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An Assessment of the Co-benefits of Greenhouse Gas Mitigation Options for Agriculture in Fiji

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Acronyms

BMP	Best Management Practice
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
CSA	Climate Smart Agriculture
CSA-PF	Climate Smart Agriculture Prioritisation Framework
GHG	Greenhouse gas
MoA	Ministry of Agriculture
Mt	Mega tonne (a million tonnes)
N	Nitrogen
OA	Organic Amendment

Contents

1 The role of co-benefits when adopting GHG mitigation options in Fiji: An introduction

Implementing mitigation options to improve environmental outcomes, while a worthy goal, is unlikely to motivate farmers to adopt mitigation actions. A clear advantage needs to be evident for farmers to bring about changes to their current practices. While financial benefits, such as subsidies or payments for ecosystem services, can act as incentives to farmers, decision-making processes are more complex than a simple financial decision. Implementing mitigation options often requires changes to farm practices such as learning new processes, different labour requirements or additional inputs (such as new feed sources or seed). Farmers may be resistant to change and the uncertainty that exists around new practices. The livestock sector is estimated to have a global mitigation potential of up to 50% of all agricultural, forestry and land-use sector emissions, but this potential has not been realised due to the low adoption rates worldwide of emissions reduction options (Herrero *et al.* 2016). The mitigation options most likely to be adopted by farmers are those that demonstrate clear advantages through co-benefits and when there is the ability to learn about the option through existing social networks (White and Selfa 2013).

Co-benefits can be broadly grouped around: increased production; greater resource efficiency, reduced waste; a healthy, resilient system; and an environmentally sustainable farm with good soil and well-managed nutrients. At a national scale, increases in production and production efficiency also improves food security because less land is required to produce the same amount of food (Herrero *et al.* 2016).

Greenhouse gas emissions can be reduced either in absolute terms (total carbon dioxide equivalents (CO_2e)) or through emissions intensity (kg product/kg CO_2e). Some mitigation options that improve animal production may increase total emissions, but will reduce the emissions intensity, creating gains through avoided emissions as the emission intensity gap declines (Figure 1). For example, the meat production of cattle and goats in Fiji is around 250 kg CO_2e/kg meat which is high when compared with other meat production systems (FAOSTAT 2018), so there are potential gains to be made in the emissions intensity of meat products, as well as in other products.

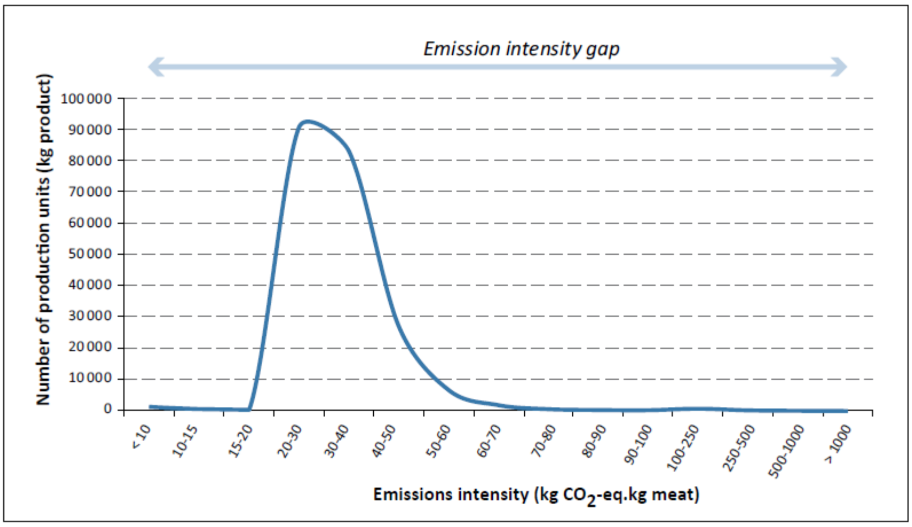

Figure 1: Example of emission intensity gap for meat production (modified from Gerber *et al.* 2013)

Emissions intensity improves when farmers adopt efficient practices, such as Best Management Practices (BMPs). BMPs are effective and practical farm management methods based on research, field testing and expert review of the best way to approach farming issues such as fertiliser runoff and animal waste, animal care, or grazing and feed management (Prokopy *et al.* 2008). BMPs are tools that can be used for improved sustainability and environmental outcomes, which is increasingly important to maintain the feasibility and productivity of farms into the future.

Emissions intensity and the use of BMPs reflect the efficiency of a farm system, and there is a negative correlation between emissions intensity and farm profitability (Reisinger and Ledgard 2013). This demonstrates that by reducing waste in farm systems and increasing efficiency there is a twofold benefit of reducing emissions intensity and increasing farm profit.

2 Method of Prioritising Mitigation Options

Identifying appropriate mitigation options can be facilitated using a decision support tool such as the CCASF-CIAT Climate Smart Agriculture Prioritisation Framework (CSA-PF). Such tools can help to prioritise strategic decisions that will improve the resilience, adaptability, and livelihoods of farmers in the face of climate change and was used as the basis for our analysis (Figure 2).

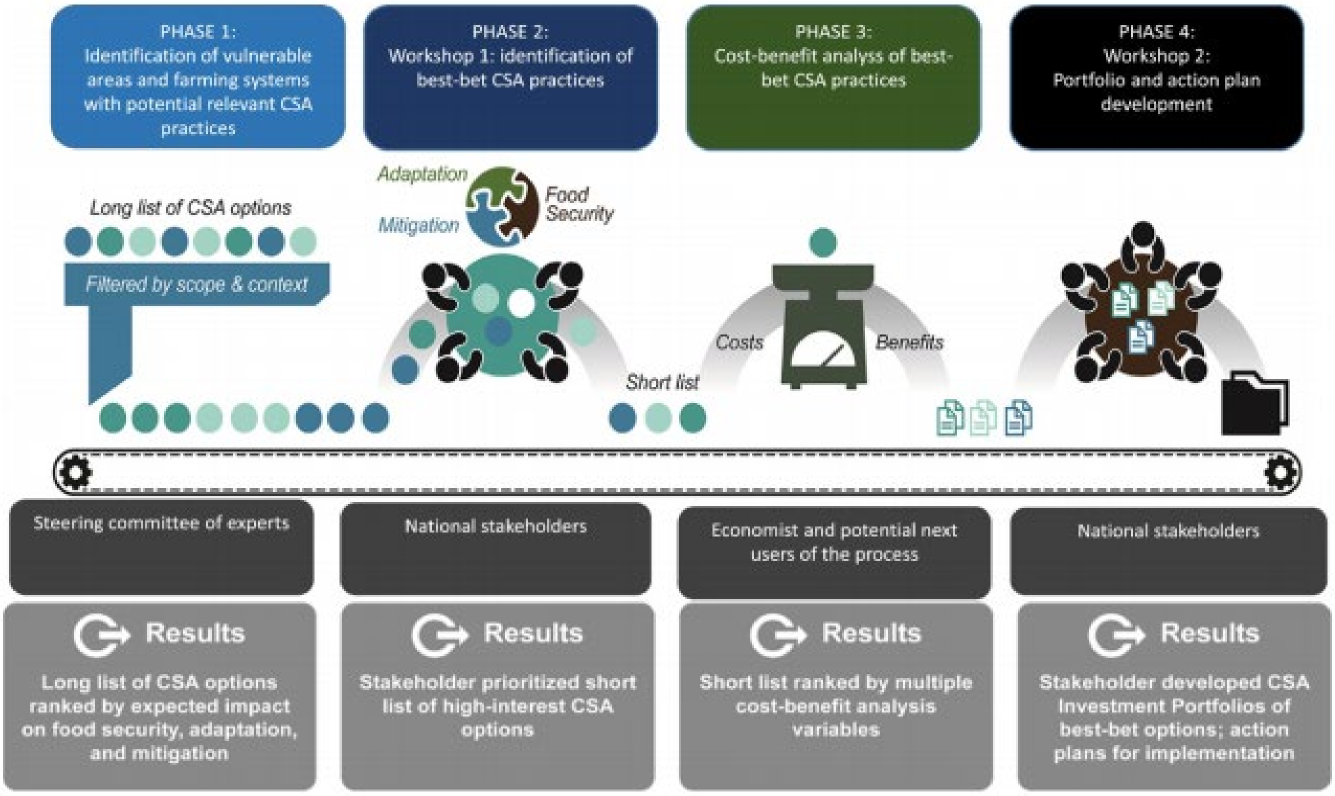

Figure 2: Overview of the Climate Smart Agriculture Prioritisation Framework (CSA-PF) demonstrating the phases and their goals, stakeholders involved and results - adapted from Wollenberg et al., (2016). The CSA-PF aims to provide a coherent process for increasing technical understanding of Climate Smart Agriculture (CSA) options and directing climate change and agriculture investment to assist national planning. With participation at the heart of the process, local knowledge, and scientific evidence unit to establish realistic pathways for CSA adoption.

The CSA-PF is divided into four phases: (1) Initial assessment of Climate Smart Agriculture (CSA) options, (2) Identification of top CSA options, (3) A more in-depth calculation of costs and benefits of top CSA options, (4) Development and evaluation of barriers to implementation of selected options. It was beyond the scope of our project to extend to phase (3) and (4) of this framework, but we used this framework to structure our initial assessment, with the view that the partner countries can progress to phase 3 and 4 of the framework given the necessary support and funding.

Our assessment of mitigation options involved an initial workshop which identified a 'long-list' of stakeholder desired mitigation options. This was then followed by a desktop review and consultation with in-country experts (including an online workshop September 2020), which analysed mitigation options in terms of their mitigation potential and delivery of co-benefits.

3 Livestock Greenhouse Gas (GHG) Mitigation Options and their Co-benefits in Fiji

Livestock farms generate a disproportionate amount of greenhouse gas emissions when compared with other agricultural industries (Garnett 2009). As a result a great deal of scientific research has occurred on mitigation methods for livestock greenhouse gas (GHG) emissions (de Vries and de Boer 2010; Montes *et al.* 2013; Tesema *et al.* 2019), especially for enteric methane (CH_4), the dominant source of emissions from ruminant livestock (Beauchemin *et al.* 2008).

Strategies to reduce livestock emissions can be broadly categorised into six areas, which each contain numerous methods for reducing GHG emissions (Figure 3):

1. Animal feed and diet manipulation
2. Animal health
3. Genetics and breeding
4. Manure management
5. Farm management
6. Rumen manipulation

A comprehensive list of mitigation options for livestock industries is provided in the Tables 1 and 2. However, for an emissions reduction strategy to be viable it must be available, economically sound and suited to the farming system where it will be implemented. Therefore, Table 1 contains mitigation options that are suited for implementation in Fiji. Table 2 shows the mitigation options that are less suited to Fijian farming systems, that are still in the research and development phase, or that are not economically viable to implement. Some options with good mitigation potential but high start-up costs may be possible if external funding can be secured.

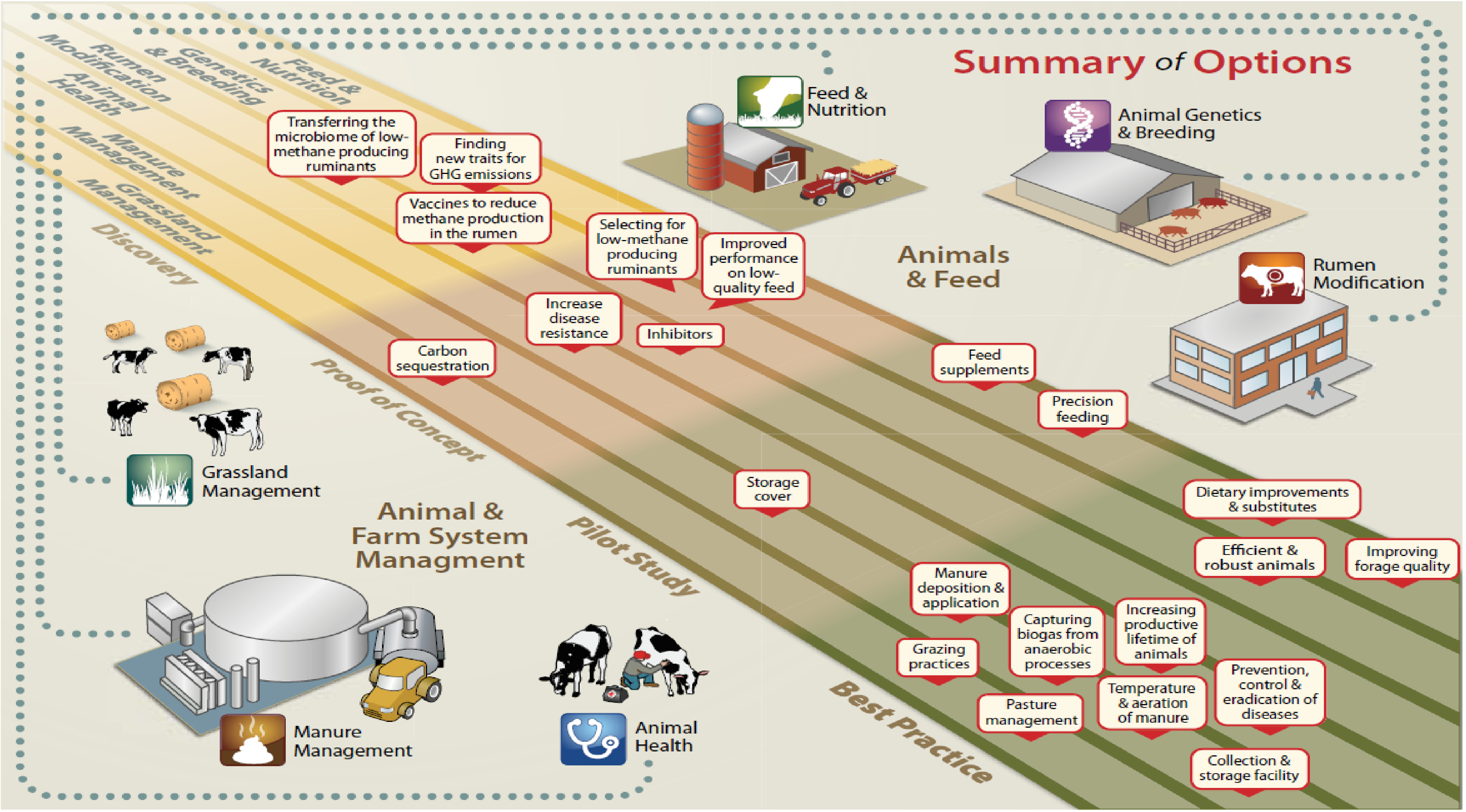

Figure 3: Summary of options for reducing GHG emissions from livestock systems (GRA and SAI 2015)

Table 1: Recommended mitigation options to reduce methane (CH_4) and nitrous oxide (N_2O) emissions from Fijian livestock farms (compiled from Eckard *et al.* 2010; GRA and SAI 2015)

Mitigation area	Mitigation option	Mitigation potential (global)[1]	GHG	Barriers	Co-benefits	Gender Considerations	Economic Benefit
Animal feed and diet manipulation							
Forage quality	Improve feed quality and digestibility	Medium-high (emissions intensity only) depending on baseline	CH_4	• Knowledge • Access to seed • Upfront costs	↑ Animal production ↑ Animal production efficiency ↑ Food security ↑ Resource use efficiency	Consider gendered norms regarding animal: who owns the animal, who feeds the animal, who pays for animal feed?	Low to high
Plant secondary compounds	Tannin and saponins	Low to medium	CH_4/ N_2O	• Upfront costs	↑ Animal production (if higher nutritional value)		Moderate to high
Dietary improvements and supplements	Dietary oils	Medium to high	CH_4	• Cost prohibitive unless by-products available • Additional emissions from transportation	↑ Energy in diet ↑ Animal production ↑ Resource use efficiency (use of by-products)		Low
Animal health and breeding							
Animal health	Detect, prevent and remove disease	Medium	CH_4/ N_2O	• Knowledge • Diagnostic tools • Access to services and medicine	↑ Animal welfare ↑ Animal production efficiency ↑ Food security	Consider gendered norms regarding the animal: who is responsible for animal health, who makes decisions about the animal & animal breeding?	Low to moderate
	Increase lifetime of productive animals	Low to medium depending on baseline	CH_4/ N_2O	• Willingness to change farming practices	↑ Food security ↑ Animal production efficiency		Low
	Remove unproductive animals	Low to medium	CH_4/ N_2O	• Willingness to change farming practices • Availability of higher producing stock	↑ Animal production efficiency		Low
Animal breeding	Efficient, healthy animals	Low to medium	CH_4	• Upfront costs • Availability of suitable animals	↑ Cost efficiency		Low to moderate
Manure management							
Storage and application of waste	Storage facilities to capture, store and reuse nutrients in effluent	High	CH_4	• Upfront costs	↑ Nutrient reuse ↓ N pollution	Consider gender norms: who is responsible for manure management, who makes decisions about manure management?	None to low

Mitigation area	Mitigation option	Mitigation potential (global)[1]	GHG	Barriers	Co-benefits	Gender Considerations	Economic Benefit
	Cover waste storage pits	Medium	CH_4	• Knowledge of best materials to use and influence on GHGs	↑ Renewable energy production ↓ Odours from waste		None to low
	Biogas facilities	High	CH_4	• Upfront costs • Adequate infrastructure • Access to parts • Maintenance • Knowledge	↑ Renewable energy production		None to moderate
	Manure deposition and application	Low to medium	CH_4	• Knowledge of BMPs	↑ Nutrient reuse ↓ N pollution		None to low
Farm management							
Grazing management	Rotational grazing	Low to medium depending on baseline	N_2O, CH_4, C	• Knowledge of BMPs for grazing • Willingness to change grazing practices	↑ Animal production	Consider gender norms: who makes decisions about farm management such as grazing, planting of trees and soils management?	Low
	Waterlogging/ compaction	Low	N_2O	• Knowledge of BMPs for grazing	↑ Soil health		None
Carbon sequestration	Plant or regenerate trees to sequester more carbon	Low to medium	C	• Availability of land	↑ Product diversification		Low to moderate
	Sequester soil C through grazing management or closed nutrient cycles	Low to medium depending on baseline	C	• Willingness to change farming practices	↑ Soil health ↑ Nutrient reuse		Low to moderate
Soil nutrient management	Increased use of legumes and recycling of animal manure	Low to medium	N_2O	• Knowledge of BMPs for grazing	↑ Nutrient reuse ↓ N pollution		Low

BMP, Best Management Practice; MRV, Measuring, Reporting, Verification

[1] Mitigation potential is estimated as low (0-10%), medium (10-20%) and high (>20%) (GRA and SAI 2015)

3.1 Animal feed and diet manipulation

Livestock that feed on low-quality and low-digestible pastures and feed have a high emissions intensity. There are many countries that have emerging economies where the livestock systems have relatively high emissions intensity that could be reduced with better quality feed (Henderson *et al.* 2017). The outcome is improved food security because when emissions intensity goes down, more food can be produced for the same output of GHG emissions. A diet that is balanced in energy and protein and that includes improved forages, by-products from cropping and crop residues has many co-benefits, including improved nutrient uptake, greater animal production and improved fertility (GRA and SAI 2015). While improving the feed quality and digestibility of forage may result in higher total emissions since the animals will eat more, emissions intensity will decrease. However, emissions from the production of off-farm feeds needs to also be considered to ensure they do not outweigh the on-farm emissions reductions.

Plant secondary compounds, especially those that containing tannins, are prevalent and available through a range of tropical legumes and have great potential to reduce GHG emissions at a large scale. Similar to increasing forage quality, animal production will increase if the feed has a higher nutritional value. Soils in Fiji are suitable for a number of tropical tree legumes that contain tannins, such as Leucaena and Gliricidia (Cowley *et al.* 2005). These plant species currently grow by the roadside or are utilised as living fenceposts in Fiji, but have not been incorporated by many farmers (<15%) into the Fijian farming system (Cowley *et al.* 2005), although work has been undertaken at the Ministry of Agriculture on the use of Leucaena (Cornelio 2015).

Supplements such as dietary oils may be economically feasible (Herrero *et al.* 2013), provided a cost-effective supply of oils, such as a by-product, can be sourced. The introduction of a new energy source into an energy-deficient diet will help improve production

3.2 Animal health

Maintaining healthy, productive animals has a direct impact on the herd and production efficiency (FAO 2019). Reducing parasites and diseases makes good economic sense while improving animal welfare, food security and animal production (Hristov *et al.* 2013). The goal for animal systems is to extend the life of productive animals by keeping these animals healthy, while removing unproductive animals that are underperforming. Additionally, improving reproduction rates will help the efficiency of livestock production. However, to improve animal health the knowledge, diagnostic tools and medicines required to detect and treat disease need to be available and affordable for farmers (Ministry of Agriculture 2016). Long-term benefits can be gained by integrating animals into the system that have been bred for heat tolerance and have greater resistance to pests and disease (Eisler *et al.* 2014).

3.3 Genetics and breeding

Genetics and breeding options are longer-term solutions with secure gains, since, once the stock are part of the farm, their desirable traits remain and are heritable for offspring. Therefore, while breeding takes a longer time, the gains also have a greater level of permanence (Tesema *et al.* 2019).

Fiji has started the process of improving beef and dairy cattle genetics through their Embryo Transfer Program (Government of Fiji 2018). This program will make available to farmers high-production animals that are well-suited to a tropical environment. Having a government program in place will help to manage the barriers that would otherwise exist with breeding strategies, namely the upfront costs and availability of animals with the desired traits. The program has the potential for long-term benefits to make beef and dairy farms more resilient, cost effective and productive with reduced total emissions and reduced emissions intensity. Existing research has shown that breeding for efficient, robust animals that are high producing per unit of input and resilient to disease has a cumulative and permanent effect on animals, with genetic improvement accounting for 0.5-1% improvement in efficiency per animal per year (GRA and SAI 2015).

3.4 Manure management

Animal manure contains valuable nutrients which are often lost due to poor manure collection or storage. Greater efficiencies can be gained through the application of manure onto crops to increase crop production. Storage facilities with hard floors can prevent runoff of nutrients into the environment. Waste storage facilities that are covered will reduce NH_3 and CH_4 emissions and importantly, covering the storage pits decreases odours (GRA and SAI 2015). Storage covers can be made from wood or concrete, or more permeable covers are often used, such as a thick layer of straw (MacSween and Feliciano 2018).

Manure from intensive animal systems such as piggeries, poultry or dairy, can be captured and stored for the production of biogas (Petersen *et al.* 2013). The benefit of biogas facilities is in the energy that is produced. Additionally, the remaining slurry from digesters can be used as fertiliser on farms. Biogas digesters can be different scales with small household digesters providing energy for cooking and heating water and larger digesters generating electricity on a larger scale (Fiji Department of Energy 2014). Although biogas installation requires upfront capital investment, this can generally be paid back within a short period of time. Tropical areas with high temperatures are ideal for biogas use since the fermentation processes are increased with high temperatures(GRA and SAI 2015).

Animal waste tends to end up on soils eventually but N_2O emissions can be significantly reduced when manure is added at a rate to optimise crop or pasture growth and avoid the excess application of nitrogen. Manure management can reduce GHG emissions when the application of manure is timed to match the nitrogen needs of the pasture during its greatest growth phases. Farmers should avoid applying manure when soils are wet (GRA and SAI 2015).

3.5 Farm management

3.5.1 Grazing management

A managed rotational grazing system will build more soil organic matter over time and help to improve soil carbon, relative to a set stocked system. Rotational grazing has the potential to increase pasture utilisation and quality by using a higher stocking rate for short periods (<3 days) to increase production per hectare and animal liveweight gain (de Klein *et al.* 2008). The increased animal liveweight gain reduces emissions intensity but total emissions will increase (de Klein *et al.* 2008). The increase in animal production is also likely to improve the farm's profitability.

When animals tread on the soils they compact the ground and reduce soil aeration (Eckard *et al.* 2010), intensifying the process of N_2O loss from dung and urine patches. Therefore, grazing on wet soils should be reduced to prevent this additional N_2O loss (van Groenigen *et al.* 2005).

3.5.2 Silvopastoral systems

Silvopasture is the integration of trees, forage and livestock farms into one intensively managed system (Eichhorn *et al.* 2006). The use of trees on farms can produce a number of co-benefits in addition to carbon sequestration such as improved soil health, reduced salinity, windbreaks, shelter and shade for stock, reduced soil erosion, suppression of weeds and improved biodiversity of indigenous plants (Doran-Browne *et al.* 2016).

Silvopastoral systems have the ability to provide both adaptation and mitigation benefits that are complementary to the overall system (Harvey *et al.* 2014) (Figure 4). For example, farms with degraded pasture systems could potentially be planted with fodder crops to improve soil health, provide feed and shade for animals, and to improve the carbon stocks on the farm.

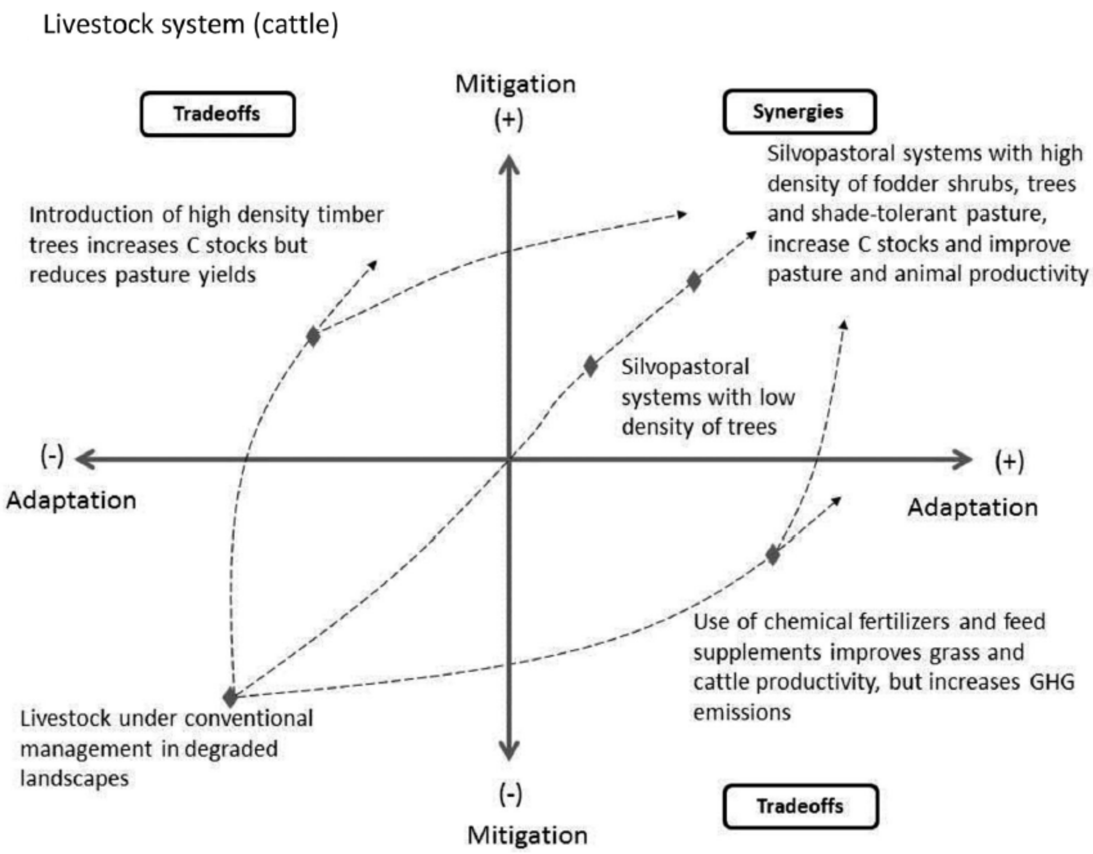

Figure 4: Summary of options for reducing GHG emissions from livestock systems (Harvey *et al.* 2014)

In Fiji, the commercial feasibility of silvopastoral systems depends on land ownership, soil condition, climate, access to markets and availability of transport (Cornelio 2015). Silvopastoral systems provide product diversification and reduced risk since livestock and forestry do not share the same markets and are susceptible to different pests and diseases (Cornelio 2015). Agroforestry systems that produce food products may also offer opportunities for women and children to participate more in farming and earn income (Karim and Harrison 2016).

3.5.3 Carbon sequestration in soils

Carbon stocks in soils on livestock farms are depleted through poor grazing management practices such as continuous grazing or overstocking grazing lands (Herrero *et al.* 2016). Good management that maximises forage production has the potential to reverse soil depletion and ensure the long-term viability of farmland. By avoiding overstocking and through improved management of grasslands, large amounts of carbon can be sequestered back into soils (Wilkes *et al.* 2017). Carbon can also be built up in soils through the application of compost.

Legumes will fix nitrogen into the soil which can reduce the need for synthetic nitrogen fertilisers. Additionally, feeding forage legumes to ruminant livestock reduces CH_4 emissions due to the faster passage of legumes through the digestive system (Eckard *et al.* 2010)

4 Additional Livestock Mitigation Options

Table 2 contains additional mitigation options that are currently less suitable for use in Fiji due to lack of availability, high cost, or being unsuited to farming conditions in Fiji. Many of these options are still within the research and development phase and have not been made commercially available (some breeding options, rumen manipulation methods). Other options are available but cost prohibitive (nitrification inhibitors), or else more suited to highly intensive systems (balancing protein and energy rations, use of salt supplements).

Table 2*: Additional mitigation options that may be of future use to reduce GHG emissions from Fijian livestock farms (compiled from Eckard et al. 2010; GRA and SAI 2015)*

Mitigation area	Mitigation option	Mitigation potential (global)	GHG	Availability	Barriers	Co-benefits	Gender Considerations	Economic Benefit
Animal feed and diet manipulation								
Dietary improvements and supplements	Probiotics	Medium	CH_4	2-5 years	• Not commercially available	None known		Low
	Enzymes (e.g. 3-NOP)	High	CH_4	< 2 years	• Not commercially available	None known		Low
	Dicarboxylic acids	Low	CH_4	n/a	• Cost too high	None known		Low
	Balancing protein: energy ration	Low. Medium in high N systems	N_2O	Now	• Fijian systems unlikely to have excess N • Knowledge • Cost of supplements	↓ N pollution		Low to moderate
Chemical interventions	Nitrification inhibitor in urine	Low	N_2O	n/a	• Cost too high	None known		None
	Salt	Low	N_2O	Now	• For intensive systems only that produce N hot spots	None known		
Animal health and breeding								
Animal health	Increase disease resistance	Low to medium	CH_4/ N_2O	5-10 years	• Long timeframe of breeding research	↑ Animal welfare ↑ Animal production ↑ Animal production efficiency		Low to moderate
Animal breeding	Feed Conversion Efficiency	Low	CH_4	2-5 years	• Long timeframe of breeding research	↑ Animal production efficiency ↑ Food security ↑ Resource use efficiency		Low
	Improved performance on low-quality feed	Low	CH_4	2-5 years	• Long timeframe of breeding research	↑ Animal production efficiency ↑ Food security		Low
	Selecting for reduced methane	Low to medium	CH_4	5-10 years	• No productivity benefits, incentives required • Equipment/knowledge to measure CH_4 from livestock	None known		Low to moderate
	Increase disease resistance	Low to medium	CH_4/N_2O	5-10 years	• Long timeframe of breeding research	↑ Animal welfare ↑ Animal production efficiency		Low to moderate

Mitigation area	Mitigation option	Mitigation potential (global)	GHG	Availability	Barriers	Co-benefits	Gender Considerations	Economic Benefit
Manure management								
Storage and application of waste	Manage temperature and aeration of manure	Low to medium depending on climate	CH_4		• Upfront costs			None
Farm management								
Soil management	Nitrification inhibitors	Low to medium	N_2O	Now	• Cost • Availability	↑ Pasture production in cold climates		
Rumen manipulation								
Inhibitors	Bacteriophages, bacteriocins	Low to medium	CH_4	>10 years	• Development costs for commercial availability • Regulatory barriers • Public acceptance • Demonstrated food products free of residues	Unknown	Consider gendered knowledge: who has knowledge about rumen manipulation and access to interventions?	None
	Reductive acetogenesis	Low to medium	CH_4	>10 years	• Development costs for commercial availability • Regulatory barriers • Public acceptance • Demonstrated food products free of residues	Unknown		Unknown
Vaccination		Unknown	CH_4	>10 years	• Development costs for commercial availability • Regulatory barriers • Public acceptance • Demonstrated food products free of residues	Unknown		Unknown
Chemical defaunation		Unknown	CH_4	>10 years	• Variable results, further research required	Unknown		Unknown
Transferring microbiome from low-CH_4 ruminants		Unknown	CH_4	>10 years	Unknown	Unknown		Unknown

5 Cropping Greenhouse Gas (GHG) Mitigation Options and their Co-benefits in Fiji

In the following section, the co-benefits of mitigation options in cropping are considered to support the early stages of decision making in Fiji at the national level. This will help to enable the most promising and locally appropriate mitigation options to be identified.

Greenhouse gas emissions from cropping in Fiji represent a small percentage of emissions from the agricultural sector. For example, rice cultivation in 2015 yielded emissions of 2.98 Gg CO_2e in comparison to ~450 Gg CO_2e from enteric fermentation (Figure 5). Therefore, in the first instance, mitigation efforts in Fiji should focus on the livestock sector to ensure a cost-effective approach to GHG reductions. An emphasis on emission reductions in livestock does not preclude opportunities for reducing emissions in the cropping sector. Mitigation options in cropping should focus on 'negative-cost' options – where the co-benefits of adoption exceed any costs associated with their implementation – and avoid high-cost solutions e.g. use of nitrification inhibitors that have limited co-benefits.

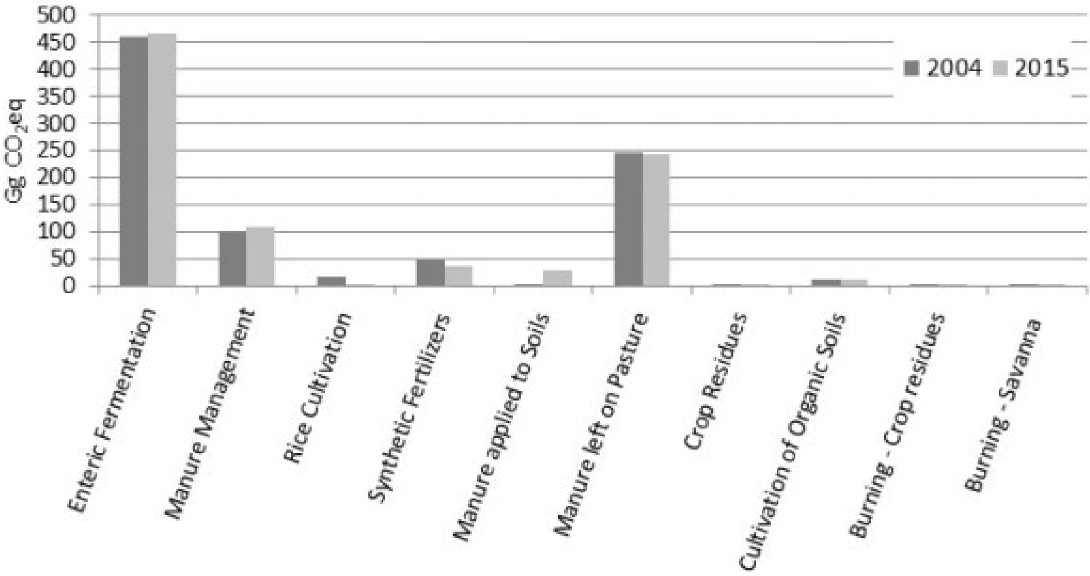

Figure 5: Emissions from different areas of the agriculture sector 2004 and 2015: Source: Low Emission Development Strategy.

Co-benefits metrics considered for cropping included: productivity (increased yields and greater food security)[1], (2) profitability (e.g. reduced input costs for farmer), (3) soil health, (4) soil water retention, and (5) reduced soil erosion. Our analysis also considered time-lags associated with co-benefits. For example, in the case of agroforestry, there is a high cost associated with establishing the system, followed by a lag-time until marketable benefits are realised (e.g. fruit, nut, timber production). Similarly, although the use of cover crops may increase productivity and profitability in the long-term, the increased labour demands in short-

[1] *The 1996 World Food Summit defined food security as the state "when all people at all times have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active, healthy life" (FAO, 1996).*

term establishment and termination of the cover crop may prevent the adoption of this mitigation option.

From our multi-criteria analysis, we were able to identify ‘most-promising’ mitigation options that will form the basis of more depth analysis moving forward in the project. This included an assessment of ease of implementation, ex-ante assessment of cost and gender implications of the mitigation options. Our evidence-based approach recognises that there is an absence of ‘perfect information’, but the process must advance despite data and resource constraints. Our decision-making process was grounded in an inclusive participatory process that brought a range of stakeholders together to ensure alignment of national NDC goals with local realities. Finally, the process included mechanisms for feedback and revisions to recognise that the priority setting process is generally non-linear and iterative process. The outcomes of our analysis are summarised in Table 3.

5.1 Organic Amendments

Organic amendments (OAs) incorporate organic matter into agricultural soil, thereby improving soil porosity, aeration, water holding capacity, aggregate stability, and nutrient availability (Thangarajan *et al.* 2013), as well as stimulating soil microbial activity and biomass (Das *et al.* 2017). As a result of improvements in soil health, there is an associated increase in plant growth, yield and productivity (Thangarajan *et al.* 2013). The use of OAs also reduces the dependence on mineral fertilisers, thereby reducing input costs and potentially increasing profitability. An increase in soil water holding capacity and a reduction in bulk density associated with OA application also reduces the likelihood of surface runoff and erosion (Urra *et al.* 2019).

While the soil health benefits of OA application are widely reported, more research under locally specific conditions accounting for variations in climate, soil type, type of OA used, application of amendment (e.g. applied on its own or combined with mineral fertilisers), and rate of application is required – particularly in tropical areas. There must also be consideration of potential trade-offs associated with OA application e.g. an increase in SOC content can lead to a corresponding increase in GHGs due to greater availability of substrate-C that promotes microbially mediated processes such as C-priming, methanogenesis, nitrification, and denitrification (Blagodatskaya and Kuzyakov 2008) – which is likely to be particularly relevant under warmer and wetter conditions in the tropics (e.g. Razanamalala *et al.* 2018).

An increase in GHG emissions due to OA application is partly why biochar (e.g. maize residue, coconut husk biochar) has been investigated as an alternative/complimentary amendment to OAs in agricultural soils. Biochar is a very stable OA that is not readily accessed by soil microbes and therefore resists decomposition (thereby reducing CO_2 production from microbial respiration). Biochar is produced from the slow pyrolysis (heating in the absence of oxygen) of biomass. The relatively stable nature of organic compounds within biochar mean that it can potentially remain in the soil for thousands of years. Biochar has also been reported to improve soil physical properties such as water retention, porosity and hydraulic conductivity, whilst reducing nutrient/ leaching loss, improving soil fertility and increasing crop yield (Mohammadi et al., 2016). Biochar is also being investigated in tropical island ecosystems as it is thought to have help contain the spread of invasive plants species (Sujeeun and Thomas 2017).

Table 3: A summary of mitigation options in agriculture in Fiji, ordered from highest mitigation potential to lowest, including a consideration of cost of implementation, barriers/ uncertainty, and co-benefits associated with adoption.

Mitigation option	*Mitigation potential (t CO_2e /ha/yr)	GHGs	Cost	Barriers to adoption/ uncertainty	Co-benefits
Organic amendments	Medium-High (3.1)	N_2O CO_2 CH_4	Low/medium	Can increase GHG emissions (e.g. CO_2 priming).	↑Soil health ↑Productivity ↓Soil erosion ↑Water retention ↑Profitability ↑Food security
Reduce tillage/residue retention/ non burning of residue	Medium (0.72-1.5)	CO_2	Low/medium	Increased weed management requirements	↓Soil erosion ↑Water retention ↑Soil health
Agroforestry	Low to medium (0.72)	CO_2	Low	Benefits not accrued immediately.	↑Soil health ↑Productivity ↓Soil erosion ↑Soil health ↑Profitability
Cover crops/ legumes/ intercropping	Low (0.1)	CO_2 N_2O	Low/medium (depending on system)	Potential increase in N_2O emissions. May become host for pathogens. Benefits not accrued immediately. Labour requirements for cover crop termination.	↑Productivity ↑Profitability ↓Soil erosion ↑Water retention ↑Soil health ↑Food security
Reduce to economically optimal fertiliser	Low (depending on baseline) – fertiliser application in Fiji generally low	N_2O	Low	Risk of crop productivity decrease	↑Profitability ↑Water retention
Enhanced efficiency fertiliser (timing and placement)	Low (depending on baseline)	N_2O	High	Availability or access to enhanced efficiency fertiliser. Costly	↑Profitability ↑Water retention

*Mitigation potential expressed on per area basis $tCO_2e\ ha^{-1}\ yr^{-1}$ (with the adoption of practice) using Smith et al., (2008) and Richards et al., (2019) for GHG mitigation potential in humid tropical zones. Categories for mitigation potential: Mitigation potential <0.5 t $CO_2e\ ha^{-1}\ yr^{-1}$ = low, 0.5-1 t $CO_2e\ ha^{-1}\ yr^{-1}$ = low/medium, 1-3 t $CO_2e\ ha^{-1}\ yr^{-1}$ = medium, > 3 t $CO_2e\ ha^{-1}\ yr^{-1}$ = high. Cost of mitigation options based on global assessment by Paustian et al., (2016).

Research on the agronomic benefits of OA application in Fiji is lacking. However, there are a limited number of studies conducted in similar agroecosystem that demonstrate the yield advantage and soil health benefits of OA application (e.g. Anand, 2018; Ortiz Escobar & Hue, 2008; Siose et al., 2018; Ch'ng et al., 2013). For example, a study in Samoa investigated the effects of Gliricidia, Gliricidia + biochar, and poultry litter on sweet potato yields. Results demonstrated that all OAs significantly increased total root storage and total marketable root yield was increased by 134%, 118% and 294% in response to Gliricidia, Gliricidia + biochar, and poultry litter (Siose *et al.* 2018). In summary, the agronomic benefits of OAs vary with type of biomass substrate, soil type, climate, and management, making generalisations difficult. Higher temperatures under tropical conditions leads to a faster turnover rate of microbial biomass and organic matter compared to temperate climates where most research has been conducted – therefore, more locally relevant studies are required.

5.2 Non-Burning of Residues

In Fiji it was estimated that 22,900 tonnes of sugar cane residue is burned per year (FAO 2017). Traditional sugar cane management is based on burning of the cane field prior to harvesting to facilitate the harvest, transportation, and processing of sugarcane stalks. The burning of cane trash leaves a residue of ash that quickly recycles the minerals of the burnt matter, giving a short-term boost in soil productivity (Galdos *et al.* 2009). Burning results in the loss of GHGs, such as carbon monoxide (CO), methane (CH_4), nitrogen (N_2O, NO_x) and non-methane volatile compounds (NMVOC). High temperatures also destroy organic matter, humus, bacteria, microorganisms, and fauna that are essential to soil health and productivity. With repeated burning this diminishes the friability and porosity of the soils and their capacity to hold nutrients and water in the root zone (Galdos *et al.* 2009; Bordonal *et al.* 2018). Compaction, drying and a much greater susceptibility to erosion by wind and rain follow directly. Thus, both the quality and quantity of the most productive portion of the soil profile are directly diminished through burning.

Studies have demonstrated that the maintenance of sugarcane trash has physical, chemical and biological effects on the soil (e.g. Robertson and Thorburn 2000, 2007; Basanta *et al.* 2003). The maintenance of sugarcane residue on the field has a positive effect on: C and N dynamics (Meier *et al.* 2006), soil temperature and water content (Dourado-Neto *et al.* 1999), soil density (Tominaga *et al.* 2002), infiltration rates and aggregate stability (Graham *et al.* 2002). However, the adoption of non-burning of residue will likely increase time demands on farmers to cut cane, meaning there is a lack of incentive to adopt in the short-term. The removal of straw from sugarcane fields for bioenergy production should also be investigated as an alternative to burning (Prasad 2020), but a portion of straw should remain on the soil to ensure the agronomic and environmental benefits of residue retention (Carvalho *et al.* 2017).

5.3 Agroforestry Systems

The integration of trees, agricultural crops, and/or animals into an agroforestry system has the potential to enhance soil fertility, reduce erosion, improve water quality, enhance biodiversity and sequester carbon (e.g. Garrity 2004; Jose 2009). Agroforestry is an integrated approach to land management that could curb land degradation and deforestation, whilst securing the livelihoods of rural households (La *et al.* 2019).

In the tropics, the deliberate use of trees in the agricultural landscape is widespread. Trees in the landscape, in various forms and under various types of management, play a critical role in reducing vulnerability to uncertain and shifting climates (Noordwijk *et al.* 2011). Trees can buffer microclimates, modulate water flows, store carbon, provide habitat for plants and animals in protected areas and corridors, and provide food for people.

Various forms of agroforestry have been identified in the Pacific islands, the most widely recognised being mixed species planting involving timber, fruit or nut trees intercropped with root crops (Karim and Harrison 2016). Agroforestry provides a great option on hilly terrain (see section 2.6) to increase yields, diversity land production, maintain the integrity of ecological systems and provide a diversified income (Cornelio 2015). However, establishing agroforestry systems can require high inputs of time and it may take several years before the trees yields harvestable product (e.g. timber, fruit, nuts). In the short-term, the system will rely on returns from the intercrop.

Different agroforestry systems in Pacific island biomes are shown in Figure 6. In Fiji, barriers of Vetiver grass have been demonstrated to dramatically reduce erosion (by 86%) within ginger cropping systems (Mahadevan and Gonemaituba 2013) (Table 4) and to increase yields e.g. sugarcane (Truong and Creighton 1994). Due to its very deep and extensive root system, Vetiver is very effective in stabilising hillslopes. The implementation of contour hedgerows is currently being promoted in Fiji, following successful trials of Sloping Land Agricultural Technology (SALT) developed in the Philippines (MoE 2018). SALT was developed as a simple, applicable, low-cost method of upland farming, involving farmers with few tools, little capital, and little knowledge of modern agriculture. The system involves planting perennial crops in bands 4-5 m wide between contoured rows of grasses or leguminous trees and shrubs (Figure 6 a). The remaining photos in Figure 6 depict common agroforestry systems in Pacific island nations (Devoe 1996). In Figure 6 b pineapple is intercropped with mango and Gliricidia trees, with spinach covering the soil under the pineapple crop. Figure 6 c shows densely planted noni trees to act as a ‘living fence’ to contain livestock, and finally, Figure 6 d shows Gliricidia and Ironwood is grown to protect tomato and banana crops.

Table 4: Average ginger yields and soil loss at Waibau, Fiji 1992-1997 (source: Land Use Department, MAFF in Mahadevan & Gonemaituba (2013).

	Ginger yield (t/ha/yr)	**Soil loss (t/ha/yr)**
Farmers practice	44	10
Vetiver grass barriers	36	0.2
Pineapple barriers	34	1.4

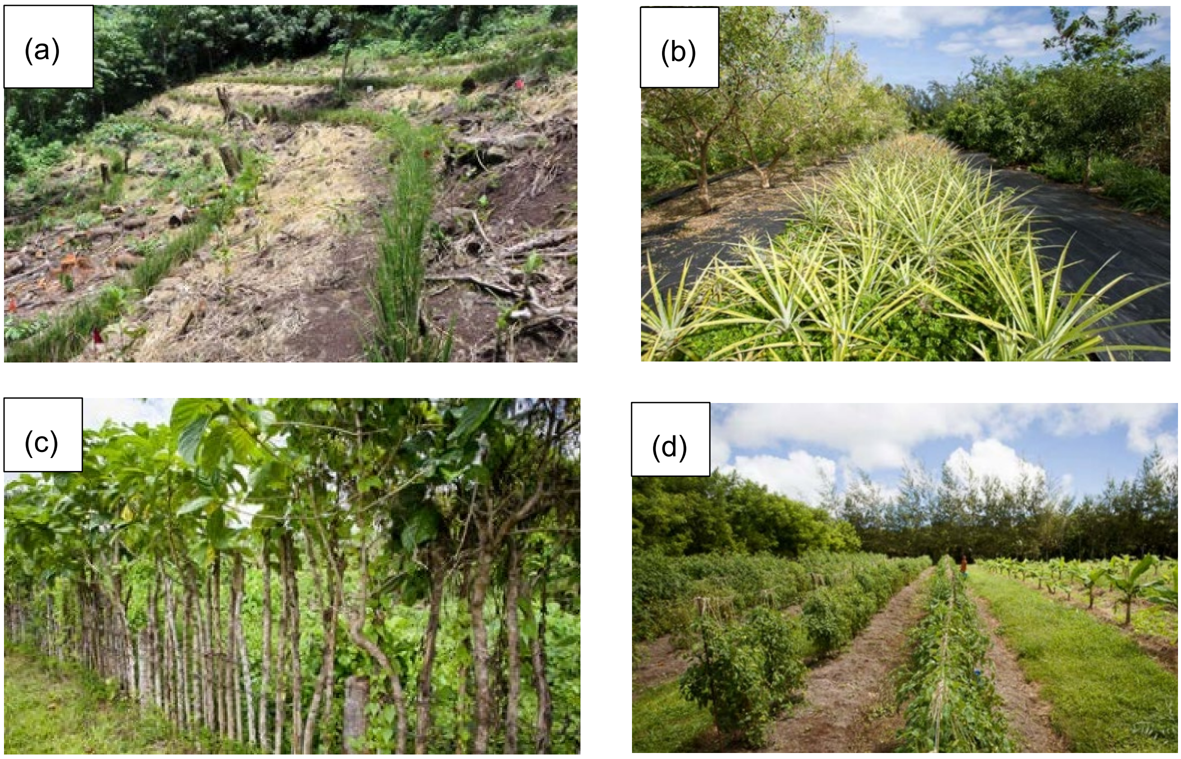

Figure 6: (a) Contour hedgerows of vetiver grass planted on a hillslope in Samoa. (b) Alley planting in North Kohala, Hawai'i where Gliricidia and mango trees are grown. In the alleys between tree rows, pineapple is growing with a ground cover of the perennial leaf vegetable spinach. (c) Densely planted noni trees to support barbed wire for containments suitable for pigs or other livestock in Yap state, Federated States of Micronesia. Noni trees are fruit bearing. (d) Windbreaks of Gliricidia and ironwood protect tomato and banana in northern Guam. Source: (Devoe 1996)

5.4 Legumes

Legume crops provide protein-rich food, while supplying nitrogen (N) to the agroecosystem through the process of biological N fixation. Biological N fixation is the process of converting atmospheric N_2 into ammonia (NH_3) or other molecules that are readily available to plants and other living organisms in the soil. Global studies indicates that for every tonne of shoot dry matter produced by crop legumes, the symbiotic relationship with rhizobium is responsible for fixing (on a whole plant basis) the equivalent of 30–40 kg/ha of N (Sharma *et al.* 2018) [2]. Cowpeas, for example, are a common grain legume grown in the tropics. It is estimated that cowpeas fix ~20-140 kg N/ha providing a significant fertility boost to later crops in rotation (NSW DPI 2020). Aside from its N fixing capabilities, cowpea is an ideal legume crop as it is drought tolerant, grows in very poor soils, and fast growing – yielding edible grains that can be used as animal fodder that is rich in protein (also low in fibre, high in digestibility and metabolizable energy) (NSW DPI 2020).

[2] The amount of N fixed by different legume species will vary depending on the legume species, the species variety, the number of effective root nodules, type of soil, agronomical and water management practices, prevailing climatic conditions and their interactions with other factors (Fageria et al. 2005).

5.4.1 Intercropping Legumes

Intercropping is a multiple cropping practice that involves growing two or more crops in proximity. A mixture of two or more crops will give better soil coverage and reduce the growth of weeds, and reduce runoff and the loss of soil and nutrients (Banik *et al.* 2006). The intercropping of legumes (e.g. soybean, groundnut) with cereals (e.g. rice, maize, sorghum) efficiently uses soil resources as cereals generally absorb nutrients from upper soil layers, while legumes are able to tap nutrients from deeper soil layers due to their more extensive root system (Layek *et al.* 2018). In Fiji, intercropping is promoted by the MoA to exploit the principle of diversity i.e. to avoid reliance on a single crop. This is important in a country where frequent crop damage occurs during extreme weather events. For example, the MoA, in partnership with the Sugar Research Institute of Fiji, is encouraging a move away from sugarcane monocropping[3] to systems that intercrop legumes such as cowpeas and pigeon peas. This will increase the nutrient status of soil, reduce soil erosion, increase resilience to climatic events, whilst providing a more diversified income for farmers.

5.4.2 Legumes in Rotation

Legumes are also commonly grown in rotation cycles (e.g. cereal-legume cycle) which has been demonstrated to improve soil organic matter and raise the nutrient holding capacity of the soil (e.g. Drinkwater *et al.* 1998; Sharma *et al.* 2018), as well as break weed and disease cycles, whilst fixing atmospheric nitrogen which can be used by the succeeding crop (Sharma *et al.* 2018). Common tropical legumes used in rotation include Cowpea, Lablab, Pigeon Pea and Milk vetch (Fageria *et al.* 2005).

There is little research on the rotation of legumes within cropping systems in Fiji or the Pacific. Only one study in Fiji (Lal, 2014) confirmed the potential of the legume *Mucuna* to increase yields (33%) of taro when grown in rotation. This demonstrates the need to explore the use of legumes as a mitigation option in the tropics to reduce inorganic N inputs, whilst improving productivity and soil health. While the literature (predominantly from temperate climates) provides a general overview of the benefits of rotating crops with legumes, there are several factors that determine the performance of these systems (e.g. selection of suitable cultivars, seeding ratio, climate, and soil type) that must be considered at the local scale in tropical biomes (e.g. Caballero et al., 1995; Layek et al., 2018; Pandita et al., 2000).

5.5 Crop Rotation/Intercropping

Diversification of cropping systems in general are known to enhance overall system productivity, while augmenting stability, resilience, and ecological sustainability. Recent research suggests that on-farm diversification supports an array of provisioning and regulating ecosystem services, especially within tropical terrestrial systems (Kremen and Miles 2012; Oliver *et al.* 2015).

The damage caused by monocropping is best illustrated by the growth of cassava in Fiji, which is the most important subsistence crop (FAO 2013). This crop is favoured as it requires minimal inputs and can be grown on marginal land. Because intermediate yields are often attainable in very poor soil, cassava is often cultivated in monocultures without proper addition of fertiliser or OAs. However, continuous production with no rotation/ intercropping leads to severe nutrient depletion and, in the most extreme cases, an abandonment of land. The effect of continuous cassava production on soil fertility several long-term fertility trials have been conducted in Malaysia, India, Thailand, and Columbia. Data from Thailand, for example,

[3] Monocropping of sugarcane was encouraged by the Fiji Government in the 1970/80s due to an increase in world sugar prices. However, the MoA is currently promoting intercropping into sugarcane systems.

shows that cassava yields of the unfertilised plots in three different soil series declines to about 60-70% of the initial yields during 20-25 years of continuous monocropping of cassava (Sittibusaya and Kurmarohita 1993).

5.6 Cover Crops

Cover crops[4] are defined as the crops that are used to cover the ground surface to protect the soil from erosion and prevent loss of nutrients in deep layers through leaching and surface runoff (Kaye and Quemada 2017). The importance of cover crops and leguminous fallow in improving productivity of subsequent crops through soil mineral N contributions has been well documented (e.g. Baligar & Fageria, 2007; Fageria et al., 2005; Reis et al., 2017). To summarise, the growth of cover crops improves overall soil health by, (1) reducing soil erosion (water and wind erosion), (2) providing better soil structural properties (e.g. aggregate stability), (3) improving soil hydraulic properties (water infiltration), (4) enhancing SOC and soil microbial population, (5) reducing nitrate N leaching and, (6) suppressing weeds. Common tropical cover crops are shown in Table 5.

Cover crops should form an integral part of cropping systems in Fiji due to its vulnerability to soil erosion. High rates of soil erosion are experienced in Fiji for three main reasons: (1) the volcanic islands have steep slopes which promote surface runoff (almost 70% of the land area of Viti Levu and Vanua Levu islands is steep mountainous terrain, (2) the soils developed on the volcanic rock types (andesites and basalts) are highly weathered clays of low cohesion when saturated, and (3) the intensive rainstorms caused by tropical depressions and the orographic effects of the high mountains create high intensity rainfall and large amount of surface runoff (Barbour & Terry, 1998; Mahadevan & Gonemaituba, 2013). These natural conditions are compounded by the intensification of agriculture to meet food security and economic aspirations, and the expansion of agriculture into increasingly marginal areas of production (Schipanski *et al.* 2014). This has resulted in a high degree of soil erosion, which has implications for agricultural productivity – for example Mahadevan (2008) estimated that soil erosion had resulted in a 9% loss per annum in sugarcane output. The use of cover crops (e.g. in rotation, intercropped, living mulch) will help to reduce the vulnerability of Fiji's soils to erosion, while improving soil health.

[4] *Cover crops are also known as "green manures" "catch crops" or "living mulch". Green manure crops are usually legumes that fix N and are grown to provide N to the following cash crop. Catch crops are cover crops that are grown during fallow periods in cropping system to take up nutrients, especially N, that would be lost from the soil system if plants were not present. Lastly, living mulches are cover crops that are grown both during and after the cash crop growing season and are suppressed or managed to reduce their competition with the cash crop when it is growing (Kaspar and Singer 2015).*

Table 5: Major tropical non-legume and legume cover crop species. Source: Baligar and Fageria (2007)

Common name	Scientific name
Pearl millet	*Pennisetum glaucum L. R. Br.*
Sorghum	*Sorghum bicolor* L. Moench
Cowpea	*Vigna unguiculata* L. Walp.
Pigeon Pea	*Cajanus cajan* L. Millspaugh
Mung bean	*Vigna radiate* L. Wilczek
Moth bean	*Vigna acontifolia* Jacq. Marechall
Guar	*Cyamopsis tetragonoloba* L. Taub.
Peanut	*Arachis hypogaea* L.
Tropical Kudzu	*Pueraria phaseoloides* (Roxb.) Benth.
Calopo	*Calopogonium mucunoides* Desv.
Hairy indigo	*Indigofera hirsuta* L.
Jackbean	*Canavalia ensiformis* L. DC
Lablab bean	*Lablab purpureus L. Sweet*
Sunnhemp	Crotalaria juncea *L.*
Velvet bean	*Mucuna pruriens* L. DC
Tepary bean	*Phaseolus acutifolius* A. Gray
Lima bean	*Phaseolus lunatus* L.
Butterfly pea	*Centrosema pubescens* Benth
Crotolaria	*Crotalaria pallida* Aiton
White tephrosia	*Tephrosia candida* (Roxb.) DC.
Vogel tephrosia	*Tephrosia vogelii* J. D. Hooker
Black gram	*Vigna mungo* L. Hepper
Egyptian clover	*Trifolium alexandrinum* L.
Brazilian stylo	*Stylosanthes guianensis* Aubl. Sw.
Adzuki bean	*Vigna angularis* Willd. Ohwi & Ohashi
Rice bean	*Vigna umbellate* Thunb. Ohwi & Ohashi
Sesbania	*Sesbania bispinosa* Jacq.W. F. Wight

6 Preliminary evaluation of cropping mitigation options in Fiji

The aim of this section is to provide a preliminary evaluation of the of the most promising mitigation options in cropping in Fiji. Our analysis is based on the outcomes of an in-country workshop, a virtual workshop (September 2020), discussion with key in-country participants (on-going), and a desk-top literature review.

From our analysis, the most cost-effective options that delivered the widest range of co-benefits were the use of OAs, residue retention, cover crops, intercropping and agroforestry. It is important to recognise that these practices are not ‘new’ to Fiji and they have been practiced by indigenous communities over hundreds of years. Thaman *et al.* (2000) observed that it was due to the traditional agroforestry systems that the people of the Pacific Islands were the most self-sufficient and well-nourished in the world. Traditional farming systems evolved through trial and error by indigenous communities resulting in agroecosystems which were not only genetically diverse but also resilient. However, these undocumented systems of knowledge have been eroded under the forces of colonialization, modernisation, and rural-urban migration (Shah *et al.* 2018). These forces have promoted monocultures and an associated decline in soil fertility e.g. commercial taro plantations have led to widespread deforestation, a focus on non-native taro (that are less tolerant to disease) at the expense of traditional varieties, an intensive application of fertiliser and herbicides, shorter fallows and lack of crop rotation practices.

A decline in the application of traditional knowledge calls for a transition of farming to neo-traditional agriculture – a system of food production that will bridge the gap between the traditional and the modern (Shah *et al.* 2018). This would allow the integration of scientific and indigenous knowledge to improve farming systems that will celebrate the cultural association in Fiji between the land and its people. Fiji’s Low Emission Development Strategy (LEDS) recognises that traditional farming methods are essential to transition to more sustainable and resilient farming systems in the face of a changing climate. In particular, the LEDS highlights the promotion of organic farming and a reduction in the use of synthetic fertilisers as mitigation options.

The barriers to adoption of best management practices are beyond the scope of this review. However, it is well established that the decision making of farmers can lead to systematic biases or deviations from optimal decision making. For example, in the context of an investment with significant up-front costs, that is paid off by a stream of benefits over time, decision-makers have been observed to place a disproportionately large weight on the initial cost. Furthermore, in an ideal world, rational profit-maximisers would balance potential gains and potential losses in a symmetric manner, but decision-makers have been observed to place disproportionate weight on avoiding losses Farmers are also likely to be influenced by desire to maintain conformity with practices of others and may be reluctant to change traditions or old ways of doing things (Marra *et al.* 2003; Rodriguez *et al.* 2009; Moran *et al.* 2013; Jaffe 2014)

Stronger scientific evidence is required to provide more in-depth advice on the best mitigation options. There is also a need for more participatory, action-oriented research with farmers to better understand which practices and landscape configurations generate resiliency and mitigation benefits within the Fijian context.

7 References

Agung GAMS, , Ketut Sardiana GMON (2015) Effects of tropical legume cover crops on soil quality at dryland farming area in Bali, Indonesia International Journal of Agronomy and Agricultural Research (IJAAR). *International Journal of Agronomy and Agricultural Research (IJAAR)*.

Anand S (2018) Evaluation of nutrient uptake of selected cover crops and biochar on the yield advantage of two taro (Colocasia esculenta) cultivars in Samoa. *The South Pacific Journal of Natural and Applied Sciences*. doi:10.1071/sp18002.

Baligar VC, Fageria NK (2007) Agronomy and physiology of tropical cover crops. *J. Plant Nutr.* doi:10.1080/01904160701554997.

Banik P, Midya A, Sarkar BK, Ghose SS (2006) Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. *European Journal of Agronomy*. doi:10.1016/j.eja.2005.10.010.

Barbour P, Terry J (1998) The hidddn economic costs of soil erosion: a case study of the ginger industry in Fiji. (Suva, Fiji)

Basanta M V., Dourado-Neto D, Reichardt K, Bacchi OOS, Oliveira JCM, Trivelin PCO, Timm LC, Tominaga TT, Correchel V, Cássaro FAM, Pires LF, De Macedo JR (2003) Management effects on nitrogen recovery in a sugarcane crop grown in Brazil. *Geoderma*. doi:10.1016/S0016-7061(03)00103-4.

Beauchemin KA, Kreuzer M, O'Mara F, McAllister TA (2008) Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture* **48**, 21–27. doi:10.1071/ea07199.

Blagodatskaya E, Kuzyakov Y (2008) Mechanisms of real and apparent priming effects and their dependence on soil microbial biomass and community structure: Critical review. *Biol. Fertil. Soils*. doi:10.1007/s00374-008-0334-y.

Bordonal R de O, Menandro LMS, Barbosa LC, Lal R, Milori DMBP, Kolln OT, Franco HCJ, Carvalho JLN (2018) Sugarcane yield and soil carbon response to straw removal in south-central Brazil. *Geoderma*. doi:10.1016/j.geoderma.2018.05.003.

Caballero R, Goicoechea EL, Hernaiz PJ (1995) Forage yields and quality of common vetch and oat sown at varying seeding ratios and seeding rates of vetch. *Field Crops Research*. doi:10.1016/0378-4290(94)00114-R.

Carvalho JLN, Nogueirol RC, Menandro LMS, Bordonal R de O, Borges CD, Cantarella H, Franco HCJ (2017) Agronomic and environmental implications of sugarcane straw removal: a major review. *GCB Bioenergy*. doi:10.1111/gcbb.12410.

Ch'ng HY, Ahmed OH, Kassim S, Majid NMA (2013) Co-composting of pineapple leaves and chicken manure slurry. *International Journal of Recycling of Organic Waste in Agriculture*. doi:10.1186/2251-7715-2-23.

Cornelio DL (2015) Land use trends and agroforestry in Fiji Islands. *Fiji Agricultural Journal* **55**, 16–24.

Cowley F, Smith G, Roschinsky R, Carnegie M (2005) Final report for 'Assessment of markets and production constraints to small ruminant farming in the Pacific island countries', LS/2016/021. (Canberra, ACT, Australia)

Das S, Jeong ST, Das S, Kim PJ (2017) Composted cattle manure increases microbial activity and soil fertility more than composted swine manure in a submerged rice paddy. *Frontiers in Microbiology* **8**, 1–10. doi:10.3389/fmicb.2017.01702.

de Klein CAM, Pinares-Patino C, Waghorn GC (2008) Greenhouse Gas Emissions. 'Environ. Impacts Pasture-based Farming'. (Ed RW McDowell)(CABI: Oxfordshire UK)

de Vries M, de Boer IJM (2010) Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock Science* **128**, 1–11. doi:10.1016/j.livsci.2009.11.007.

Devoe NN (1996) Agroforestry in the Pacific Islands. Systems for sustainability. *Agriculture, Ecosystems & Environment*. doi:10.1016/s0167-8809(97)87010-7.

Doran-Browne N, Ive J, Graham J, Eckard R (2016) Carbon neutral wool farming in south eastern Australia. *Animal Production Science* **56**, 417–422. doi:10.1071/AN15541.

Dourado-Neto D, Timm LC, Oliveira JCM de, Reichardt K, Bacchi OOS, Tominaga TT, Cássaro FAM (1999) State-space approach for the analysis of soil water content and temperature in a sugarcane crop. *Scientia Agricola*. doi:10.1590/s0103-90161999000500025.

Drinkwater LE, Wagoner P, Sarrantonio M (1998) Legume-based cropping systems have reduced carbon and nitrogen losses. *Nature* **396**, 262–265. doi:10.1038/24376.

Eckard RJ, Grainger C, de Klein CAM (2010) Options for the abatement of methane and nitrous oxide from ruminant production: A review. *Livestock Science* **130**, 47–56. doi:10.1016/j.livsci.2010.02.010.

Eichhorn MP, Paris P, Herzog F, Incoll LD, Liagre F, Mantzanas K, Mayus M, Moreno G, Papanastasis VP, Pilbeam DJ, Pisanelli A, Dupraz C (2006) Silvoarable Systems in Europe – Past, Present and Future Prospects. *Agroforestry Systems* **67**, 29–50. doi:10.1007/s10457-005-1111-7.

Eisler MC, Lee MRF, Tarlton JF, Martin GB, Beddington J, Dungait JAJ, Greathead H, Liu J, Mathew S, Miller H, Misselbrook T, Murray P, Vinod VK, Van Saun R, Winter M (2014) Steps to sustainable livestock. *Nature* **507**, 32–34.

Fageria NK, Baligar VC, Bailey BA (2005) Role of cover crops in improving soil and row crop productivity. *Commun. Soil Sci. Plant Anal.* doi:10.1080/00103620500303939.

FAO (2013) The Root Crop Development Project. http://www.fao.org/3/x5018e/x5018E0b.htm.

FAO (2017) Burning Agricultural Residues. http://www.fao.org/faostat/en/#data/GB.

FAO (2019) Climate-smart agriculture and the Sustainable Development Goals: Mapping interlinkages, synergies and trade-offs and guidelines for integrated implementation. (Rome, Italy)

FAOSTAT (2018) Country Profiles: Fiji.

Fiji Department of Energy (2014) Fiji Renewable Energy Power Project (FREPP). (Suva, Fiji)

Galdos M V., Cerri CC, Cerri CEP (2009) Soil carbon stocks under burned and unburned sugarcane in Brazil. *Geoderma*. doi:10.1016/j.geoderma.2009.08.025.

Garnett T (2009) Livestock-related greenhouse gas emissions: impacts and options for policy makers. *Environmental Science & Policy* **12**, 491–503. doi:10.1016/j.envsci.2009.01.006.

Garrity DP (2004) Agroforestry and the achievement of the Millennium Development Goals. 5–17. doi:10.1007/978-94-017-2424-1_1.

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G (2013) Tackling climate change through livestock - A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), (Rome, Italy)

Government of Fiji (2018) Fiji Low Emission Development Strategy 2018 -2050. (Suva, Fiji)

GRA, SAI (2015) Reducing greenhouse gas emissions from livestock: Best practice and emerging options (K Andeweg and A Reisinger, Eds.). Livestock Research Group of the Global Research Alliance on Greenhouse Gases and Sustainable Agriculture Initiative, (Palmerston North, New Zealand)

Graham MH, Haynes RJ, Meyer JH (2002) Changes in soil chemistry and aggregate stability induced by fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. *European Journal of Soil Science*. doi:10.1046/j.1365-2389.2002.00472.x.

Harvey CA, Chacón M, Donatti CI, Garen E, Hannah L, Andrade A, Bede L, Brown D, Calle A, Chará J, Clement C, Gray E, Hoang MH, Minang P, Rodríguez AM, Seeberg-Elverfeldt C, Semroc B, Shames S, Smukler S, Somarriba E, Torquebiau E, van Etten J, Wollenberg E (2014) Climate-Smart Landscapes: Opportunities and Challenges for Integrating Adaptation and Mitigation in Tropical Agriculture. *Conservation Letters* **7**, 77–90. doi:10.1111/conl.12066.

Henderson B, Falcucci A, Mottet A, Early L, Werner B, Steinfeld H, Gerber P (2017) Marginal costs of abating greenhouse gases in the global ruminant livestock sector. *Mitigation and Adaptation Strategies for Global Change* **22**, 199–224. doi:10.1007/s11027-015-9673-9.

Herrero M, Grace D, Njuki J, Johnson N, Enahoro D, Silvestri S, Rufino MC (2013) The roles of livestock in developing countries. *Animal* **7**, 3–18. doi:10.1017/S1751731112001954.

Herrero M, Henderson B, Havlik P, Thornton PK, Conant RT, Smith P, Wirsenius S, Hristov AN, Gerber P, Gill M, Butterbach-Bahl K, Valin H, Garnett T, Stehfest E (2016) Greenhouse gas mitigation potentials in the livestock sector. *Nature Climate Change* **6**, 452–461. doi:10.1038/nclimate2925http://www.nature.com/nclimate/journal/vaop/ncurrent/abs/nclimate2925.html#supplementary-information.

Hristov AN, Ott T, Tricarico J, Rotz A, Waghorn G, Adesogan A, Dijkstra J, Montes F, Oh J, Kebreab E, Oosting SJ, Gerber PJ, Henderson B, Makkar HPS, Firkins JL (2013) SPECIAL TOPICS — Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. *Journal of Animal Science* **91**, 5095–5113. doi:10.2527/jas.2013-6585.

Jaffe A (2014) Barriers to adoption of no-cost options for mitigation of agricultural emissions.

Jose S (2009) Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry Systems* **76**, 1–10. doi:10.1007/s10457-009-9229-7.

Karim S, Harrison S (2016) 'Promoting sustainable agriculture and agroforestry to replace unproductive land use in Fiji and Vanuatu.' (Australian Centre for International Agricultural Research (ACIAR))

Kaspar TC, Singer JW (2015) The Use of Cover Crops to Manage Soil. 'Soil Manag. Build. a Stable Base Agric.' doi:10.2136/2011.soilmanagement.c21.

Kaye JP, Quemada M (2017) Using cover crops to mitigate and adapt to climate change. A review. *Agronomy for Sustainable Development* **37**,. doi:10.1007/s13593-016-0410-x.

Kremen C, Miles AF (2012) Comparing biologically diversified with conventional farming systems: What is known about environmental benefits, externalities and tradeoffs among crop productivity and ecosystem services. *Ecol Soc* **17**, 40.

Layek J, Das A, Mitran T, Nath C, Meena RS, Yadav GS, Shivakumar BG, Kumar S, Lal R (2018) Cereal+Legume Intercropping: An Option for Improving Productivity and Sustaining Soil Health. 'Legum. Soil Heal. Sustain. Manag.' doi:10.1007/978-981-13-0253-4_11.

MacSween K, Feliciano D (2018) Co-benefits of mitigation options in the CCAFS- Mitigation Options Tool (CCAFS-MOT). doi:10.13140/RG.2.2.14525.41446.

Mahadevan R (2008) The high price of sweetness: The twin challenges of efficiency and soil erosion in Fiji's sugar industry. *Ecological Economics*. doi:10.1016/j.ecolecon.2007.10.011.

Mahadevan R, Gonemaituba W (2013) A note on soil erosion and the loss in crop production: case study of Fiji's ginger farms. *Journal of the Asia Pacific Economy*. doi:10.1080/13547860.2012.742688.

Marra M, Pannell DJ, Abadi Ghadim A (2003) The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: Where are we on the learning curve? In 'Agric. Syst.', doi:10.1016/S0308-521X(02)00066-5.

Meier EA, Thorburn PJ, Wegener MK, Basford KE (2006) The availability of nitrogen from sugarcane trash on contrasting soils in the wet tropics of North Queensland. *Nutrient Cycling in Agroecosystems*. doi:10.1007/s10705-006-9015-0.

Ministry of Agriculture (2016) Fiji Livestock Sector Strategy: Final Report.

Ministry of Economy (2018) Fiji Low Emission Development Strategy. (Suva, Fiji)

Mohammadi A, Cowie A, Anh Mai TL, De La Rosa RA, Kristiansen P, Brandão M, Joseph S (2016) Biochar use for climate-change mitigation in rice cropping systems. *Journal of Cleaner Production* **116**, 61–70. doi:10.1016/j.jclepro.2015.12.083.

Montes F, Meinen R, Dell C, Rotz A, Hristov AN, Oh J, Waghorn G, Gerber PJ, Henderson B, Makkar HPS, Dijkstra J (2013) SPECIAL TOPICS — Mitigation of methane and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. *Journal of Animal Science* **91**, 5070–5094. doi:10.2527/jas.2013-6584.

Moran D, Lucas A, Barnes A (2013) Mitigation win-win. *Nat. Clim. Chang.* doi:10.1038/nclimate1922.

NSW DPI (2020) Pasture legume species. https://www.dpi.nsw.gov.au/agriculture/pastures-and-rangelands/species-varieties/cowpea.

Oliver TH, Heard MS, Isaac NJB, Roy DB, Procter D, Eigenbrod F, Freckleton R, Hector A, Orme CDL, Petchey OL, Proença V, Raffaelli D, Suttle KB, Mace GM, Martín-López B, Woodcock BA, Bullock JM (2015) Biodiversity and Resilience of Ecosystem Functions. *Trends Ecol. Evol.* doi:10.1016/j.tree.2015.08.009.

Ortiz Escobar ME, Hue N V. (2008) Temporal changes of selected chemical properties in three manure - Amended soils of Hawaii. *Bioresource Technology*. doi:10.1016/j.biortech.2008.04.069.

Pandita AK, Shah MH, Bali AS (2000) Effect of row ratio in cereal-legume intercropping systems on productivity and competition functions under Kashmir conditions. *Indian Journal of Agronomy*.

Paustian K, Lehmann J, Ogle S, Reay D, Robertson GP, Smith P (2016) Climate-smart soils. *Nature* **532**, 49–57. doi:10.1038/nature17174.

Petersen SO, Blanchard M, Chadwick D, Del Prado A, Edouard N, Mosquera J, Sommer SG (2013) Manure management for greenhouse gas mitigation. *Animal* **7**, 266–282. doi:10.1017/S1751731113000736.

Prasad SD (2020) Potential for Biobutanol Production in Fiji from Sugarcane and Timber Industry Residues: Contribution to Avoided Emissions. 'Adv. Glob. Chang. Res.' doi:10.1007/978-3-030-30211-5_12.

Prokopy LS, Floress K, Klotthor-Weinkauf D, Baumgart-Getz A (2008) Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil and Water Conservation* **63**, 300–311. doi:10.2489/jswc.63.5.300.

Razanamalala K, Razafimbelo T, Maron PA, Ranjard L, Chemidlin N, Lelièvre M, Dequiedt S, Ramaroson VH, Marsden C, Becquer T, Trap J, Blanchart E, Bernard L (2018) Soil microbial diversity drives the priming effect along climate gradients: A case study in Madagascar. *ISME Journal*. doi:10.1038/ismej.2017.178.

Reis AFDB, De Almeida REM, Chagas Júnior AF, Nascente AS (2017) Effect of cover crops on soil attributes, plant nutrition, and irrigated tropical rice yield. *Revista Caatinga*. doi:10.1590/1983-21252017v30n403rc.

Reisinger A, Ledgard S (2013) Impact of greenhouse gas metrics on the quantification of agricultural emissions and farm-scale mitigation strategies: a New Zealand case study. *Environmental Research Letters* **8**,. doi:10.1088/1748-9326/8/2/025019.

Richards M, Arslan A, Cavatassi R, Rosenstock T (2019) 'IFAD RESEARCH SERIES 35 - Climate change mitigation potential of agricultural practices supported by IFAD investments: An ex ante analysis.' doi:10.22004/ag.econ.284726.

Robertson F, Thorburn P (2000) Trash Management Consequences for soil carbon and nitrogen. *Proc Aust Soc Sugar Cane Technol*.

Robertson F, Thorburn P (2007) Management of sugarcane harvest residues: Consequences for soil carbon and nitrogen. *Australian Journal of Soil Research*. doi:10.1071/SR06080.

Rodriguez JM, Molnar JJ, Fazio RA, Sydnor E, Lowe MJ (2009) Barriers to adoption of sustainable agriculture practices: Change agent perspectives. *Renewable Agriculture and Food Systems*. doi:10.1017/S1742170508002421.

Schipanski ME, Barbercheck M, Douglas MR, Finney DM, Haider K, Kaye JP, Kemanian AR, Mortensen DA, Ryan MR, Tooker J, White C (2014) A framework for evaluating ecosystem services provided by cover crops in agroecosystems. *Agricultural Systems*. doi:10.1016/j.agsy.2013.11.004.

Shah S, Moroca A, Bhat JA (2018) Neo-traditional approaches for ensuring food security in Fiji Islands. *Environ. Dev.* doi:10.1016/j.envdev.2018.11.001.

Sharma P, Singh A, Kahlon CS, Brar AS, Grover KK, Dia M, Steiner RL (2018) The Role of Cover Crops towards Sustainable Soil Health and Agriculture—A Review Paper. *American Journal of Plant Sciences* **09**, 1935–1951. doi:10.4236/ajps.2018.99140.

Siose TK, Guinto DF, Kader MA (2018) Organic amendments increased sweetpotato (Ipomoea batatas L.) yield in a calcareous sandy soil of Samoa. *The South Pacific Journal of Natural and Applied Sciences*. doi:10.1071/sp18005.

Sittibusaya C, Kurmarohita K (1993) Workshop on Cassava Production and Utilisation. In 'ASPAC Proc.', Rayong, Thailand.(Rayong, Thailand)

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O, Howden M, McAllister T, Pan G, Romanenkov V, Schneider U, Towprayoon S, Wattenbach M, Smith J (2008) Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences* **363**, 789–813. doi:10.1098/rstb.2007.2184.

Sujeeun L, Thomas SC (2017) Potential of biochar to mitigate allelopathic effects in tropical island invasive plants: Evidence from seed germination trials. *Tropical Conservation Science*. doi:10.1177/1940082917697264.

Tesema Z, Taye M, Ayichew D (2019) The role of phenotypic and genetic basis of livestock selection for climate change adaptation and mitigation: A review. *Journal of Applied and Advanced Research* **4**, 66. doi:10.21839/jaar.2019.v4i2.251.

Thaman R, Elevitch C, Wilkinson K (2000) Multipurpose Trees for Agroforestry in the Pacific Islands.

Thangarajan R, Bolan NS, Tian G, Naidu R, Kunhikrishnan A (2013) Role of organic amendment application on greenhouse gas emission from soil. *Science of the Total Environment* **465**, 72–96. doi:10.1016/j.scitotenv.2013.01.031.

Tominaga TT, Cássaro FAM, Bacchi OOS, Reichardt K, Oliveira JCM, Timm LC (2002) Variability of soil water content and bulk density in a sugarcane field. *Australian Journal of Soil Research*. doi:10.1071/sr01020.

Truong P, Creighton C (1994) Report on the potential weed problem of vetiver grass and its effectiveness in soil erosion control in Fiji.

Urra J, Alkorta I, Garbisu C (2019) Potential benefits and risks for soil health derived from the use of organic amendments in agriculture. *Agronomy* **9**, 1–23. doi:10.3390/agronomy9090542.

van Groenigen JW, Velthof GL, van der Bolt FJE, Vos A, Kuikman PJ (2005) Seasonal variation in N2O emissions from urine patches: Effects of urine concentration, soil compaction and dung. *Plant and Soil* **273**, 15–27. doi:10.1007/s11104-004-6261-2.

White SS, Selfa T (2013) Shifting Lands : Exploring Kansas Farmer Decision-Making in an Era of Climate Change and Biofuels Production. *Environmental Management* **51**, 379–391. doi:10.1007/s00267-012-9991-6.

Wilkes A, Reisinger A, Wollenberg E, Van Dijk S (2017) Measurement, reporting and verification of livestock GHG emissions by developing countries in the UNFCCC: current practices and opportunities for improvement. (Wageningen, the Netherlands)

Wollenberg E, Vermeulen SJ, Girvetz E, Loboguerrero AM, Ramirez-Villegas J (2016) Reducing risks to food security from climate change. *Global Food Security* **11**, 34–43. doi:10.1016/j.gfs.2016.06.002.