURE 1 | Stand-off pad systems using wood waste bedding materials.

studies allow monitoring of different N speciation throughout the soil and in collected leachate (Paramashivam et al., 2015; Esperschuetz et al., 2017) and provide opportunities to test such materials in different controlled environments. Field studies equipped with sampling devices and drainage collection systems can verify results from lysimeter experiments *in situ* (Al-Marashdeh et al., 2017).

Moving stock out of paddocks into barns (henceforth referred to as " MOOtels") can further reduce soil damage and N leaching from farm systems, simultaneously increasing animal performance, animal health and welfare. "MOOtels" describe open-barn structures with bedding materials to absorb urine and dung, which is turned daily to allow a maximum of animal welfare (Piddock, 2015). The bedding material in such "MOOtels" could be sourced from trees on-farm or nearby wood processing industries. This material immobilises nutrients, especially N from stock excrement. Maintained properly, the bedding material can be turned into compost and used within the farm system or sold as a nutrient-rich compost product with beneficial properties for soil and stock health, depending on plant materials used in the bedding.

WOOD RESIDUES IN STAND-OFF PADS

For stand-off pads, many surface materials have been investigated, including sand, gravel, rubber mats, shredded newspaper, cardboard, wood residues and crop residues such as shredded chestnuts or oilseed rape straw residues (Ward et al., 2001; HCC, 2010; Logan, 2011; Dairy NZ, 2017). Woodchips may have certain benefits over other materials due to their low cost, good water absorption capacity, and provision of a soft and warm stock bedding, which is preferred by stock compared with other materials (Gregory and Taylor, 2002; Mills et al., 2016; Dairy NZ, 2017). Stand-off pad designs using woodchips as a bedding material are common in the UK, Ireland and New Zealand (Christianson et al., 2017).

The volume of wood chips required for an engineered stand-off pad can be calculated on the basic space recommendation of 5 m^2/cow, the number of cows, and the pad chip depth of 500 mm. For example, a total volume of loose wood chips of 750 m^3 is required for a pad area of 0.15 ha for 300 cows.

Wood chips are commonly sourced from commercial providers. However, an unexplored alternative is obtaining wood chips directly from roundwood harvested from farm woodlands and chipped on-site (CREH, 2005; Dairy NZ, 2017). Assuming a ratio of loose woodchip to roundwood volume of 2.6 and an annual forest roundwood yield of 40 m^3/ha, a forest area of 7.2 ha is required to provide a roundwood volume of 288 m^3 which is equivalent to 750 m^3 of wood chips.

To maximise the efficacy of the stand-off pad, the wood chips require monthly renewal: scraping-off of the top 100 mm off the surface is recommended by Dairy NZ (2015). Additionally, a woodchip top-up may be required to maintain the pad's recommended 500 mm woodchip depth. The woodchip area should also be well-drained to prevent waterlogging or bedding material from becoming too wet (Dairy NZ, 2015). Stand-off pads that are in poor condition are likely to result in stock disorders and diseases. However, processes within and below the woodchip bedding that may potentially influence the health and wellbeing of stock are not well researched. This lack of reliable information poses difficulties in making management recommendations for stand-off pads.

The use of woodchips has become popular, especially in temporary stand-off solutions, where the surface material is directly applied to soil— either with or without topsoil removed (CREH, 2005). In such scenarios, the woodchip-soil bedding needs to capture and adsorb a significant amount of the stock effluent and potentially harmful compounds therein. Depending on woodchip size, the depth of the woodchip layer and the thickness and soil type underlying such pads, some of the nutrients or even contaminants and pathogens may be leached out of the pad and enter waterways and groundwater (Fenton, 2012). The woodchip-soil matrix in temporary stand-off pads with no engineered drainage should ideally be capable of capturing all liquids that result from stock inputs, or at least adsorb nutrients and contaminants within the pad structure, so the leachate output does not pose risks to the environment.

Studies that are available from trials investigating free-draining stand-off pads show contradictory results, and the leachate quality depends on a variety of factors, including stock density (Smith et al., 2010; Fenton, 2012), woodchip species (Ward et al., 2000, 2001; Molnar and Wright, 2006; Vinten et al., 2006; Luo et al., 2008), woodchip size (Shukla et al., 2002; Smith et al., 2010) and soil type (CREH, 2005; Camberato, 2007). Woodchips have been shown to absorb moisture and bind solids, and enable the formation of biofilms on woodchip particles that can assist in N-transformation processes, hence biologically treating leachate passing through the woodchip surface (Smith et al., 2010; Fenton, 2012). Materials with a high cation exchange capacity (CEC) can be capable of retaining contaminant particles, including N as well as faecal bacteria (Luo et al., 2008), but research around processes at the woodchip-soil interface is scarce, and contaminant removal by bedding materials in stand-off pads needs further research (Fenton, 2012). However, leaching of environmental contaminants, such as N, P and faecal microorganisms, can be high—especially if such temporary pads are overstocked (Smith et al., 2010; Fenton, 2012) and/or located in areas with high rainfall or sandy soils (CREH, 2005). A risk assessment considering all individual factors in the farm scenario can help to assess the potential loss of contaminants through a system (Fenton, 2012). Depending on the size and the tree species from which they were manufactured, wood chips can hold between 200 and 300% of their weight in water (Smith et al., 2010). Smaller chip sizes have a higher water holding capacity than larger ones, likely due to their higher specific surface area. Site restrictions must be considered in areas prone to frost since effluent flow through the woodchip surface may be impeded (Smith et al., 2010).

Wood Residues to Adsorb Nitrogen

Different wood residues have been widely used as soil amendments in agricultural systems and investigated regarding their water holding capacity and use as animal beddings (Schofield, 1988; Deininger et al., 2000; Ward et al., 2000; Molnar and Wright, 2006; Vinten et al., 2006). Wood material, such as sawdust, bark or wood shavings, can adsorb nutrients, especially nitrogen (N), hence minimising the risk of these leaching into groundwater and waterways. The (dry) wooden material can act as a filter for up to 90% of animal N and phosphorous (P) inputs (Christianson et al., 2017) due to a large number of negatively-charged binding sites called the cation exchange capacity (Shukla et al., 2002; Dumont et al., 2014). CEC indicates the amount of negatively charged binding sites available to adsorb positively charged ions, such as NH_4^+. The adsorption ability of such wood residues mainly depends on the CEC and surface area since this controls the capacity to hold water (Dumont et al., 2014). In conjunction with CEC variations, pH can potentially affect the absorbency rate of NH_4^+- into the woodchip matrix, where an increase in pH would result in lower adsorption rates (Özacar and Sengil, 2005 as supported by Shukla et al., 2002). In addition, studies have suggested microbial immobilisation plays a large role in removing N from leachate (Bolan et al., 2004).

The N removal capacity of different wood chips varies depending on the size and type of the woodchip and other factors such as pad design and feeding management (O'Driscoll et al., 2007; Murnane et al., 2016). Depending on diet and feeding management, there may be variations in the dry matter content of the dung and N concentration in the effluent (Smith et al., 2010). Also, the wood residue type (tree species, particle size) can influence the capacity to remove N and other contaminants in agricultural systems (O'Driscoll et al., 2007; Dumont et al., 2014). However, contradictory results have been published concerning the NH_4^+-N retaining capacity of wood chips and its correlation to particle size. Luo et al. (2004) reported NH_4^+-N as the most common form of N in drainage in a lysimeter study investigating the effect of animal effluent on leachate quality through soil, bark, wood chips and zeolite. In contrast, sawdust and bark have been shown to retain >90% of the applied N, indicating that the N loss through leaching is almost negligible (Luo et al., 2008). Vinten et al. (2006) observed no effect of woodchip particle size on N retention, contradicting the assumption that NH_4^+ retention by wood residues is correlated to the particle size of the material.

Other studies propound the importance of osmotic pressure since it has been suggested that high osmotic pressure in a solution (e.g., effluent) may force NH_4^+-N into the low-osmotic pressure woodchip material until the point of equilibrium (Abdoun et al., 2003). Therefore, using wood residues in stand-off pads that are high in NH_4^+-N themselves may not result in any significant N adsorption, thereby resulting in leachate containing high N concentration that subsequently enters the environment (Dumont et al., 2014).

Nonetheless, Smith et al. (2010) suggest that temporary stand-off pads result in less N leachate per animal than an overwintering grass field. However, after dung and effluent have been filtered through the woodchip pad, the nutrient content within the leachate may still exceed maximum allowable values for receiving waters (Murnane et al., 2016).

NH_4-N has been reported as the dominant proportion of N in leachates from woodchip pads (Luo et al., 2004; CREH, 2005), which may be a result of high NH_4-N loading rates (dung, stock effluent) followed by rainfall so that there is not enough time and surface area within the woodchip matrix for adsorption to prevent N from leaching. In some studied woodchip pads, NH_4-N concentrations of leachate range from 76.1 to 399.1 mg l^{-1}

per day during stocked periods (CREH, 2005). The potential and capacity of wood residues for removing N has been investigated in mixtures where wood residues have been either turned into biochar or blended with biochar (Sironi et al., 2009; Ruane et al., 2010; Christianson et al., 2011). These studies have tested the N removal capacity in leachate by reducing NO_3-N *via* enhancing N_2O losses *via* denitrification or enhancing the adsorption of NH_4-N onto negative binding sites. Reyes-Escobar et al. (2015) have investigated the use of biochar as a matrix to adsorb plant extracts, generating a complex that prolonged the nitrification inhibition at field condition.

Contradictory results have been reported as to what extent N adsorption takes place in woodchip materials (Dumont et al., 2014). Nutrient dynamics in the woodchip-soil matrix and at the woodchip-soil interface are likely to be different from a soil profile, where nitrification and denitrification usually occur in the upper soil layers (CREH, 2005). The removal of N from the woodchip-soil matrix *via* denitrification involves bacteria that convert NO_3^--N to N_2O and N_2 and may reduce N compounds in the leachate. However, N_2O is known as a greenhouse gas and ozone destroyer, so its formation must be taken into account when mitigating NO_3-N loss at the cost of N_2O production, hence causing potential adverse environmental impacts (Abusallout and Hua, 2017). Nevertheless, N removal mechanisms in woodchip filters have been suggested as being of physical rather than biological origin (Murnane et al., 2016). The role of condensed tannins in wood residues and plant parts may be strongly related to N transformation, complexation and leaching processes out of stand-off pads hence further research will help to identify better woodchip-stand-off-pad designs. Mixing woodchips with other materials and farm wastes such as biochar may provide further possibilities to improve bedding systems (Christianson et al., 2017) and enable more sustainable farming practices.

Phytochemicals in Wood Residues

All plants contain chemical compounds necessary to assist in their metabolism, defend against pathogens or give them a competitive advantage (Joanisse et al., 2007). Such "phytochemicals" are commonly characterised by hydroxylated aromatic rings and are categorised as secondary metabolites (Swain, 1979; Julkunen-Tiitto, 1986; Nichols-Orians et al., 1992; Orians, 1995; Orians et al., 2000). Among secondary metabolites, tannins are considered as one of the largest groups, including condensed tannins and hydrolysable tannins as subgroups (Adamczyk et al., 2013). Secondary metabolites are commonly synthesised in leaves and enter the soil *via* litterfall and subsequent decomposition. *Cupressus macrocarpa,* for instance, produces monoterpenes such as α-pinene and myrcene (Malizia et al., 2000), which are known to interfere with the nitrogen cycle and terpinen-4-ol, a monoterpenoid alcohol that has high antimicrobial activity (Carson and Riley, 1995). High levels of phenols have been extracted from radiata pine (*Pinus radiata* D.Don) bark, and these inhibited nitrification and mineralisation, and decreased soil respiration and microbial biomass (Suescun et al., 2012). Some of these chemicals may also be present in other woody plant tissue and, therefore, within the woodchip material of a stand-off pad.

Tannins, lignin and other phenolic substances that may be present in the woodchip matrix as a result of the chipped plant species could potentially cause adverse effects in waterways when these are leached out of the stand-off pad system and enter waterways in the form of dissolved organic carbon (DOC) (Abusallout and Hua, 2017). Concentrations of DOC in the leachate may vary depending on the chipped tree species and could potentially reduce oxygen concentrations in waterways due to stimulated biological activity (Schipper et al., 2010; Shih et al., 2011; Warneke et al., 2011). In addition, DOC in waterways can impact the colour of receiving waters resulting in reduced light penetration (Svensson et al., 2014). Although high concentrations of DOC in woodchip leachate have been detected in an initial flush, concentrations seem to decrease over time (Abusallout and Hua, 2017).

Phytochemicals can interfere with the nitrogen cycle, influence nitrifying microbes, and affect soil organic matter degradation (Fierer et al., 2001; Kraus et al., 2003; Kanerva et al., 2006). In this context, tannins play a major role because they can form proteins and N compounds, necessary to form recalcitrant N complexes, which may reduce N leaching into waterways (Adamczyk et al., 2013, 2017). The effects and interactions of tannins can be related to their polymer structure, where different chain lengths, hydroxylation patterns and the stereochemistry of links between monomers may trigger different reactions with nutrient complexes and microbes (Kraus et al., 2003). It has been shown that tannins affect carbon (C) and N mineralisation by providing C sources for microorganisms, but also possibly acting as toxins for microbes (Cadisch and Giller, 1997; Kraus et al., 2003; Adamczyk et al., 2013) or decreasing enzyme activities (Adamczyk et al., 2009; Joanisse et al., 2009). Adamczyk et al. (2017) and Wu (2011) reported a complexation of dissolved organic N into protein-tannin complexes, hence increasing the long-term N-storage pool in soils (Verkaik et al., 2006). Although such protein-tannin complexes are not easily accessible by plants and microbes, these complexes can serve as a temporary storage pool for later access if needed (Hättenschwiler and Vitousek, 2000; Joanisse et al., 2009). Tannin production varies between and within plant species and with nutrient availability during plant growth (Cadisch and Giller, 1997; Dalzell and Shelton, 2002). Therefore, woodchips from different tree species may vary in their tannin composition and thus exert different effects on the amount of N or DOC that is leached out of a stand-off pad (Cadisch and Giller, 1997). Experiments with purified tannins added to soil have shown an inhibitory effect that scales with increasing tannin concentration and has decreased soil respiration (Kanerva and Smolander, 2008).

Tannins that have been extracted from pine needles inhibit nitrification in soil (Zhang et al., 2010). This has been related to high concentrations of epigallocatechin, which has been shown to inhibit nitrification, mainly due to its chemical structure (Zhang et al., 2010). Black spruce (*Picea mariana* (Mill.) BSP) and kalmia (*Kalmia angustifolia* L.) tannins have been found to inhibit important soil enzymes, depending on their concentrations (Joanisse et al., 2007). Talbot and Finzi (2008) have reported the inhibition of N mineralisation after the addition of sugar maple tannins.

Willows and poplars belong to the family *Salicaceae* and can synthesise low molecular phenolic glycosides and condensed tannins (McWilliam, 2004), which have been linked to important pharmacological activities and medicinal uses (El-Shazly et al., 2012). The most common compounds associated with poplars and willows are salicin and salicortin (McWilliam, 2004). Salicin can be isolated from willow bark, and the substance is known as "aspirin", commonly used to relieve pain and fever. These chemicals have been reported as beneficial in removing organic and N loads within the soil matrix *via* stimulating microbial activity (Duggan, 2005; Randerson et al., 2010).

POPLARS AND WILLOWS IN NZ FARMING SYSTEMS

Wood residues from poplars and willows could be an easily sourced material from trees planted within the farm environment. Poplar and willow trees were introduced to New Zealand by European settlers and are commonly planted as shelterbelts or riparian plantings for erosion control and emergency stock feed in times of drought (Dickmann and Kuzovkina, 2014). In New Zealand, most poplar and willow plantings are located in hill country, but silvopastoral adaptation into dairy systems could be feasible (McGregor et al., 1999). In contrast, in many parts of the world poplar and willow plantings are located on alluvial plains or other flat or low relief terrain, and therefore use of machinery for economic harvesting and chipping of wood material is quite feasible and has already been implemented (see for example Spinelli et al., 2020).

Most poplar and willow clones can be easily propagated vegetatively from unrooted poles and/or rooted cuttings and have shown a superior growth rate to other tree species (McWilliam, 2004). Poplars and willows may provide a range of different uses within an agricultural system and enhance agricultural productivity while simultaneously mitigating adverse environmental effects. Studies have shown the beneficial use of poplars to minimize pasture production loss due to soil conservation measures, fodder and animal welfare (McGregor et al., 1999; Dominati et al., 2014). Their large root systems can access nutrients and water from deep soil layers, thereby providing a safety net, preventing the nutrients from leaching into groundwater (Guevara-Escobar et al., 2000). High organic C inputs in the form of leaves could potentially increase denitrification and alter the soil's physical, chemical and microbial properties, thereby influencing the N cycling in the system and minimising NO_3-leaching into waterways (Haycock and Pinay, 1993; Randerson et al., 2010).

Nutrients accumulated in leaves can be fed back to the stock to prevent nutrient deficiencies, especially in times of drought. Poplar and willow trees can provide leaves with a high concentration of condensed tannins, proteins and trace elements (Moore et al., 2003; McWilliam et al., 2005; Robinson et al., 2005), that may be beneficial for livestock health. Both willow and poplar leaves showed high concentrations of condensed tannins (Matheson, 2000), which may enhance protein digestion in animals. Carulla et al. (2005) have shown a decrease in the urine N concentrations due to high levels of tannins in fed willow leaves, which can minimise N inputs into the farm system and reduce nutrient loss *via* leaching. Condensed tannins have been reported to shift N excretion from urine to faeces, reducing N loss due to reducing the NH_4^+ concentration in urine where it would be subsequently converted to NO_3- and potentially nitrous oxide (N_2O) (Whitehead, 1995). However, depending on the tree species and concentrations of tannins present in the fodder parts, such mitigation effects may vary (Carulla et al., 2005; Beauchemin et al., 2007; Getachew et al., 2008; Grainger et al., 2009; Aboagye et al., 2018).

Compared with poplar, willow tree fodder showed higher concentrations of condensed tannins (Matheson, 2000), but both tree species have been reported to provide tree fodder with the ability to improve protein digestion in grazing ruminants (McCabe and Barry, 1988). Willow leaves fed to cows have proven health benefits and have been shown to enhance growth and fecundity due to high protein, tannin and trace element concentration (Isebrands et al., 2014). Willow leaves can reverse weight loss of cows when fed in times of drought, and high levels of tannin may efficiently de-worm stock (Isebrands et al., 2014). Tannins may also reduce the N concentration in the urine of ruminants (Carulla et al., 2005), which could benefit the environment and reduce N leaching from urine patches. Such benefits have resulted in the successful inclusion of poplar and willow tree fodder into beef, sheep and deer farming systems (Charlton et al., 2003).

Especially on hills and in riparian zones, poplars and willows reduce soil erosion through their extensive root systems and high evapotranspiration rates (Douglas et al., 2010), which helps drying out waterlogged soil (Guevara-Escobar et al., 2000; Ball et al., 2005; McWilliam et al., 2005). Erosion control may result in an increase in livestock carrying capacity and mitigating soil and nutrient losses into nearby streams and catchments (McWilliam, 2004).

Poplars and willows can also minimise nutrient runoff from farms when planted in shelterbelts or wide-spaced plantings on pasture (silvopastoral forests) while providing shade and shelter for livestock. Sheltered farms can result in less need for irrigation (Douglas et al., 2013; Millner et al., 2013), which could minimise nutrient runoff caused by excess water. Poplar and willow silvopastoral plantings can reduce wind speeds, provide shade in summer and positively affect animal welfare (Bloomberg and Bywater, 2007). However, tree canopy cover has to be carefully managed so as to not excessively shade understorey pastures (Wall et al., 2006).

A SILVOPASTORAL SYSTEM PRODUCING WOODCHIPS FOR TEMPORARY STAND-OFF PADS

Poplars and willows are proven agroforestry species on New Zealand farms, and their woodchips have high suitability for stand-off pad bedding. Here we propose an integrated

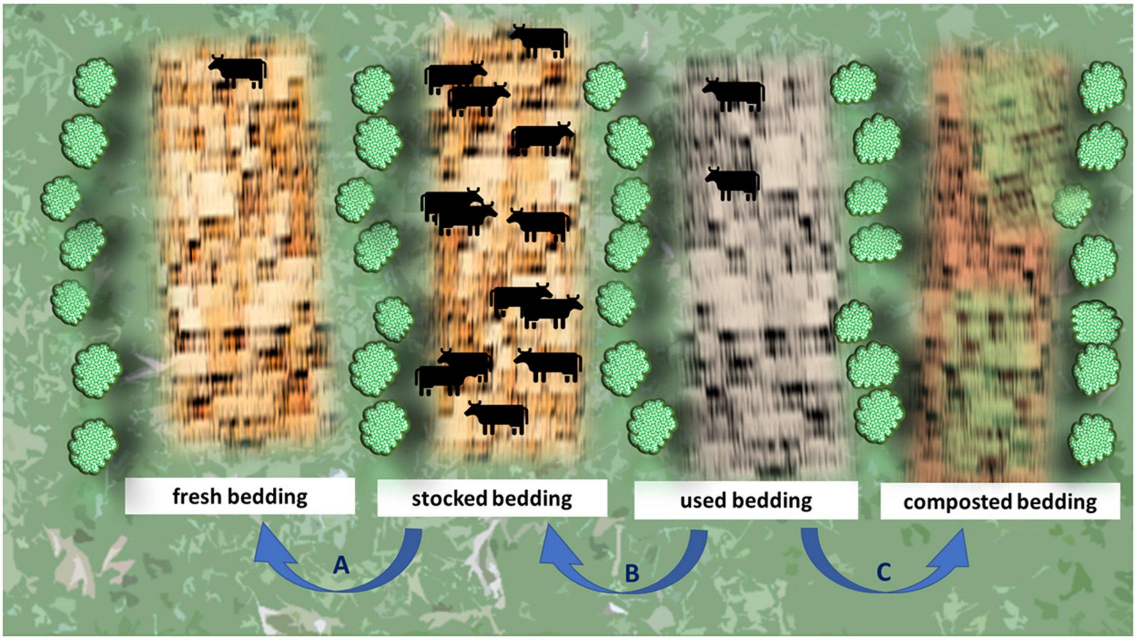

FIGURE 2 | Temporary stand-off bedding in a silvopastoral scenario. Livestock are moved sequentially from one temporary pad to the next **(A,B)** once a pad becomes fully loaded with water or animal wastes. The used bedding material will be subject to composting processes **(C)** for subsequential use within the farm environment.

silvopastoral system, where woodchips are produced by chipping branches and small stems. This material could be used to build up a stand-off area within the silvopastoral site, where beneficial properties of poplar and willow-woodchips are combined with other properties, such as NO_3- leaching reduction, reduced water content, animal shelter and biofortified fodder. This also has the advantage of minimising handling and transport of the woodchip material, as handling and transport are a high proportion of the cost of woodchip material.

Thus, woodchips would be chipped directly onto certain areas of a farm system, to be used as a temporary stand-off pad as long as animal welfare conditions are adequate. Once the temporary pad becomes fully loaded with water or animal wastes, the chipping can be repeated for the next farm section to create a new temporary stand-off pad (**Figure 2**).

The freshly chipped, new temporary stand-off pad ensures adequate conditions for animals again. Building up a stand-off system with built-in trees could potentially obviate the need for engineered drainage structures since (1) root systems of surrounding trees can uptake soil moisture and keep the moisture content at levels favoured by the cows and (2) the deep tree roots would act as a "safety net" for nutrients that have leached from the woodchips into the soil.

The top 100 mm woodchip/soil layer of the soiled pad could be recycled by application to fields, simultaneously providing organic fertilisation for new pasture growth. Timber residues of such temporary stand-off pads can contain significant nutrients and be beneficially recycled back to land (Smith et al., 2010). The resulting mixture of woodchips and manure may have the potential to be used for on-farm biogas production *via* anaerobic digestion (Bolan et al., 2009; Massé et al., 2011; Victorin et al., 2019), or be turned into fertiliser by using aerobic composting techniques (Food Fertilizer Technology Center, 2001; Augustin and Rahman, 2016), hence increase revenue through saleable products or the reduction of costs for mineral fertilisation. However, application rate and amount have to be considered since the application of larger quantities, or larger chip sizes may potentially impact grass response and silage quality (Smith et al., 2010). Both processes have benefits and disadvantages, and future studies that directly compare these in the context of farm operations would help provide management advice to farm owners for manure treatment options.

Repeated chipping on the same area on a rotational basis could build up a bedding system over time, creating a compost stock with beneficial inputs of cow urine and tree bark, suitable for use to promote plant growth in other riparian plantings, shelterbelts or stand-off areas. Such composting systems need accurate management since the composting process works best at 45–55% moisture content, a minimum depth of 45–60 cm, and temperatures between 43–60°C (Dairy NZ, 2015). However, due to the usually high C/N ratio of the woodchip matrix, optimum composting temperatures may not always be achieved (Airaksinen et al., 2001), hence resulting in a compost product that is low in available N (Sommerfeldt and MacKay, 1987; Sommer and Dahl, 1999; Smith et al., 2010). Furthermore, maintaining the composting systems can be labour intensive and, if not managed properly, may endanger stock health or milk quality due to high levels of bacteria in the bedding.

CONCLUSIONS

Trees on farms provide several benefits, including supplementary stock fodder, animal shelter, erosion control and revenue through timber products. In addition, deep root systems act as a safety net to mitigate nutrient loss. Waste material from timber harvesting can be turned into bedding material for stand-off pads, barns, and open barn systems, further reducing paddock damage and N leaching and contributing to animal welfare. Absorbed nutrients in the woodchip matrix may contain beneficial plant compounds to further inhibit nutrient leaching, improve soil structure, and increase organic matter when subsequently reused in a farm environment. More studies, especially lysimeter experiments, could assist in developing guidelines and recommendations to support designing temporary stand-off pads and assessing risks associated with individual farm scenarios. Bedding material chipped from poplar and willow trees may provide a suitable alternative to commonly available pine bedding, but a wide range of materials should be investigated to identify plant compounds in woodchips beneficial for reducing contaminant leaching. Studies addressing various plant materials regarding composting strategies will be important to improve and accelerate the recycling of bedding materials on farms. Properly designed stand-off pads may improve both environmental and economic outcomes of animal husbandry by reducing both the nutrient inputs and losses from farming systems.

AUTHOR CONTRIBUTIONS

MB: developing idea and topic, funding of initial batch experiments to identify the further need for research, and proofreading and editing of manuscript drafts. JE: developing idea and topic, review literature, carrying out batch experiments, and writing manuscript. Both authors contributed to the article and approved the submitted version.

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