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PROGRAMME

Carbon sequestration rates on different land uses

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1.0 Executive Summary

Soil carbon is a key indicator for the health of the land. Arguably, the long-term agrarian wealth of a nation is determined by whether soil is being formed or lost. If soil carbon is being lost, so too is the economic and ecological foundation on which production and conservation are based. Soil carbon provides the infrastructure for micro-organisms to thrive, stabilises soil, improves nutrient and water cycling, increased biodiversity, all leading to soil resilience and improved profitability.

The purpose for my research was to understand the science related to changing soil carbon concentrations in NZ and how this has provided the framework for policy.

Approximately half of NZ's land mass is in pastoral production and has been excluded from the emission trading scheme along with any land uses other than commercial forestry due to the science. No research has yet been validated on how to increase soil carbon stocks in NZ, but the wider science related to carbon depletion is not so limited. Conclusive evidence is forecasted to be published in 2020. This understanding needs to be data rich and not driven by models. End goal is to include soil carbon crediting for other land uses such as pastoral and horticulture.

Silvopastoral system provides a diverse range of land uses similar to nature with livestock and trees grown in symbiosis. Not only does this diversify income, but financially rewarding. This land use qualifies for the Afforestation Grant Scheme by MPI to fund tree establishment. Further trials are necessary to substantiate the potential carbon sequestration from this land use but trials from similar conditions overseas are generating exciting results.

Exposed soil reduces soil carbon stocks via oxidation (released as CO2) and/or increased risk of soil erosion at a rate of 35kg C/ha/day leading to sediment contamination in waterways and is one of the main issues facing NZ. Disincentivise and/or educating land users from this practice will mitigate soil carbon losses providing flow on effects. Diversity has a key contribution; diverse plants have higher root biomass, leading to high storage capability contributing to increased soil carbon compared to monocultures.

The most valuable, productive soil types in NZ have the highest soil carbon losses due to intensification, particularly cultivation. The biggest potential for addressing climate change and sequestering carbon from the atmosphere is from our Brown soils that make-up 22% of our land area.

NZ soils are young and generally have high carbon content, unlike soils elsewhere. This reduces the plausibility of using overseas science to adopt in NZ emphasising the need for greater investment in this field. Society seems more interested in space than what I believe is one of the final frontiers.

2.0 Acknowledgements

Firstly I would like to thank my family for their support over the past 6 months. It has been a very busy time in our lives and I have been fortunate for their understanding and support.

I would like to acknowledge and thank the Kellogg Rural Leadership Programme for the opportunity I have received to participate in this program given the calibre of my fellow participants and being selected as one of the limited millennials. The tools and lessons learnt have been invaluable and I endeavour to share any experiences with others to contribute to society in anyway.

People who contributed to this report cannot be thanked enough. Patrick Aldwell on pointing me in the right direction, Madeline Hall on policy and ETS, Isaac Murphy from Pan Pac for forestry financials and modelling, and the many others that helped in small ways.

I have not only learnt a lot about leadership but also about myself and I'm sure the lessons learnt will continue to develop me as individual, open doors and unlock new networks and opportunities in the future.

This course could not happen without the support of the key partners and sponsors and I thank them all for their involvement.

All content is my own and any omissions or mistakes are mine.

3.0 Introduction

3.1 Background

Only once the last tree has died and the last river been poisoned and the last fish been caught will we realise we cannot eat money – Cree Indian Proverb

This topic was born out of my passion for the environment and primary industries in New Zealand. Currently primary industries are under heavy scrutiny from the public, particularly related to environmental issues such as deterioration of water quality and climate change.

The most meaningful indicator for the health of the land, and the long-term wealth of a nation, is whether soil is being formed or lost. If soil is being lost, so too is the economic and ecological foundation on which production and conservation are based.

Since 1960, global food production has doubled. At the same time, the soil resource on which food production depends has become seriously degraded.

It has been calculated that in the next 50 years, the planet will need to produce as much food as has already been produced in the entire history of human-kind. The way we produce that food will require a radical departure from business as usual.

The rural-urban gap is gradually widening where both parties are pointing the finger at each other in relation to pollution when we all have a problem.

Active and ongoing soil sequestration of atmospheric carbon dioxide and the rebuilding of carbon-rich topsoil is one of the greatest challenges - if not the greatest challenge facing human societies around the world.

"A mere two percent increase in the carbon content of the planet's soils could offset 100 percent of all greenhouse gas emissions going into the atmosphere." – Dr. Rattan Lal, Ohio State Professor of Soil Science, and Nobel Prize Certificate Recipient

3.2 Government Policy

The coalition government has committed NZ's agriculture sector to the emissions trading scheme (ETS) by 2020 with a net zero carbon emissions by 2050. To assist this process, the targets will be written into legislation under the 2015 Paris global climate change accord. The first step to slowly introducing the sector into the ETS is to exclude 90% of net emissions in year 1 (Smellie, 2017).

49% of NZ's greenhouse house gas (GHG) emissions come from agriculture. Fewer options exist for reducing GHG emissions compared to other sectors without limiting production due to our biological systems. Agriculture is a critical part of NZ's economy contributing 40% of our merchandisable export earnings. (New Zealand Agricultural Greenhouse Gas Research Centre, 2018) Pastoral industries will be directly affected by climate change (CC) from weather extremities such as drought, changing pasture productivity and pest and weed prevalence.

As at 22 February 2017, NZ had pledged to reduce emissions in 2030 by 30% below 2005 emissions under the Paris Climate Accord. There are two components to reducing agricultural GHGs without constraining total production – improving efficiency on-farm and researching novel solutions to support mitigation.

Currently there are 26.8 million hectares in New Zealand: 13 million in grazing pastoral, 500,000 ha in cropping, 2.1 million in forestry, and 10.4 million in native bush, scrublands, or vegetation. (Stats NZ, 2018) There are 1.1 million ha of erosion prone pastoral land in NZ (Ministry for the Environment, 2007). The recent coalition government has pledged to plant 1 billion trees over a 10-year period equating to 1 million hectares under a commercial pine plantation operation (MPI, 2018) to mitigate erosion and offset GHG emissions.

Greens co-leader James Shaw has proposed an introduced Kiwi Climate Fund (KCF) initiative implemented by 2020 to tackle climate change. Included in this fund are taxes on greenhouse gases: carbon dioxide, nitrous oxide and methane, with taxation rates of $40, $6 and $3 per tonne respectively (Shaw, 2017).

3.3 Purpose of this research

We need to develop a comprehensive understanding of soil dynamics and how these improve environmental outcomes. Using these current goals as parameters, there is a need to explore land uses to understand how soil carbon stocks change and is measured, but also what practices can be undertaken to store additional carbon.

The current practice that only trees sequester carbon and agriculture is the main polluter requires significant reframing to include a holistic approach taking into consideration all sequesterers and emitters, providing a framework that can include all stakeholders. Why should only trees be preferred (and/or included in policy) for building soil carbon when half of NZ's land mass is in pasture and a significant amount of that area will be building soil carbon via photosynthesis? This is a simple question that needs to be answered soon for us to move forward as a whole.

4.0 Method

Research was conducted using thematic analysis. Data was collected on soil organic carbon (SOC) stocks including baseline here in NZ from peer assessed scientific literature. This data were summarised based on the different quantitative measurements and compared to similar soil types and climate oversees. In this case Patagonia, Chile and Oregon, USA.

Secondly, a literature review was undertaken to identifying any common changes in SOC (gain or loss) and analysed to conclude on whether any land use changes were viable here in NZ, both financially and sustainably.

5.0 Measuring soil carbon

The steadily increasing atmospheric CO2 concentrations have been largely contributed by fossil fuels and industrial C emissions of approximately 10 GT C/yr (Le Quéré, 2015). Estimates of global soil C sequestration potential ranges from 0.4 to 1.3 GT C/yr, offsetting 4-13% of global emissions (Smith, 2016). This statement contradicts earlier work by Dr. Rattan Lal who states that all emissions can be offset by increasing soil carbon by 2%. The availability and quantity of published science related to carbon sequestration is good, but is staggering in variation both in methodology and results.

Total soil carbon stored can be measured by the total of above ground biomass (leaves, stem, trunk, and branches), coarse woody debris (broken branches, thinning, and prunings), forest floor vegetation (decaying leaves, undergrowth), and below ground biomass (roots) (Ministry Primary Industries, 2017).

With respect to the ETS, carbon sequestration rates have been quantified and used extensively within the carbon stock in forests categorised by forest type, age, and region. The Ministry for Primary Industries (MPI) states that "good quality data exists modelling the growth for Pinus radiata and Douglas-fir. " (Climate Change Forestry Regulation, 2008)

Improved understanding of soil properties that affect C sequestration would allow for better estimates of size and scope of potential C sequestration and the governing land uses with the greatest potential (McNally *et al*., 2017). It is widely accepted that a soil's potential to sequester C sustainably is finite and dependant on the capacity to stabilise SOC levels. Stabilisation of SOC has attributed to several mechanisms, but the formation of fine soil particles (silt and clay) is generally regarded most important (Baldock *et al.*, 2000 & Dungait *et al.*, 2012).

Fine fraction is relatively resistant to change characterised by long-term turnover times. However, intensive management (short-term turnover) can result in losses of SOC leaving a deficit of stable C that has the potential for being increased using appropriate management practices (Mudge *et al.*, 2017 & Schipper, 2014).

SOC concentration has a current upper limit, the difference between upper limit and current SOC concentrations are termed saturation deficit or future potential C sequestration. Previous efforts by McNally *et al*., 2017 to determine C deficits effects by the Hassink (1997) model focused on either mass or chemical/physical characteristics of the fine particles. (Beare, 2014) using the least squares regression statistical method (linear regression model), based on soil analysis globally based solely of agricultural land use.

This has significant limitations as results are observational based and being prediction modelling instead of physical results consistant with Feng *et al.,* 2013, suggesting the variance in clay particles in regions globally, limited land use investigated and importance of aluminium (Al) and iron oxides.

Previous efforts to estimate C stabilisation rates showed that specific surface area (SSA) and extractable Al were more important than fine friction soil particles (Beare, 2014). Although a general model for predicting SOC stabilisation rates has been described by NZ's soils (Beare, 2014), no account has been taken for difference between Allophanic and non-Allophanic soils to apply best-fit model for SOC saturation deficit on different soil types and represents a significant gap in C sequestration rates from the atmosphere (McNally S. B., 2017).

Another carbon modelling method is pre-treatment baseline followed by a paired comparison design. Paired comparisons are a valid approach if the objective is to determine differences between treatments in a soil after a long-term study and the difference can be determined in the last year if replications are sufficient. The pair comparison method has been used successfully in many agronomic studies where the change in soil property by treatment or yield response difference between treatments is important (Olson *et al.*, 2013). However, this is not the case for SOC sequestration since the difference between treatments only highlights gain or loss in SOC stocks over certain time (Kenneth *et al.,* 2014).

Pre-treatment baseline method evaluates absolute changes in SOC concentrations that can be used to determine SOC sequestration rates. This requires strong historical data to construct fair experimental results and discussion. Pre-treatment baseline is better suited to unstable soil carbon stocks similar to most overseas soils.

Using the pre-treatment baseline approach, Olsen *et al.,* 2013 indicated that a reduction of 0.34 Mg C ha^{-1} yr^{-1} occurred during the 20 yr study (Olson, 2010). The same plot area was used and the findings were so different (0.455 Mg C ha^{-1} yr^{-1} of SOC sequestration vs. 0.34 Mg C ha^{-1} yr^{-1} loss) suggests that the paired comparison was not valid to determine SOC sequestration since the treatment in this case was not at steady state and continuously losing SOC.

Current global estimates of C sequestration potential have generally not accounted for variability in soil types and capacity to sequester C within these different soil types. Additionally, the upper limits of C sequestration rates are determined by the land use (eg. Grassland or forest) with the highest carbon stocks.

There is no conclusive evidence to suggest that one specific method, model or tool can be used to accurately measure soil carbon concentrations. All data based in this field uses estimates and modelling techniques to provide predictions. There is a clear need for further investment not only in field trials and fine tune modelling techniques but furthermore into how carbon can quantitatively be measured physically.

6.0 Spatial Soil Carbon Levels

NZ soils are very young and generally have high carbon content, unlike soils elsewhere which have been cultivated for thousands of years. This has resulted in difficulties to measure variation in soil carbon concentrations and potential improvements as the deficit is relatively small compared to overseas.

NZ Greenhouse Gas Research Centre has confirmed that allophane-rich and non-allophanic soils behave differently. Allophane rich (and gley) soils having the potential to store 25% more carbon than non-allophanic soils. This finding improves estimates of how much more carbon NZ's pastoral soils can potentially store.

Natural spatial soil variability occurs at both large and small scales. Natural variation is reflected in different soil parameters causing significantly different outcomes. This limitation can be mitigated using correct experimental design, sufficient replication, and careful soil evaluation dealing with SOC sequestration with different land use systems is essential (Kenneth *et al.,* 2013).

NZ soils are classed into 12 orders ranging from the rich allophanic to semi arid soils. Total C sequestration potential nation wide is 124 MT C. Soil order C sequestration potential ranged significantly from 1.6 MT C in Semiarid soils (Central Otago) to 50.9 MT C in Brown soils (central north and south island hill country. Allophanic and Gley soils had the largest C deficit's consistant with intensive land use areas. These areas had lower C sequestration potential compared to Brown soil as they are much smaller. C sequestration potential of Brown soils corresponds to 19 T/ha or 22% increase on current C levels.

7.0 Diversity

(Rutledge, et al., 2017) undertook a 3-year trial comparing newly established traditional ryegrass/white clover (RGC) against newly established diverse range of plant species (DS). Results showed DS contributed to above ground pasture production, but higher root biomass, and net carbon retention after the 3-year trial compared to the base line.

This suggestion of greater belowground root allocation was consistent with the significantly higher root biomass and calculated root C inputs reported by McNally et al. (2015) for DS compared to a recently sown standard ryegrass-clover sward.

All 3 blocks resulted in a net loss in carbon stocks over the three-year period. The loss may have been due to effects associated with pasture renewal such as ongoing increased respiration from decomposition of dead roots of the old sward and oxidation of stored carbon. Consistent with annual C losses from SOC from oxidation and CO2 emmissions could be greater than amount of annually stored SOC from any agricultural system (Olson, 2013).

8.0 Silvopastoral systems (SPS)

Recent studies in temperate areas have shown that agroforestry practices sequester greater C than from mono-cropping, forest plantations, or pastures (Bambrick AD, 2010) (Dube F, 2011) (Gordon AM, 2005) (Montagnini F, 2004) (Oelbermann M, 68) (Peichl M, 2006) (Sharrow SH, 2004). Similar to this case study by Dube *et al* 2012 compared carbon sequestration in Patagonia, Chile on *Pinus ponderosa* plantation (PPP), Silvopastoral system (SPS), and natural pasture with traditional cattle grazing (NP). Chile has a similar climate and soil type to New Zealand, both being temperate and volcanic. In New Zealand's case, volcanic soils are a major contributor to erosion prone land and consequent sediment discharge particularly into waterways.

PPP was planted at 2000 stems/ha, naturally thinned to 1500 stems/ha and mechanically thinned down to 800 stems/ha. This is at a high planting rate compared to NZ's industry standard for commercial pine plantations (900 stems/ha, thinned to 300 stems/ha). SPS was thinned to 400 stems/ha arranged in strips at same time of thinning in PPP (2003) and includes perennial pasture grown within the rows and cattle grazed at 0.5 cow/ha. By 2009, there was a significant difference between C content on a tree basis as shown in figure 1.

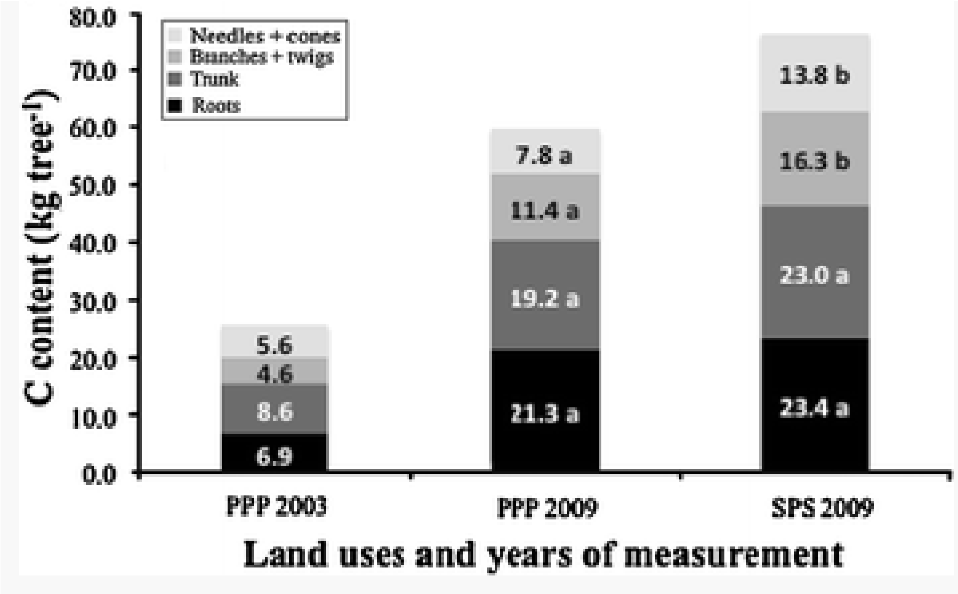

Figure 1: Change in C sequestration rate influenced by tree density (Dube *et al.*, 2012)

Table 1: SOC stocks on an area basis

	Total carbon (tonne/ha)	
Treatment	**SPS**	**PPP**
Above ground	21.2	30.7
Below ground	9.4	17
Total tree	30.6	47.7

Source: Dube *et al.,* 2012

Significantly larger amounts of C stored on an area basis in PPP were expected due to the large difference of tree densities as stated above. However, larger trees in SPS compensated to an extent for the lower tree density not including additional C sequestered from pasture. Individual trees under SPS sequester 30% more C biomass compared to PPP suggests that a moderate increase in tree density with a modification in system design could further enhance C sequestration from a tree component.

On the contrary, even though PPP sequesters more carbon on an area basis. The trees will be harvested to simulate a commercial forestry operation and the above ground carbon stored will be majority exported (MPI, 2018).

Mean aboveground net pasture biomass was measured over the trial period with similar results for SPS and NP, but significantly higher than that of PPP (2958, 3173 and 732 kg DM/ha/yr respectively). This demonstrates the influence exerted by trees have on favourable microclimates within pasture alleys under SPS. According to (Garrett, et al., 2004), trees in SPS reduce wind speed, moisture through evapotranspiration and soil, and increased air temperature. Additionally, thermal cover provided by trees may aid in frost protection. All of which improves pasture production and improves growing seasons in the shoulder seasons (Garrett, et al., 2004).

8.1 Financial Analysis SPS

For any SPS to be realistic, it needs to be a financially viable option not just for environmental benefits. The two scenario areas are both in Hawkes Bay and were identified by the coalition government as potential area for regional development, significant tree planting areas, and are located on critical erosion prone areas. Putere is known for its pumice soil, and forestry sector with its relative close proximity to port and timber mill. Land prices are relatively low and the area shows great opportunity to diversify away from traditional forestry, or red meat producing land uses.

Table 2: Marginal Land – Putere, Napier-Wairoa Road, East Coast

Expenditure	$/ha/yr	Reference
Purchasing/converting land	200	North Island East Coast valuations $6000/ha
Tree planting	43.33	MPI historical tree planting $1300/ha
Tree pruning x2	66.67	Pan Pac: $1000/ha
Tree thinning x1	23.33	Pan Pac: $700/ha
Harvesting	1583.33	Pan Pac: 100m @ $100/m (roading), 750 tonne @ $50/Tonne (harvest)
Pasture Establishment	33.33	Baker Ag: $1000/ha
Stock purchases	680	1 bull 200kg @ $3.4/kg
Animal Health	10	$10/head
Interest	187.13	6% interest rate

Net present value	87.95	3% per year
Total Expenses	**2915.07**	

Income	**$/ha**	**Reference**
Cattle	1404	1 Fresian R2 bull/ha 270kg @ $5.20/kg
Export timber	2000	$60,000/ha over 30 yrs NZ Forest Research Centre
MPI Afforestation subsidy	43.33	MPI – Afforestation Grant Scheme
Kiwi climate fund	60	MPI 45 tonne C @ $40/tonne over 30 yrs
Total Income	**3507.33**	

Assumptions: 30 year rotation, production thin 15-20 year period

Waiwhare is also regarded as an opportunity area as part of both the regional development fund and billion-tree policy. This land is regarded as good quality, producing large amounts of products across a range of land uses from forestry, horticulture, viticulture, and predominantly sheep and beef. This area consists of volcanic soils, regarded as some of the most critically erosion prone for sediment discharge into waterways in the country.

Table 3: Good quality Land – Waiwhare, Napier-Taihape Road, Hawkes Bay

Expenditure	**$/ha/yr**	**Reference**
Purchasing/converting land	400	North Island East Coast $12,000/ha
Planting	43.33	MPI historical tree planting, Pan Pac $1300/ha
Pruning x2	66.67	Pan Pac: $1000/ha
Thinning x1	23.33	Pan Pac: $700/ha
Harvest (incl roading)	1756.67	Pan Pac: 100m @ $100/m (roading), 854 tonne/ha @ $50/Tonne (harvest)
Pasture Establishment	33.33	Baker Ag: $1000/ha
Stock purchases	1360	2 bulls 200kg @ $3.40/kg
Animal Health	20	$10/head @ 2 bull/ha
Interest	276.68	6% interest rate

Net present value	146.64	3% per year
Total Expenses	**4126.65**	

Income	**$/ha/yr**	**Reference**
Cattle	2808	2 Fresian R2 bull/ha 270kg @ $5.20/kg
Export timber	2233.33	$67,000/ha over 30 yrs NZ Forest Research Centre
MPI Afforestation subsidy	43.33	$1300/ha MPI: Afforestation Grant Scheme
Kiwi Climate Fund	60	MPI 45 tonne C @ $40/tonne over 30 yrs
Total Income	**5144.66**	

Assumptions: 30 year rotation, production thin 15-20 year period

Table 4: Silvopastoral - Marginal vs. Quality Land

	Net Income pre-tax ($/ha/year)
Marginal – Putere	592.26
Good quality - Waiwhare	1018.01
East Coast Sheep and Beef (MPI, 2012)	223

As illustrated above, the good quality land provides approximately double the financial return under a silvopastoral system compared to marginal land. The cost difference in purchasing the land initially ($12,000/ha vs. $6,000/ha) had a significant contribution. Stocking rate was double on good quality land signifying greater returns overall. Comparing to MPI's Hawkes Bay Sheep and Beef monitoring farm on their recent publication 2012, both scenarios outperform that status quo in this area. These values are theoretical and greatly depend on market, location, topography, soil type, and climate.

There is a significant opportunity in purchasing both good quality and marginal land in Hawkes Bay and undertaking an integrated silvopastoral farming system whilst utilising the multiple funding options available. Under the provincial growth fund, Hon Shane Jones has committed $5 million to reopening the railway line between Napier and

Wairoa. This may have colossal benefits for this system utilising the railway line, reducing transport costs and ultimately improving long term returns while boosting economic growth and improving communities in a relative low socioeconomic area. There is a risk involved in budgeting on harvest returns based on current log prices and 30 years before a return on investment.

Since conducting initial research, heavy rain events have occurred in both East Cape and Tasman districts leaving destruction from forestry debris. The costs are piling in the $10 million category. There is a need to implement new regulation related to forestry debris on how to mitigate in the future.

9.0 Landcorp's Afforestation Commitment

The minister for Forestry Shane Jones has publicised the government is in agreement with Landcorp to plant an additional 1 million trees current year and another million following year totalling 2000 ha to add to their 10,000ha currently in trees. This is a 3.3% of Landcorp's area they manage in trees from their 357,000 ha (Landcorp, 2012). "A review of its portfolio to identify any other potential land for planting is underway within Landcorp." (Jones, 2018) The suggestion that marginal land managed or owned by Lancorp is under review for tree planting. The biggest station in NZ Molesworth Station will be seriously review once Landcorp's Molesworth lease comes up for review in 2020 (Department of Conservation, 2017). My opinion is some of this marginal land in critical areas will be planted into trees and this lease will not be fully renewed come 2020.

Landcorp praises itself as "recognised as an agriculture leader in New Zealand and all around the world where our farming practices are studied and emulated." If this is the case, Lancorp should be trialling agroforestry practices on marginal, erosion prone land to evaluate if this is a viable option.

10.0 Afforestation Grant Scheme (AGS)

MPI has put aside $6.5 million a year (MPI, 2018) to fast track their goal of 100 million trees a year through the AGS. In relation to silvopastoralism, there is the opportunity for this practice to come underneath this umbrella. Criteria for gaining the grant are as follows:

Minimum of 30% of the crown area needs to be planted in trees and cannot be any narrower than 30m at the crown (MPI, 2018). This allows for 70% of the remaining land area to be planted in a pastoral system providing grazing opportunities.

750 stems/ha is the minimal required planting density and thinned to minimum 300 stems/ha for minimum of 10 years (MPI, 2018). This can fit in with (Dube, *et., al,* 2012) trial work around densely planting trees of 1500 stems/ha. Concluding, 750 stems/ha maybe planted on the 30% land area rule in strips and still make funding available.

Five to 300 ha eligible planting exotic or native species that grow 5m or higher. Trees cannot have been in forestland in 1989 or in the previous 5 years and cannot be used for fruit or nut production (MPI, 2018).

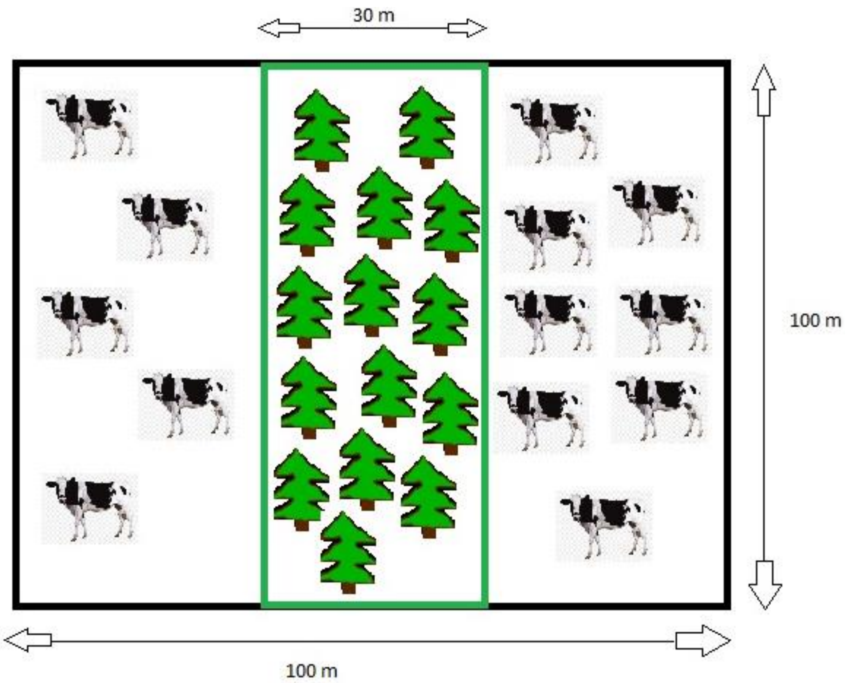

Figure 2: Silvopastoral system under AGS (1 ha)

This is a simple example of how the SPS could qualify for the AGS. 70% is still available for pastoral farming while 30% is locked up in forest. Once the trees are established, there is the option to remove the fence to allow livestock to graze within the trees. Note this is only a one hectare area and to qualify for AGS needs to be minimum five hectares or scaled 5x with a range of combinations of trees in strips. Most logical approach would be to plant unproductive areas on critical erosion prone land areas.

11.0 Alternative Tree Options

The faster a tree can grow, the more carbon can be removed from the atmosphere and stored as biomass either above or belowground.

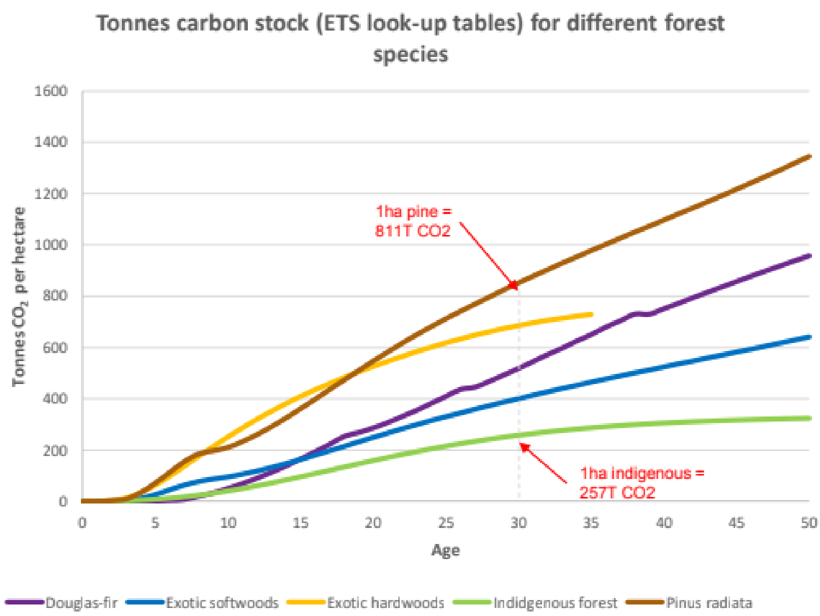

Figure 3: Carbon stock for different forest species (lookup tables ETS), MPI 2017

As illustrated above, radiata pine stores the most carbon in the long term. Consistent with the coalition government's goal to plant 1 billion trees to offset NZ's human activities as the best land use based on MPI's modeling for the ETS.

Note the significant importance of exotic hardwoods on carbon sequestration rates for the first 20 years are similar to Pinus radiata. This shows substantial potential for planting a combination of exotic hardwoods such as eucalyptus, ash, elm, poplar, oak, acacia, and Tasmanian blackwood and Pinus radiata. This would improve biodiversity, shift the forest state away from monoculture such as permanent pine plantations and has potential to improve long term yields, and consequent returns. This is consistent with Peichl *et al.,* 2006 suggesting use of faster growing species such as poplars (*Poplus* spp.) may have potential to store large amounts of C in short periods of time.

Other fast growing varieties of plants that may have potential for rapid carbon sequestration rates could be tropical or C4 plants such as bamboo, sugar cane, or miscanthus. Moso bamboo has been recorded to sequester 8.13 T carbon/ha/yr (Yen, 2011) similar to Pinus radiata in the first three years. Miscanthus has recently been publicized as an option for shelter, biofuel, animal bedding, mulch and biodiversity. It has been praised for its fast growing ability and option in lowland areas such as Canterbury and its use under centre pivot irrigation without affecting the irrigator's operating ability. C4 plants may have a short term place for sequestering carbon but not long term compared to conventional tree planting species.

12.0 Biochar

Biochar is derived from charcoal burnt under limited oxygen availability and has been a recorded use in the Amazon basin at least 2500 years ago in areas called Terra Preta (Biogrow NZ, 2018) and more recently in New Zealand 12-1400 AD (Camps Arbestain *et al.,* 2014). The Amazon basin is notorious for infertility but with little to no fertiliser use in these Terra Preta areas, fertility remains high.

Biochar enhances plant growth, improves soil water holding capacity, cation exchange, nutrient status, tilth, soil microbial respiration, life and biodiversity, reduces fertiliser requirements, soil acidity, greenhouse gas emissions, leaching of nutrients and stores a significant amount of carbon in a long term stable sink (Biogrow NZ, 2018).

To optimize the agricultural and environmental benefits of biochar, we need to overcome its potentially undesirable effects. Addressing the elephant in the room is the role CO2 plays in biochar application. Producing this charcoal rich product requires energy and biomass to be burnt, releasing CO2 into the atmosphere. Applying biochar to soil requires tilling deep farrows leaving exposed soil to incorporate well into the root zone (Yang *et al.,* 2015). As stated previously, bare land oxidises soil carbon releasing it as CO2.

Wardle *et al.,* 2008 concluded after a 10-year study in boreal forest of applying biochar, led to soil degradation and increased soil microbial activity also releasing CO2 into the atmosphere. This is consistent with similar practices of applying nitrogen-based fertilisers that feed the soil microbes on soil carbon making it plant available. If SOC is not utilised by the plant; can be released into the atmosphere as CO2. Different results may occur under a silvopastoral, pine plantation or pastoral system here in NZ.

Finally the addition of biochar leads to soil colour transitioning to a rich black colour. This maybe high in soil carbon but also lowers reflectivity (also known as albedo effect) of the soil surface, potentially exacerbating climate warming (Meyer *et al.*, 2012).

13.0 Limitations

The most limiting contribution to my research was there is no standardized approach to measuring soil carbon stocks. There are a vast number of different models on offer all providing estimates to quantify either change (gain/loss) in soil carbon stocks or stationary levels. As soil is dynamic, levels are most likely always fluctuating.

As New Zealand is a unique land mass compared to the rest of the world, it is difficult to compare and contrast similar research in this field as the nature of the data is far from compatible. This makes it difficult to provide recommendations and viability based on overseas modelling research.

The ETS look up tables contains immense variability both within regions (growing and decomposition rates), planting densities, and management of the trees (thinning and pruning). Additionally, these data are generated using above-ground stem measurements and modelled to measure below-ground performance. MPI was approached but not willing to cooperate and disclose what modelling was undertaken to disclose figures publicized in the ETS carbon look up tables. Nor were they willing to comment on any other carbon sequestration rates outside of forestry or alternative trees listed prior.

14.0 Conclusions

A continuous shift will be required in the way we ultimately farm and conduct other land use practices in New Zealand to accomplish our aspiration goal of carbon neutral by 2050. This may not have immediate consequences or results, but will gravely affect future generations.

New Zealand soils generally have high SOC stocks compared to other soils internationally due to New Zealand's land mass relatively young, late colonisation and the geological processes creating our soils. NZ soils have had fewer cultivation years leading to minor carbon losses compared to overseas. Climate change has become a current event, soil carbon and how to gain/loss it has not been on government agenda's.

Trees provide a significant sink in atmospeheric carbon. The opportunities of increasing tree plantings is endless providing biodiversity, shade and shelter for livestock, mitigating erosion and improving nutrient and water cycles. Silvopastoral system fits well within NZ's green, green image while improving profitability.

All soil carbon stocks are estimated or modelled. This provides only limited available conclusive science on how soil carbon can be built upon in NZ. This limits the ability to include these models in domestic policy. However, this provides an exciting opportunity for further investigation into this sector to improve both soil and water health on a global scale.

15.0 Recommendations

- Significant increase of investment into research and development for NZ Agricultural Greenhouse Gas Research Centre and Pastoral Greenhouse Gas Research Consortium (PGgRc). Fields of greatest importance to research is how to build soil carbon, and quantifying carbon stocks on other land uses other than forestry. End goal is to include soil carbon crediting for other land uses such as pastoral production, horticulture, and debiting from urbanisation. Investment should come from industry bodies such as DairyNZ, Beef and Lamb, Foundation Arable Research, Horticulture NZ
- Halt livestock introduction into ETS until further research in how other land uses can affect carbon cycling. In particular what land practices increase carbon sequestration with a focus on pastoral agriculture.
- Investment in soil carbon geospatial mapping; including UAV and hyperspectoral technologies. Primary growth partnership programme Pioneering to Precision - Application of Fertiliser in Hill Country pivot some of the $3 million funding available towards this space
- Educate land users on the negative impact of bare land (exposed soil). Decentivise bare land or similar poor land management practices through a tax; any land use that exposes bare soil pays for each day exposed. Tax raised will be used on mitigating carbon emissions, sediment runoff and R and D in this field.
- Establish a long term funded trial of SPS within AGS parameters. If successful results, incentivise producers to introduce this system onto their land and promote SPS. Allow land users to obtain carbon credits instead of forfeiting to the crown. This will incentivise land users further.

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