Climate-Smart Agriculture, a Mitigation Framework, and the ETS

James Shirley
University of Waikato
jtshirley@xtra.co.nz

Summary: This paper explores the potential contribution to climate change mitigation resulting from the adoption of the Climate-Smart Agriculture (CSA) mitigation scheme methodologies. CSA is an internationally recognized approach that helps guide the actions needed to transform and reorient agricultural systems, to effectively support sustainable development and ensure food security in a changing climate. CSA is based on principles developed in conjunction with the Intergovernmental Panel on Climate Change (IPCC), so its Mitigation Scheme framework of differentiated incentivization is readily transferable across IPCC regions, without the need for radical new policy initiatives. This methodology links with an emissions trading scheme (ETS), as an incentive compatible mechanism to improve environmental outcomes. In this case the NZETS trades carbon certificates based on farm systems that effectively measure, report and ultimately verify the land user's contribution towards the country's nationally determined contributions (NDCs).

Keywords: mitigation policies, food security, mitigation scheme, differentiated incentivization, sustainable land management

Introduction

The agriculture sector is coming under increasing scrutiny as countries seek to meet internationally agreed emissions targets, with several recent studies suggesting that, combined with the right climate-smart policy approaches, the sector has the potential to become a significant source of near-term mitigation (Chabbi et al., 2017; Cornell Institute for Climate Change and Agriculture, 2015; Paustian et al., 2016; Saj et al, 2017). However, relative to other GHG source categories, agricultural mitigation presents particular challenges. Rates on an individual farm are relatively low, but vast areas of land are devoted to agriculture, and the implementers of mitigation practices—the land-users—number in the thousands. Therefore, engaging a substantial number of these people is a massive undertaking in itself. In addition, because of the dispersed nature of agriculture, reporting on management and technology impacts might be required at various scales, from field and farm to regional and national levels (Holzworth et al., 2015; Paustian et al., 2016; Saj et al, 2017).

Furthermore, agricultural mitigation is challenging to quantify, owing to the dispersed and variable nature and the multiplicity of controlling factors, operating across heterogeneous landscapes. Direct measurement of fluxes requires specialized personnel and equipment, normally limited to research environments, and hence not feasible for most mitigation projects (Ewert et al., 2015; Paustian et al., 2016). Model-based methods, in which emission rates are quantified as a function of location, environmental conditions and management, provide a more feasible approach. Process-based models, which dynamically simulate mechanisms and controls on fluxes as a function of climatic and soil variables and management practices, and empirical models based on statistical analysis of field-measured flux rates, represent differing but complementary approaches. In general, model-based quantification systems enable monitoring to focus on practice performance and thus dramatically reduce transaction costs for implementing mitigation policies (Ewert et al., Lehmann, et al., 2013; Paustian et al., 2016; Saj et al, 2017).

Another challenge for projects on existing agricultural lands is obtaining and processing the management activity data. For example, the Kenya Agriculture Carbon Project (KACP) involves a total of 60,000 individual small-holder farmers (Paustian et al., 2016; Swallow & Goddard, 2013). In contrast to projects involving major land-cover changes, where remote sensing can provide much of the activity monitoring (for example, retention of forested land over time), remote-sensing options are poorly suited for monitoring crop type, fertilizer, residue and water management, and organic matter amendments (Saj et al, 2017; Swallow & Goddard, 2013). However, advances in information technology can now overcome this, by directly engaging farmers in the recording of on-farm management practices, via web-based computer or mobile apps, thus driving advanced model-based metrics (Paustian et al., 2016).

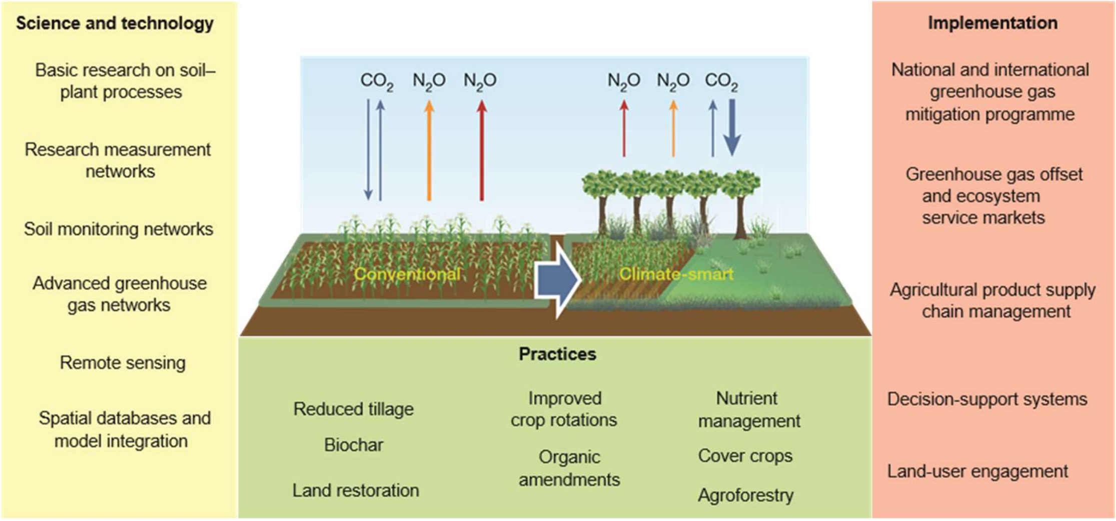
This paper fills the gap in our current understanding of how to design and implement agricultural carbon market projects in New Zealand so that farmers are eligible, willing, and able to participate in mitigation. It examines the institutional design of an agricultural carbon market project in order to determine the framework and identify the actors and rules that lead to farmer eligibility and the adoption of sustainable land management (SALM) practices. It also describes the development of a web-based tool (based on the original KACP), designed specifically to collect raw SALM practice information at the farm level. This tool drives advanced model-based metrics, allowing reporting on practices and subsequent carbon (C) production at various scales, from field and farm to region. Finally, this paper outlines how the agricultural carbon market project can be facilitated by the implementation of climate-smart soil management policies, via cap-and-trade systems, and national and international mitigation policies; in order to promote more sustainable and climate-resilient management practices at the farm level.

A Mitigation Framework for Agriculture

CSA was first proposed to address the need for a strategy to manage agriculture and food systems under climate change (Food and Agriculture Organisation of the United Nations, 2016). CSA lies at the interface between science and policy-making and strives to foster action on the ground and mobilize financing. It provides the means to help stakeholders from local to national and international levels, identify agricultural mitigation strategies suitable to their local conditions and to incorporate these in the planning and investment process (Food and Agriculture Organisation of the United Nations, 2016; Paustian et al., 2016; Saj et al., 2017).

CSA is targeted on the strategies needed to manage agriculture and food systems under climate change. As such, part of CSA addresses very large scales (global, regional, national) and uses "soft sciences" that are intertwined with (inter)national issues and which therefore require high political will (Lipper et al., 2014). It has a strong focus on policies, institutions and financing, it does not state which agricultural practices are climate smart, and actually the underlying message is that there is no specific climate smart blueprint or practice, it rather depends on site-specific conditions. Site-specificity, though, is seen as an advantage for CSA as it allows genuine farmers' practices to be recognized and supported by adequate policies (Lipper et al., 2014).

Figure 1: Climate-Smart Agriculture (CSA)



According to the FAO (2016), CSA needs to be integrated into core government policy, expenditure and planning frameworks. To be effective CSA policies must contribute to broader economic growth, poverty reduction and sustainable development goals. They must also be integrated with disaster risk management strategies, actions, and social safety net programs (Food and Agriculture Organisation of the United Nations, 2016).

The CSA Mitigation Scheme

The CSA Mitigation Scheme is an agricultural carbon market project design based on principles developed in conjunction with the IPCC, so its mitigation scheme framework of differentiated incentivization, based on the adoption of SALM practices, is readily transferable across IPCC regions, without the need for radical new policy initiatives (Lee, 2017). SALM methodologies, such as those developed by Verified Carbon Standard and the World Bank's BioCarbon Fund, are seen as a cost-effective way to respond to the needs of the mitigation scheme framework in terms of site-specificity and potential for adoption by farmers, because they are strongly based on local practices (Saj et al, 2017; World Bank, 2014).

The agricultural carbon market project design includes localized **mitigation objectives** that guide the actions needed to transform and reorient agricultural systems through the adoption of SALM practices tailored to that locality or region:

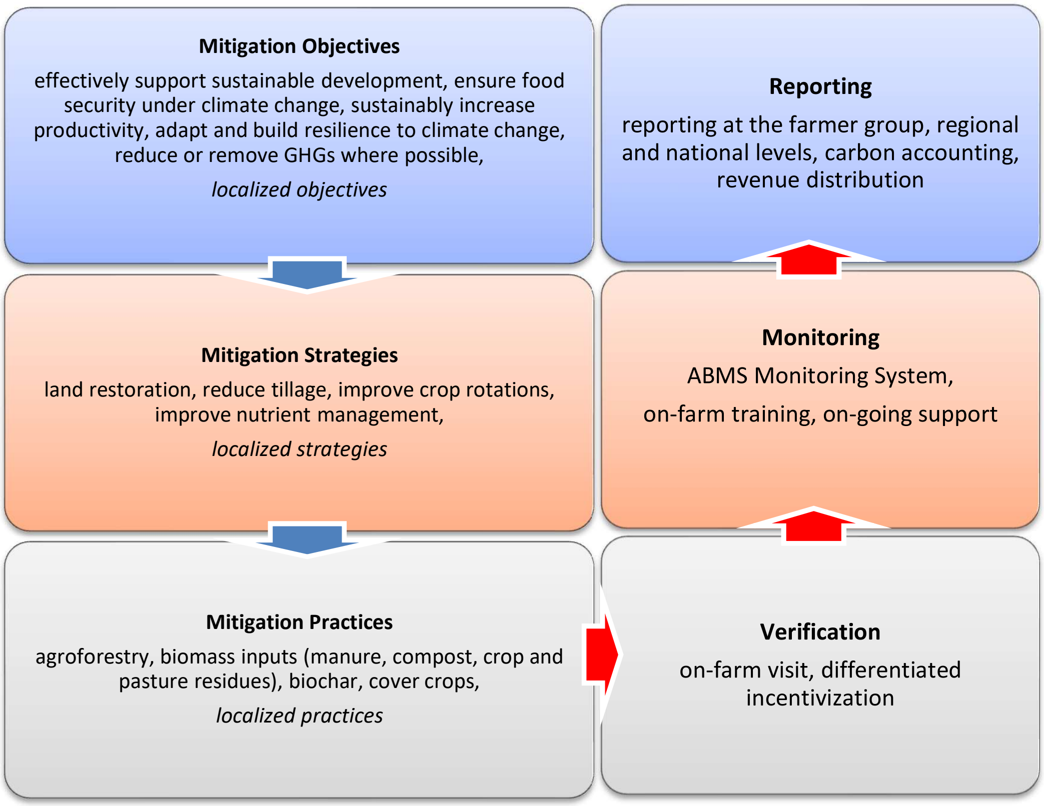
- to support sustainable development and food security under climate change
- to sustainably increase agricultural productivity
- adapt and build resilience to climate change

- reduce or remove GHGs, where possible

The project design employs the land management practices and accounting methodology of Approved VCS Methodology VM0017. Within the project the list of SALMs to be adopted includes both management strategies and management practices. For instance, reducing tillage, improving crop rotation and nutrient management over time are **mitigation strategies** that will ultimately result in increased carbon stocks. VM0017 incentivizes the **mitigation practices** i.e. those SALMs that directly increase carbon stocks in the agricultural landscape, through **bio-mass addition**.

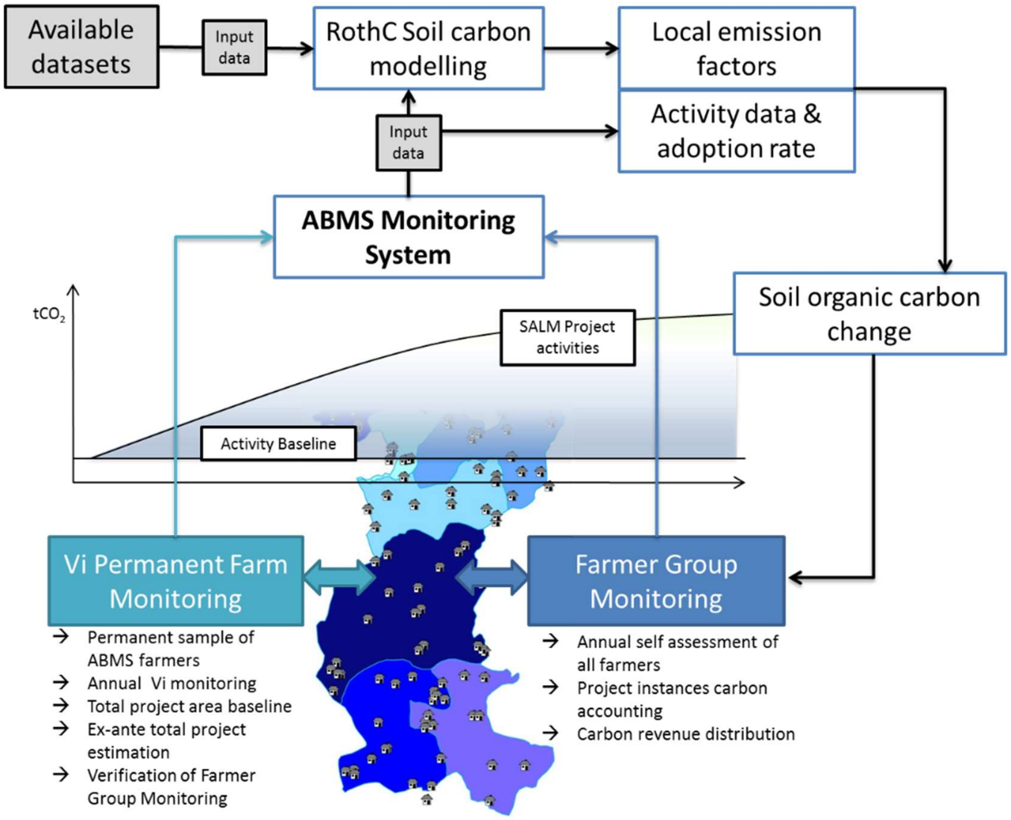
Inventories of soil C stock changes and net C fluxes using process-based models will always have uncertainty due to lack of process understanding, inadequate parameterization, and limitations associated with model inputs such as weather, management and soils data (Ogle et al., 2010). Within the scheme design uncertainty is reduced through **verification**, **monitoring** and **reporting** systems. Such systems place different levels of importance on uncertainty depending on program type (Bellassen et al., 2015), but discounting payments on the basis of the level of uncertainty is likely to be part of any scheme with financial incentives, such as cap-and-trade. Discounting encourages monitoring efforts to reduce uncertainty over time (IPCC, 2006).

Figure 2: Reducing uncertainty in the CSA Mitigation Scheme Framework



The monitoring structure supports regional responses, using published regional / national datasets. This ensures external data validity and integrity and assists in constructing meaningful reporting at the farmer group, regional and national levels.

Figure 3: Farmer Group Monitoring in the CSA Mitigation Scheme Framework



The **Activity Baseline Monitoring System** (ABMS) monitoring system manages the project requirements. It monitors the adoption of SALMs at the farm level and identifies on-going training needs, impact on farmers and food security issues.

Figure 4: ABMS in the CSA Mitigation Scheme

Project requirements	ABMS	Examples	Synergies with project management & extension
Project boundaries	Identification of project areas (GPS farm tracking)	High residue crops areas, tillage areas,	Land use classification & prioritization
Baseline - activities	Identify the actual agricultural management practices	Residue management practices, tillage, manure management practices , crop area, existing trees	Training needs assessment, identification of primary fields for extension and training, sensitization
Project - activity monitoring	Identify adoption of SALM practices	Improved crop land management , mulching, composting…	Project impact assessment, farmer's commitment
Baseline - soil model input data	Organic matter inputs (biomass and manure); soil cover	Annual crop yields, rotational patterns, crop areas, livestock & grazing assessment	Livelihood assessment, Livestock management
Project - soil model input data	Organic matter inputs (biomass and manure); soil cover	Changes in crop productivity, manure management, crop areas	Food security monitoring

The scheme calculates Soil Organic Carbon (SOC) amendments in a two-stage process. The Farmer enters SALM information via a web-based **Annual Return**. This effectively measures on-farm mitigation, in order to calculate bio-mass additions. The Farmer Group subsequently employs the **RothC Soil Decomposition Model** to calculate **SOC changes**.

Figure 5: Model-based Metrics in the CSA Mitigation Scheme Framework

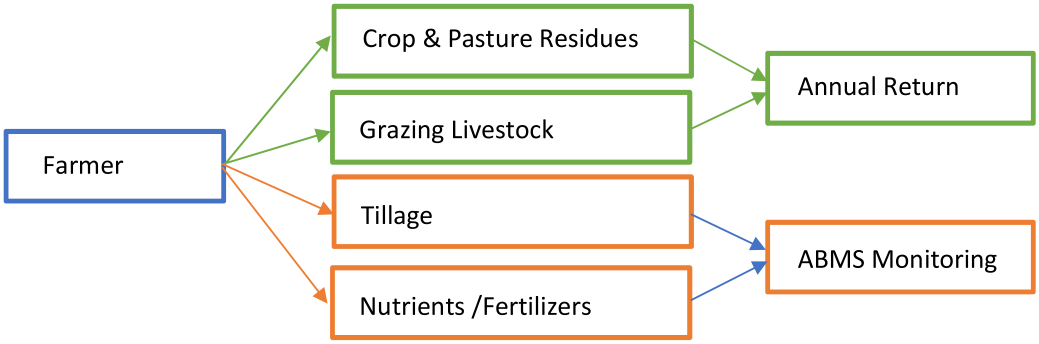
Farmer Annual Return – Modelling on a Waikato Dairy Farm

In this study a web-based interface was developed to model the **Annual Return** process, which records on-farm SALM strategies and practices and transforms this raw data into the input format required by the soil decomposition model. The study's objective was to identify those changes in farm practice, farm reporting and incentive policies, designed to foster mitigation and adaptation efforts in New Zealand. This study modelled the current land management practices on a Waikato dairy farm over a two year period in-order to identify any localized strategies and/or practices that might need to be incorporated and the local datasets needed to support these. The model-based reporting transforms the inputs by applying the calculations prescribed in the VM0017 methodology, into annual C production from bio-mass addition.

Methodology

The **Annual Return** was developed as a web-based interface using PostgreSQL as the database manager. PHP was used to write the transaction processing interface, based on the data specifications of the VM0017 methodology. Through this model-based interface the farmer enters information on **mitigation practices** that result in bio-mass addition i.e. annual crop yields/ areas - residue management, average number and type of grazing livestock, average grazing area. The farmer also enters details on mitigation practices which represent progress towards both **mitigation objectives** and **mitigation strategies** i.e. recording tillage, nutrient and fertilizer application annually allows trajectory to be measured for the mitigation strategies.

Figure 6: Annual Return and AMBS Monitoring in the CSA Mitigation Scheme



Measurement of C content is derived by applying the calculations specified in the VM0017 methodology, which utilize IPCC rates for both crop residues (including pasture) and manure production (Verified Carbon Standard, 2014*)*. Agroforestry removals are calculated based on the local Climate Change Regulations 2008 - Schedule 6, but expressed as the difference between the prior and current years balance. This presents agroforestry growth data as an addition unit, consistent across all SALM practices.

For residues management from crops the harvest fresh yield in kgs per ha is converted to residues in kgs dry matter per ha, using values from Table 11.2 in Volume 4 of the 2006 IPCC Guidelines.

Pasture is treated like any other crop when calculating residues. The crop is spread across the available grazing area of the whole farm on a per hectare basis. The harvest fresh yield in kgs per ha is converted to residues in kgs dry matter per ha using values from Table 11.2 in Volume 4 of the 2006 IPCC Guidelines.

In the **Annual Return** details of each management practice are recorded dependent on the choice of soil model and the type of activity being promoted. For example, if the activity is improving the use of crop residues then for use with the Roth-C model, the ABMS should record:

- Area of each crop (ha)
- Productivity of each crop (kg/ha)
- The amount of crop residues (kg/ha)
- Existing crop residue management practices and their frequency
- Future crop residue management practices to be implemented with the project

Estimation of input values from residues management

The calculation of residues inputs from crops is based on yield data collected from farms via the web-based interface. Pasture is treated like any other crop when calculating residues. The crop residue is spread across the available grazing area of the whole farm on a per hectare basis. The harvest fresh yield in tons per ha is converted to amount of residues produced in tons dry matter per ha on the basis of the equations reported in Table 11.2 in Volume 4 of the 2006 IPCC Guidelines.

The amount of aboveground residues is equal to:

$R = a * b * Y + c$

Where:

R Aboveground residues in tdm/ha

Y Harvest fresh yield for each crop in tfm/ha.

a Dry matter fraction of harvest product b	Slope of the equation

c	Intercept of the equation

The amount of C of crop residues is finally calculated by multiplying the amount of aboveground residues (R) with a default carbon fraction. The IPCC default value of 0.4 is used.

Estimation of input values from raw manure

The calculation of raw manure inputs is based on information on the amount and types of livestock animals in each farm collected in ABMS. The factors from Tables 10A-4 to 10A-9 in Volume 4 of the 2006 IPCC Guidelines are used to calculate the amount of raw manure produced by animal type within an IPCC region. The amount of C of manure is finally calculated by multiplying the amount of manure residue (R) with a default carbon fraction. The IPCC default value of 0.4 is used.

Estimation of input values from composted manure

The estimation of composted manure at each farm is based on several assumptions about the composting of manure and residues which need to be surveyed on a farm level.

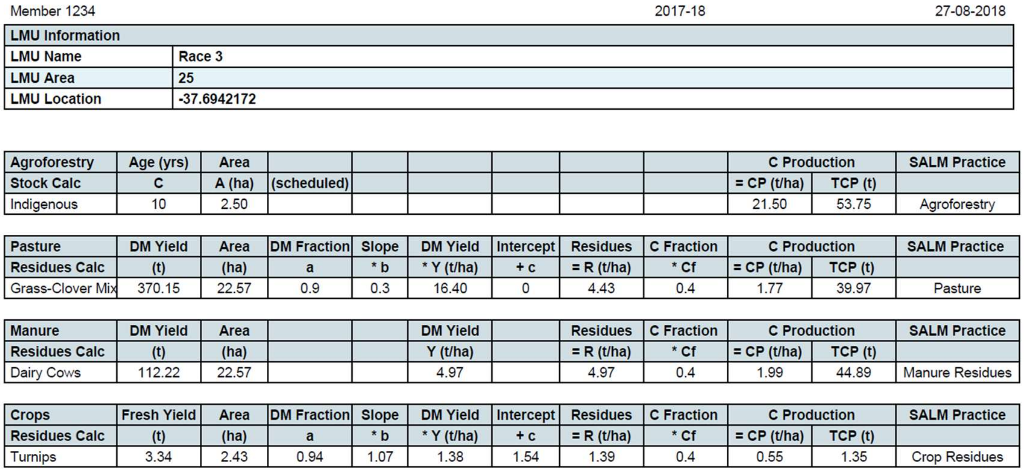
Estimation of input values from agroforestry

Agroforestry is recorded and calculated in accordance with the current ETS schedule. A date planted is entered in order to dynamically calculate the age. Consistent with the rest of the management practices, the resulting value is the difference between last year and this year, based on the local Climate Change Regulations 2008 - Schedule 6

Results – Modelling on a Waikato Dairy Farm

The web-based interface transforms the inputs, by applying the factors and calculations as described. The reporting divides the farm into separate land management areas (in this case 3). For clarity calculations are shown in the header of each section, showing calculations applied to each management practice.

Table 1: Annual Return Report in the CSA Mitigation Scheme



Member 1234 2017-18 27-08-2018

LMU Information	
LMU Name	Race 3
LMU Area	25
LMU Location	-37.6942172

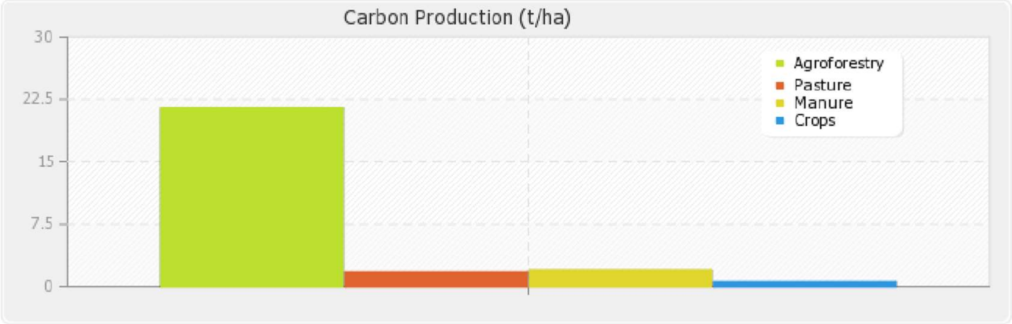
Agroforestry	Age (yrs)	Area							C Production		SALM Practice
Stock Calc	C	A (ha)	(scheduled)						= CP (t/ha)	TCP (t)	
Indigenous	10	2.50							21.50	53.75	Agroforestry

Pasture	DM Yield	Area	DM Fraction	Slope	DM Yield	Intercept	Residues	C Fraction	C Production		SALM Practice
Residues Calc	(t)	(ha)	a	* b	* Y (t/ha)	+ c	= R (t/ha)	* Cf	= CP (t/ha)	TCP (t)	
Grass-Clover Mix	370.15	22.57	0.9	0.3	16.40	0	4.43	0.4	1.77	39.97	Pasture

Manure	DM Yield	Area			DM Yield		Residues	C Fraction	C Production		SALM Practice
Residues Calc	(t)	(ha)			Y (t/ha)		= R (t/ha)	* Cf	= CP (t/ha)	TCP (t)	
Dairy Cows	112.22	22.57			4.97		4.97	0.4	1.99	44.89	Manure Residues

Crops	Fresh Yield	Area	DM Fraction	Slope	DM Yield	Intercept	Residues	C Fraction	C Production		SALM Practice
Residues Calc	(t)	(ha)	a	* b	* Y (t/ha)	+ c	= R (t/ha)	* Cf	= CP (t/ha)	TCP (t)	
Turnips	3.34	2.43	0.94	1.07	1.38	1.54	1.39	0.4	0.55	1.35	Crop Residues

The report graphs C productivity rates per hectare for each SALM practice.



The report also graphs Total C production per land management area for each SALM practice.

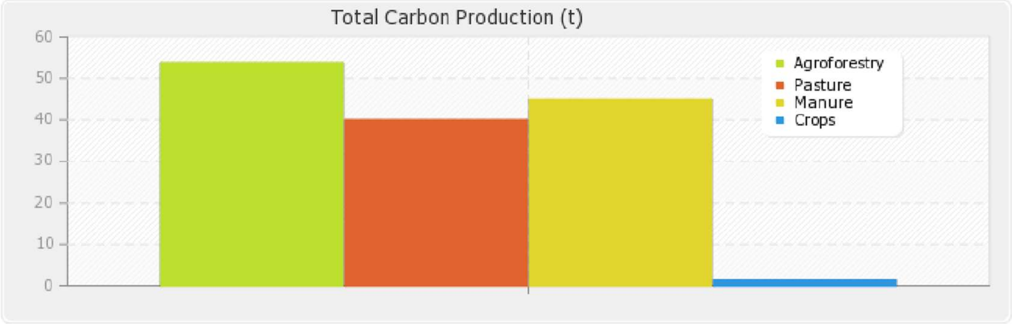
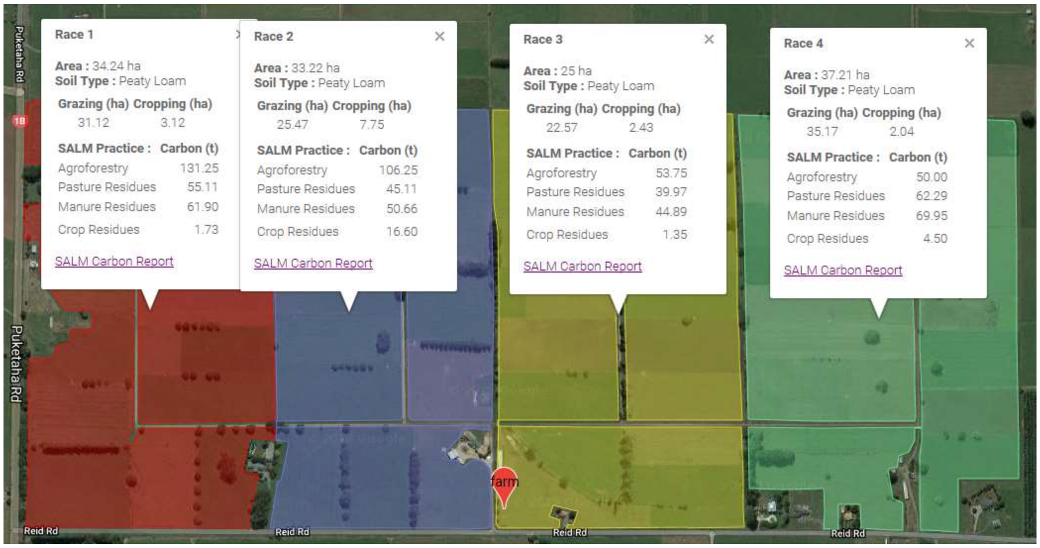


Figure 7: Spatial mapping tool for SALM practices

SALM practices are also summarize annually within the spatial mapping tool across the entire farm.



Race 1

Area : 34.24 ha
Soil Type : Peaty Loam

Grazing (ha)	Cropping (ha)
31.12	3.12

SALM Practice :	Carbon (t)
Agroforestry	131.25
Pasture Residues	55.11
Manure Residues	61.90
Crop Residues	1.73

SALM Carbon Report

Race 2

Area : 33.22 ha
Soil Type : Peaty Loam

Grazing (ha)	Cropping (ha)
25.47	7.75

SALM Practice :	Carbon (t)
Agroforestry	106.25
Pasture Residues	45.11
Manure Residues	50.66
Crop Residues	16.60

SALM Carbon Report

Race 3

Area : 25 ha
Soil Type : Peaty Loam

Grazing (ha)	Cropping (ha)
22.57	2.43

SALM Practice :	Carbon (t)
Agroforestry	53.75
Pasture Residues	39.97
Manure Residues	44.89
Crop Residues	1.35

SALM Carbon Report

Race 4

Area : 37.21 ha
Soil Type : Peaty Loam

Grazing (ha)	Cropping (ha)
35.17	2.04

SALM Practice :	Carbon (t)
Agroforestry	50.00
Pasture Residues	62.29
Manure Residues	69.95
Crop Residues	4.50

SALM Carbon Report

Conclusions – Modelling on a Waikato Dairy Farm

The results of modelling the on-farm data inputs of the VM0017 methodology suggest that it would be relatively straight forward to engage large numbers of dispersed land-users using this web-based modelling approach. In addition, based on the VM0017 methodology, C from bio-mass addition on the Waikato Dairy Farm modelled is significant for the incentivized SALM practices. In the annual return example (see table 1) Agroforestry is a significant contributor in both C productivity per hectare and total C production with 40% of total C from only 10% of the area. C from Pasture residues represents 28% of the total C from 82% of the total area. At a stocking rate of 3.9 cows per hectare manure production represents 32% of the total C, from 82% of the total area. Crop residue contribution was not significant in this example at less than 1% from 8% of the total area, however this varies significantly by crop type so larger contributions are purely dependent on crop choice. The incentivized SALM practices modelled here represent total annual C from bio-mass addition 140 tonnes (see table 1) and total annual C from bio-mass addition across the entire farm of 795 tonnes per annum (see figure 7).

Farmer Group Processing

The **Farmer Group Processing** subsequently employs the RothC Soil Decomposition Model to calculate SOC changes, based on the Annual Returns. RothC applies input parameters to estimate the SOC density in each of the identified SALM practices, measuring C removals over time through decomposition (Verified Carbon Standard, 2016). As indicated in the SALM methodology three types of input values are required for meteorological and soil parameters and for soil inputs of management practices. Mean values for the estimation of SOC density. Values at the upper and lower confidence limit for the estimation of uncertainty in the model output and the subsequent adjustment of the resulting project removals due to changes in SOC (Verified Carbon Standard, 2016).

The RothC version utilized is a simplified version, developed by the Australian Greenhouse Office (2002) on the basis of the RothC-26.3 program. It was modified by Joanneum Research and Unique forestry and land use for the BioCarbon Fund in the frame of the Kenya Agricultural Carbon Project (KACP). The model was enhanced with comments and automatic operations for the estimation in a simple manner of project removals due to changes in SOC according to the SALM methodology. Enhancements include ability to use the historical weather time series rather than average weather, calculating plant residues and soil cover from cropping data, and numerous improvements to the radiocarbon dating computations (Verified Carbon Standard, 2016). The farmer group manages the process, calculates carbon stock changes on-farm, then reports and verifies removals and distributes revenue with minimal transaction costs.

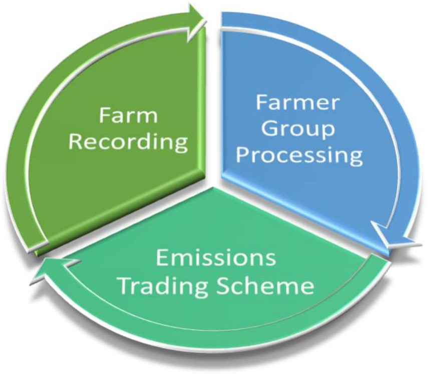
The Emission Trading Scheme (ETS)

As agricultural carbon markets seek to gain traction, effective strategies to recruit farmers and scale up projects, without marginalizing farmers and compromising their livelihoods, will be critical to success. Originally conceived to use carbon payments to incentivize land use changes and lower agricultural emissions, agricultural carbon markets have now evolved into a potential mechanism to fund CSA initiatives. Farmer participation is critical for achieving widespread impact, yet their adoption has been constrained by eligibility, willingness, and ability to participate (Lee, 2017). Providing incentives for adopting SALM practices, such as payments for environmental services (managing land to provide an ecological service), encourages farmers to take on climate-smart practices and to overcome initial investment barriers (Lee, 2017; World Bank, 2014).

Recent research examining the effects of climate change on agriculture with the costs and effects of mitigation policies, considered the subsequent effects on food security. It concluded that without careful planning, the burden of mitigation policies was simply too great. That a single climate mitigation scheme applied to all sectors, such as a global carbon tax, would have a serious impact on agriculture and result in far more widespread hunger and food insecurity than the direct impacts of climate change (Hasegawa et al., 2018). This research shows the importance of "smart", targeted policy design, particularly in agriculture. When designing climate mitigation policies, policymakers need to scrutinize other factors and development goals more closely, rather than focusing only on the goal of reducing emissions. Smarter, more inclusive policies are necessary.

Within many cap-and-trade systems, a limited amount of emission reductions (termed 'offsets') can be provided by non-capped entities. The inclusion of agricultural activities as offset providers has been growing, particularly within voluntary markets. To maintain the integrity of emission caps, key criteria for offset providers include demonstrating additionality (that is, ensuring that reductions result from project interventions and not simply business-as-usual trends), avoiding leakage (that is, unintended emission increases elsewhere as a consequence of the project activities), and providing for permanence (meaning that increased soil C storage, credited as a CO2 removal, is maintained long-term) (Paustian et al., 2016).

Figure 8: ETS normative framework for the CSA Mitigation Scheme



As an incentive compatible mechanism, the ETS provides a normative framework (see figure 8), trading carbon units based on farm systems which effectively measure, report and ultimately verify agriculture's contribution towards a country's NDCs. Carbon credits create a revenue stream that enhances the extension services provided to farmers, which are critical to the adoption of these practices and also adds to farmers' income beyond their increased crop yields (World Bank, 2014).

According to the World Bank (2014), experience from 1,505 farmer groups over three years illustrates how targeted carbon finance can promote the adoption of SALM practices and open up the carbon market to farmers. Results to date showed that SALM can help increase farmers' yields. These productivity gains from greater soil fertility help counteract the effects of increasingly extreme weather conditions (World Bank, 2014).

Conclusions

Given the challenge of reaching net zero emissions, how can the agriculture sector become a significant source of near-term mitigation? How can the NZ government support mitigation efforts? This paper seeks to address these questions by exploring the adoption of CSA agricultural carbon market project methodologies. Key findings are that the CSA Mitigation Scheme Framework overcomes the challenges of designing and implementing Agricultural Carbon Market Projects in the New Zealand context. Also, that the CSA Mitigation Scheme Framework is designed to reduce uncertainty and ensure data validity and integrity. That it provides robust and verifiable metrics that supports Carbon accounting. The model-based web-interface overcomes the difficulties of obtaining and processing activity data by engaging the individual farmer in the monitoring of crop types, fertilizers and organic amendments.

In addition, the scheme framework includes metrics developed for the purpose by the World Bank Bio-carbon Fund and the Verified Carbon Standard Project. These include on-farm verification, monitoring and reporting to reduce uncertainty. The scheme framework links with an ETS in order to incentivize on-farm mitigation efforts. The integrity of the ETS is maintained by the framework which demonstrates additionality, avoids leakage and provides for permanence.

In this paper I have shown that the New Zealand Agriculture Sector can become a significant source of cost-effective abatement and near-term mitigation. With the right policy approach government can legitimately support mitigation efforts in a way which is fully compliant with multilateral climate and trade agreements. By adopting these practical, credible and politically acceptable metrics which promote on-farm mitigation efforts, with a validation and reporting structure that not only supports but also incentivizes farmer participation in mitigation. Coupled with an incentive compatible mechanism like the NZETS, this would create a revenue stream for farmers that resulted from managed mitigation responses at the farm level.

References

Bellassen, V., Stephan, N., Afriat, M., Alberola, E. Barker, A., Chang, J., Shishlov. I. (2015). Monitoring, reporting and verifying emissions in the climate economy. *Nature Climate Change, 5*(4), 319-328.

Chabbi, Lehmann, Ciais, Loescher, Cotrufo, Don, . . . Rumpel. (2017). Aligning agriculture and climate policy. *Nature Climate Change, 7*(5), 307-309.

Conant, R., Ogle, S., Paul, E., & Paustian, K. (2011). Measuring and monitoring soil organic carbon stocks in agricultural lands for climate mitigation. *Frontiers in Ecology and the Environment, 9*(3), 169-173.

Cornell Institute for Climate Change and Agriculture (2015). *Climate Smart Farming 2015*. Retrieved from http://climateinstitute.cals.cornell.edu/climate-smart-farming/

Ewert, Rötter, Bindi, Webber, Trnka, Kersebaum, . . . Asseng. (2015). Crop modelling for integrated assessment of risk to food production from climate change. *Environmental Modelling and Software, 72*(C), 287-303.

Food and Agriculture Organisation of the United Nations (2016). *Climate-Smart Agriculture 2016.* Retrieved from http://www.fao.org/climate-smart-agriculture/en/

Hasegawa T, Fujimori S, Havlík P, Valin H, Bodirsky BL, Doelman JC, Fellmann T, Kyle P. (2018). Risk of increased food insecurity under stringent global climate change mitigation policy. *Nature Climate Change* DOI: 10.1038/s41558-018-0230-x [pure.iiasa.ac.at/15389]

Holzworth, Snow, Janssen, Athanasiadis, Donatelli, Hoogenboom, . . . Thorburn. (2015). Agricultural production systems modelling and software: Current status and future prospects. *Environmental Modelling and Software, 72*(C), 276-286.

IPCC (2006). *Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories* (eds Eggleston, S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K.) Vol. 4, *Agriculture, Forestry and Other Land Use (AFOLU)* http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (Institute for Global Environmental Strategies, 2006).

Lake, I., Hooper, L., Abdelhamid, A., Bentham, G., Boxall, A., Draper, A., Waldron, K. (2012). Climate change and food security: Health impacts in developed countries. *Environmental Health Perspectives, 120*(11), 1520-1526.

Lee, J. (2017). Farmer participation in a climate-smart future: Evidence from the Kenya Agricultural Carbon Project. *Land Use Policy, 68*, 72-79.

Lehmann, N., Finger, R., Klein, T., Calanca, P., & Walter, A. (2013). Adapting crop management practices to climate change: Modeling optimal solutions at the field scale. *Agricultural Systems, 117*, 55-65.

Lipper, L., Thornton, P., Campbell, B., Baedeker, T., Braimoh, A., Bwalya, M., Torquebiau, E. (2014). Climate-smart agriculture for food security. *Nature Climate Change, 4*(12), 1068-1072.

Ministry for the Environment. (2017). *Briefing to the Incoming Ministers – Environment and Climate 2017*. Retrieved from https://mfe.govt.nz/publications/about-us/briefing-incoming-ministers-—-environment-and-climate

Ogle, S., Breidt, F., Easter, M., Williams, S., Killian, K., & Paustian, K. (2010). Scale and uncertainty in modeled soil organic carbon stock changes for US croplands using a process-based model. *Global Change Biology, 16*(2), 810-822.

Parsons, Thornley, Newton, Rasmussen, & Rowarth. (2013). Soil carbon dynamics: The effects of nitrogen input, intake demand and off-take by animals. *Science of the Total Environment, 465*(C), 205-215.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, P., & Smith, P. (2016). Climate-smart soils. *Nature, 532*(7597), 49-57.

Saj, Torquebiau, Hainzelin, Pages, & Maraux. (2017). The way forward: An agroecological perspective for Climate-Smart Agriculture. *Agriculture, Ecosystems and Environment, 250,* 20-24.

Swallow, & Goddard. (2013). Value chains for bio-carbon sequestration services: Lessons from contrasting cases in Canada, Kenya and Mozambique. *Land Use Policy, 31*, 81-89.

Verified Carbon Standard. (2014*). Approved VCS Methodology VM0017.* Retrieved from http://verra.org/wp-content/uploads/2018/03/VM0017-SALM-Methodolgy-v1.0.pdf

Verified Carbon Standard. (2016*). Guidance for the estimation of project removals due to changes in soil organic carbon with the RothC model.* Retrieved from http://database.v-c-s.org/sites/vcs.benfredaconsulting.com/files/VCS%2BSC%20Guidance%20Project%20Development%20Process%2C%20v3.0.pdf

World Bank. (2014). *Kenyans Earn First Ever Carbon Credits From Sustainable Farming 2014*. Retrieved from http://www.worldbank.org/en/news/press-release/2014/01/21/kenyans-earn-first-ever-carbon-credits-from-sustainable-farming