Exploring methodologies for assessing the outcome of soil management practices in Unilever's Sustainable Agriculture Code

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Philosophy in Sustainable Development in the Faculty of Economic and Management Sciences at Stellenbosch University

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March 2020

Declaration

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March 2020

Abstract

Agricultural soils are under immense pressure from modern farming practices, leading to unsustainable rates of degradation. Unchecked soil erosion and compaction reduce agricultural yields, while a loss of soil organic matter leads to a reduction in the soil's capacity to sequester carbon, a key strategy to mitigate climate change. In recent decades, Voluntary Sustainability Standards (VSS) have been established to manage the health of soils and a range of other environmental and social impacts, providing safeguards that prohibit detrimental activities while promoting good agricultural practices. However, the effectiveness of these standards in meeting their objectives has been questioned, as the outcomes of prescribed practices usually go unmeasured.

Unilever's Sustainable Agriculture Code is a company-own VSS implemented globally with suppliers of a range of vegetables, fruits and cereals and other crops. Although this code contains measures to quantify some environmental impacts, there is no methodology to assess the outcomes of management practices for soil health. This thesis explores available methodologies to measure the outcomes of soil management practices, relating to soil compaction, erosion and soil organic carbon, with a particular focus on China and the United States. Barriers to adoption of methodologies by supply chain actors, as well as a system by which to capture and administer progress were also investigated. A systematic review of peer-reviewed and grey literature, as well as semi-structured interviews were methods used to explore these questions.

It was determined that traditional in-field sampling and laboratory analysis methods were deemed unsuitable, except for the measurement of soil compaction. Instead, the Fieldprint Calculator's soil conservation and soil carbon tools are suitable models to estimate soil loss and soil organic matter for farmers in the United States. The globally relevant Cool Farm Tool was considered a viable method to model the greenhouse gas emissions from farming, including carbon sequestered as the result of management practices. Finally, the SLAKES mobile application is considered an accessible tool to measure wet aggregate stability, a principle indicator of the erodibility of soil.

Barriers to the adoption of these tools/methods by supply chain actors were also investigated, identifying the need for incentives like premiums and learning opportunities as a key lever to facilitating the participation of farmers. For Unilever,

the selection of methods would need to consider objectives, weighing up contextual relevance with the benefits of standardisation and scientific rigour. Finally, the logical framework was identified as useful system by which to capture and administer performance against these methodologies, because of it's ability to synthesise key components of the monitoring and evaluation process into a simple and transparent format.

Opsomming

Moderne landboupraktyke plaas landbougrond onder geweldige druk en dit lei tot onvolhoubare degradasiekoerse. Ongekontroleerde grond-erosie en -verdigting verlaag landbou-opbrengste, terwyl ŉ verlies aan organiese materiaal in grond lei tot ŉ vermindering van die grond se vermoë om koolstof te isoleer, wat strategies noodsaaklik is om klimaatsverandering te versag. Oor die afgelope paar dekades is Vrywillige Volhoubaarheidstandaarde (VVS) vasgestel om grondgesondheid en verskeie ander maatskaplike en omgewingsinvloede te bestuur, deur voorsorg wat skadelike aktiwiteite verbied en goeie landboupraktyke bevorder. Hoe doeltreffend hierdie standaarde hulle doelwitte bereik, word egter bevraagteken, aangesien die uitkomste van die voorgeskrewe praktyke gewoonlik nie gemeet word nie.

Unilever se Kode vir Volhoubare Landbou is die maatskappy se eie VVS, wat wêreldwyd deur die verskaffers van ŉ groot verskeidenheid groente, vrugte, graan en ander gewasse toegepas word. Hoewel hierdie kode maatreëls vir die kwantifisering van sommige omgewingsinvloede bevat, is daar geen metodologie vir die beoordeling van die uitkomste van bestuurspraktyke vir grondgesondheid nie. Hierdie proefskrif verken die metodologieë wat beskikbaar is om die uitkomste van grondsbestuurspraktyke ten opsigte van grondverdigting, -erosie en organiese koolstof in grond te meet, met spesifieke fokus op China en die Verenigde State. Hindernisse wat die toepassing van metodologieë deur spelers in die voorraadketting strem, en ŉ stelsel waardeur vordering vasgelê en geadministreer kan word, word ook ondersoek. ŉ Stelselmatige oorsig van gerefereerde en grys literatuur, asook semigestruktureerde onderhoude, is gebruik om hierdie vrae te ondersoek.

Die tradisionele metodes van steekproefneming in die veld en laboratoriumontleding is as ongeskik beskou, buiten vir die meting van grondverdigting. In plaas daarvan is die grondbewarings- en grondkoolstofwerktuie van die Fieldprint Calculator beskou as geskikte modelle om grondverlies en organiese materiaal in grond vir boere in die Verenigde State te beraam. Die wêreldwyd-relevante Cool Farm Tool is beskou as ŉ haalbare metode om die kweekhuisgasvrystellings uit landbou, ingeslote die koolstof wat as gevolg van bestuurspraktyke geïsoleer word, te modelleer. Laastens is die

SLAKES-selfoontoepassing beskou as ŉ toeganklike werktuig om die stabiliteit van nat aggregate, ŉ hoofaanduider van die erodeerbaarheid van grond, te meet.

Hindernisse wat verhoed dat hierdie werktuie/metodes deur spelers in die voorraadketting gebruik word, is ook ondersoek, en aansporings, soos subsidies en leergeleenthede, is geïdentifiseer as noodsaaklik vir die fasilitering van boere se deelname. In sy keuse van metodes sou Unilever doelwitte in ag moet neem, en kontekstuele relevansie, saam met die voordele van standaardisering en wetenskaplike strengheid, moet opweeg. Laastens is die logiese raamwerk geïdentifiseer as ŉ nuttige stelsel vir die vaslegging en administrasie van prestasie op hierdie metodologieë, omdat dit die hoofkomponente van die moniterings- en beoordelingsproses in ŉ eenvoudige en deursigtige formaat saamstel.

Acknowledgements

I wish to thank all of the people who supported me during this period, balancing work and study commitments.

Candice Kelly, my supervisor and sounding board during moments of insecurity, you brought clarity at many points along the way and continuously motivated me.

Dr Jan Kees Vis, you imparted great wisdom and a constructive eye to all my work. With your steer and strategic thinking, you helped shape my research approach.

Vanessa King, for encouraging me to keep persevering and for being there to test ideas with.

To the interview participants, for generously giving of their valuable time and knowledge. These conversations uncovered many insights which helped expand the scope of this research and enrich my findings.

To my family, for your unconditional love and support during periods of doubt and anxiety.

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List of Acronyms and Abbreviations

APEX	Agricultural Policy/ Environmental eXtender Model
APSIM	Agricultural Production Systems sIMulator
C	Carbon
CHN	China
CO_2e	Carbon dioxide equivalent
FAO	Food and Agriculture Organization
FSA	Farm Sustainability Assessment
GHG	Greenhouse Gas
GPS	Global Positioning System
Gt	Gigatonne
ha	hectare
IET	Integrated Erosion Tool
IFOAM	International Federation of Agriculture Movements
InVEST	Integrated valuation of ecosystem services and tradeoffs
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainability & Carbon Certification
kg	Kilogram
LCA	Lifecycle Assessment
M&E	Monitoring and evaluation
NASA	National Aeronautics and Space Administration
NRCS	National Resources Conservation Service
NGO	Non-governmental Organisation
PFI	Practical Farmers of Iowa
PM10	Particulate matter
RCBD	Randomised Complete Block Design
RFA	Rainforest Alliance
RothC	Rothamsted Carbon Model

RSPO	Roundtable for Sustainable Palm Oil
RUSLE	Revised Univeral Soil Loss Equation
RWEQ	Revised Wind Erosion Equation
SAI	Sustainable Agriculture Initiative
SCI	Soil Conditioning Index
SDG	Sustainable Development Goals
SMAP	Soil Moisture Active Passive
SNIP	Source Normalised Impact per Paper
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
t	Tonnes
USA	United States of America
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
VSS	Voluntary Sustainability Standards
WEPP	Watershed Erosion Prediction Project
WEPS	Wind Erosion Prediction System
WEQ	Wind Erosion Equation
WWF	World Wildlife Fund

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Chapter 1 – Introduction

1.1. Introduction

Agriculture already occupies 38% per cent of ice-free terrestrial land (Ramankutty, Evan, Monfreda & Foley 2008) yet the human population is projected to surpass 9 billion by 2050 (Godfray 2014), while increased wealth will lead to rising demand for meat and dairy products (Godfray 2014). Consequently, production will need to increase between 60 and 110% (Food & Agriculture Organisation (FAO) 2009; Tilman et al. 2011), while at the same time, a reduction in agriculture's environmental footprint must be achieved (Foley et al. 2011).

Responsible consumption will need to play a vital role to address these challenges, (Vermeir & Verbeke 2006), a point captured in Sustainable Development Goal (SDG) 12 (United Nations 2019). Target 12.6 of SDG 12 requires manufacturers to "adopt sustainability practices". Even before the launch of the SDGs, many companies have been working towards greater responsibility, often via Voluntary Sustainability Standards (VSS) (Komives & Jackson 2014), which help farmers improve their environmental social and economic performance (Blackman & Rivera 2011). VSS are defined as a set of guidelines for producing, selling and buying products in a sustainable way (IISD 2019). They typically consist of a set of guidelines that regulate the management practices a farmer may or may not use in production. Despite the exponential growth in the number of standards available on the market to meet demand, clear evidence of positive impact generated by these is not always detected and where found, the significance of this is often disputed (Blackman & Rivera 2011; Brad et al. 2018).

The incorporation of outcome-based measures by standard holders may help quantify the effects that management practices are having. Unilever's Sustainable Agriculture Code (USAC) collects environmental performance data from farmers; however, there is no measure to assess the health of soils. My thesis reviewed ways to monitor and measure the effect of practices to manage erosion, soil organic carbon and compaction, using a logic model framework. By way of a systematic review and interviews, I sought to establish what appropriate monitoring measures are available to measure changes in erosion, soil organic carbon and compaction, what barriers to adoption are, and to identify a framework to implement such methods.

This chapter provides a brief review of the literature to give more detail on the background to the research topic, before presenting the problem statement that the research sought to address. Next, I describe the research objectives, the research design and approach, and methods used to gather and analyse evidence to answer them. The chapter concludes with a discussion of the limitations before presenting an outline of the rest of the thesis.

1.2. Background

1.2.1. Introduction

In the following section I provide an overview of pivotal subjects applicable to the conceptualisation of the research topic, namely VSS and the debate around their impact, followed by an overview of potential monitoring and evaluation frameworks, concluding with a description of the soil health aspects and practices considered in this thesis. A search of academic databases and search engines was performed to ensure the study is not a duplication of previous research. Searches of Scopus, AGRIS and AGRICOLA found no evidence of replication.

1.2.2. The global standards agenda

Agriculture is having a substantial impact on the world and its resources (Foley et al. 2011). During the 1980s and 1990s, an estimated 80% of newly cultivated land in the tropics replaced biodiversity-rich forests (Gibbs et al. 2010). This figure is alarming when considering that, under present trends, an estimated 1 billion hectares of uncultivated land will need to be converted to feed the global population expected by 2050 (Tilman et al. 2001). Other significant impacts are agriculture's contribution of between 19 and 29% of global greenhouse gas emissions, mainly due to tropical deforestation, livestock methane emissions, rice cultivation and nitrous oxide from fertilised soils; as well as the consumption of about 70 per cent of available global freshwater supply (Vermeulen et al. 2012; Campbell et al. 2017). Agriculture's impact on livelihoods is equally important, with smallholder farming in the global South estimated to support 2.1 billion individuals across 500 million households (De Schutter 2009).

These environmental impacts and livelihood dependencies characterise the global food system, leading to considerable threats to social, economic and ecological ambitions (IAASTD 2009). This characterisation can be explained in part by the complex nature of the ‘modern’ food system, characterised by long supply chains with many actors and nodes, under which produce is grown using industrialised methods on homogenised lands (Adam & Gollin 2015). Few crops predominate, typically under intensive, high-input conditions, resulting in environmental concerns that include nutrient loading, chemical runoff and unsustainable water abstraction (Matson et al. 1997).

VSS emerged in the 1990s as multi-stakeholder groups convened to find ways to compensate for regulatory failure to drive sustainable production and are today increasingly shaping the governance of crop production, trade and consumption (Ponte & Cheyns 2013). By providing a standard set of requirements to evaluators, users and their audience, VSS provide a model against which people, products or actions can be assessed and compared (Ponte & Cheyns 2013). Examples of typical standard requirements include: developing a plan to manage biodiversity and critical habitat in or adjacent the farm, ensuring workers have access to potable water and hygienic facilities, and that waste materials do not pollute land and rivers (Global Gap 2017; ProTerra Foundation 2014; Rainforest Alliance 2017).

The global consumer goods company Unilever have developed a standard for implementation with their agricultural suppliers, the Unilever Sustainable Agriculture Code (USAC). I chose to relate my research to this standard, because I work for the company and sought to research a topic from which the results could have a relevant business application.

1.2.3. The impact evidence-gap?

The International Institute for Sustainable Development (IISD) currently recognises approximately 400 of these standards (2019). Despite their prevalence, results of research to detect the positive impact VSS have on the socio-economic and environmental conditions are inconclusive (Blackmann & Rivera 2011, Ruysschaert & Salles 2016). This status is partly due to the inadequacy of the design of some primary research studies, while positive impacts are not always significant or consistently reported (Blackmann & Rivera 2011). Consequently, the need to drive impact and transformation through standards is a growing area of concern of industry stakeholders (ISEAL Alliance 2014; Milder & Newsom 2015). For example, ISEAL Alliance[1] developed a code of practice in 2010 that "supports standards systems to measure and improve the results of their work and to ensure that standards are delivering the desired impact" (ISEAL Alliance 2014 2014:3). The Alliance's reasons for monitoring a standard's performance and impact include evidencing achievement of stated objectives, providing accountability to stakeholders and enhancing societal learning by sharing results to understand the cumulative effects of VSS. In subsequent years, several of their members, including Better Cotton Initiative, Bonsucro and Rainforest Alliance, have sought to demonstrate evidence of the positive impact their programmes are having as a result of the activities and practices that certified farmers implement (Better Cotton Initiative 2017; Newsom & Milder 2018; Seixas et al. 2019).

In parallel with the standards agenda, food system experts argue for the need to monitor the effects of different farming systems, to thrust agriculture down a more sustainable path (Sachs et al. 2010). Such monitoring would be particularly critical to unveiling the lifecycle environmental impacts of production, which are typically not reflected in market prices of agricultural products, the cost of which is borne by society (Zaks & Kucharik 2011). However, Sachs et al. (2010) argue that a crucial barrier to this is that measures are typically assessed at different scales, using incompatible methods and narrow criteria, like profitability and yield. Scale presents a challenge for comparability, as measurements of indicators collected at the field, landscape or regional levels are founded on different methodologies, limitations and assumptions, making their comparison problematic. The often narrow or simplistic nature of indicators undermines the multiplicity of issues in focus and can mean that only specific effects of farming are captured, while trade-offs may not be actively acknowledged. An example of this can be found in organic farming, which is recognised as ecologically

[1] ISEAL Alliance is an international membership organisation for VSS, whose members are required to meet a set of credibility principles and adopt various good codes of practice

friendly but can result in additional land and livestock demands with their associated impacts (Sachs et al. 2010).

Sachs et al. (2010) argue for the adoption of multiscale and integrated systems for monitoring of agricultural systems. While this position is applied to assess the effects of farming systems in a broader context (local to global), it seems that this logic could be implemented through a monitoring and evaluation system to complement VSS, which would connect typical practice-based with outcomes-based measures. For example, requirement F30 of USAC 2017 asks that management practices be put in place to maintain or enhance soil carbon. To confirm that the provision is adopted and complied with, auditors observe records and conduct interviews at the time of an audit. Records and interviews would constitute field or farm-level evidence, while aggregating compliance data of a farmer group located in the same valley provides landscape or ecosystem level evidence. If USAC were to include outcomes-based measures, at field level, this could consist of taking soil samples; while at the landscape level, this may involve the assessment of change in soil carbon between the pre-audit and audit years using a biophysical model (Borrelli et al. 2017) or the World Soil Information database (Hengl et al. 2014).

1.2.4. Impact measurement framework

The prospect of bringing together a set of standard requirements and multiscale monitoring and evaluation measures would complement the current movement among standards to show impact (Better Cotton Initiative; Bonsucro 2019; Rainforest Alliance 2019), as well as help to address the criticisms of some voices in the sector. One organisation setting and promoting best practice guidelines for credibility among VSS is ISEAL Alliance. Among their codes of good practice is the Impact Code, which outlines a range of principles and related requirements to establish a monitoring and evaluation (M&E) system that tracks and monitors performance (ISEAL Alliance 2014). One component of the M&E system is the logical framework or casual pathway, a diagram which demonstrates the linear flow of strategies leading to outcomes and impact (ISEAL Alliance 2014). In addition to the logical framework, requirements like identifying the scope and boundaries of the M&E system and resources needed to operate and sustain this, create a common understanding for all involved and an explicit way for VSS to adopt methodologies to measure effet of soil health practices (Gorter & Wojtynia 2017).

1.2.5. Viability of measurement tools

Zaks and Kucharik (2011) emphasise the importance of measures in predicting the impact of the global food system on the environment. Although their research takes a global perspective, the notion of linking farm-based and remote-sensing data, map well with the indicators of Bockstaller, Feschet & Angevin (2015).

The main issue affecting the usefulness of these measures as a basis for decision-making is a lack of coordination between measurement activities, both for field and remote-sensing activities. Differences in field data comparability are often hampered by methods that vary based on the scale of interest, their intended purpose and accessibility, discrepancies which Sachs et al. recognises (2010). For example, fields under irrigation can be monitored using satellites, however farmers are best equipped to collect data at at the field level and would not likely have access to remotely-sensed data.

It is therefore not unexpected that no unified infrastructure of measures exists yet to collate the ongoing collection of data (Zaks & Kucharik 2011). This gap suggests that outcome-based methods chosen to detect the state of soil health may need to be context-specific, although the issue is one of capability, as systems to address this shortfall are already available according to the authors. Moreover, any results derived from measurements collected at multiple scales would need to be carefully communicated to ensure that findings do not get misinterpreted, or that their association get overstated.

The cost of field-level monitoring, like the use of soil sensors, is a possible barrier to monitoring at scale (Zaks & Kucharik 2011). However, as technologies become more widely available, the cost of these has dropped. Moreover, while most of the soil sensors are field-based, remote-sensing tools like airborne hyperspectral imaging have been used to measure soil organic carbon, and such devices have been shown to reduce costs by 80% (Zaks & Kucharik 2011).

1.2.6. Unilever's Sustainable Agriculture Code

Unilever is a global consumer goods company, with an estimated 2.5 billion people using their brands daily, which include Knorr, Magnum, Dove and Lifebuoy (Unilever 2018a). At the core of its vision and strategy for business is the Sustainable Living Plan, which sets out targets to facilitate decoupling of environmental impact from economic growth, while increasing positive social impact (Unilever 2018b). The plan incorporates many goals applying to all reaches of the business, including one for the sustainable sourcing of agricultural raw materials.

Unilever reported that 56% of agricultural raw materials were 'sustainably sourced' in 2018, a term used for materials produced per the principles and practices of USAC or equivalent standards and systems (Unilever 2019). Crops which are sustainably sourced include vegetables, paper and board, soy, tea, cocoa, vanilla, dairy, sugar and palm oil. For some of these crops, Unilever is a key end-receiver of global supply, buying around ten per cent of the world's black tea, eight per cent of the world's global palm kernel oil and three per cent of processing tomatoes (Unilever 2018c; Unilever 2018d; Lam et al. 2017).

The USAC is a production standard primarily used in the farming of temperate crops. To help suppliers to achieve compliance against the USAC, Unilever provides free technical agronomic support via a network of third-party consultants (JK Vis 2019, personal communication, 2 April). As an alternative to the USAC, Unilever also benchmarks other external VSS and recognises these as equivalent, so suppliers do not need to comply to an additional code if they already meet the requirements of another (King 2018). Although compliance to the USAC or an equivalent standard is not a precondition to supply Unilever, suppliers are encouraged to convert conventionally-grown to sustainably-grown materials, through the support of Unilever's sustainable sourcing team and procurement networks (JK Vis 2019, personal communication, 2 April).

The USAC describes 12 indicator topics that include soil, water, waste, human rights and energy use. Each specifies a range of commitments, practices and documentation to be complied with by farmers or Unilever's direct suppliers, who when ready, get certified by a third-party certification body at the cost of Unilever (Unilever 2019a).

Although most requirements are qualitative and responses to these are binary, several of these require the reporting of environmental performance indicators on the amount of water, pesticide and nitrogen applied, for example. Over time, the reporting of farm data allows for trend analysis to assess whether changes in performance can be detected. However, although trends may be observable and interpreted, these data only model change using a limited number of variables and are unable to show what the outcome of practices may have been (e.g. a reduction in water applied led to increased groundwater levels at the source). Although the USAC has five indicators to track environmental performance areas, it neglects to allocate one for soil[2], which is the motivation for this research.

1.2.7. A spotlight on soil

Global land resources are under higher pressure than ever before in human history, with a quickly expanding population and growing levels of consumption, placing mounting demands on natural capital and competition between land uses (UNCCD 2017). As pressure on land increases, so does its degradation. Over the past 20 years, roughly 20% of the Earth's vegetated surface is showing continued declining trends in productivity, primarily due to the use of land and water, and management practices. Meanwhile, an estimated 24 billion tonnes of fertile soil is lost annually. These signals suggest that agricultural lands are under immense threat, and modern farming practices, like conventional tilling, multiple harvests and the excessive use of pesticides, are contributing factors. At risk is the long-term sustainability of agricultural lands, as diminishing fertility has been shown to lead to abandonment and eventually desertification in cases (UNCCD 2017).

Lal (2010) defines soil degradation as the decline in soil function or its capacity to provide economic goods and ecosystem services. Such degradation threatens agricultural productivity and food security, the replenishment of aquifers, and biodiversity (Koch et al. 2013). Symptoms of deterioration may take the form of erosion, fertility loss, compaction and a loss of soil carbon; and while naturally

[2] The previous version of the USAC – SAC 2010 – does include a qualitative proxy measure that recognises soil health where farmers have adopted a minimum of 4 out of 5 soil management practices.

occurring, excessive land clearing and inappropriate farming practices can accelerate these processes 1000-fold (van Lynden et al. 1998). Unfortunately, soil degradation is a significant issue of our time, with current rates exceeding those of soil formation (Scherr 1999). Unilever's Sustainable Agriculture Code recognises the importance of managing several aspects of soil commonly impacted by conventional agriculture. Three of these criteria require the management of erosion, compaction and soil organic carbon and were chosen as the focus of this research, due to their prescriptive nature and the importance of the issues addressed. Below is a brief description of these aspects and the challenges associated.

i. Soil erosion

Soil erosion is a major environmental problem worldwide, with croplands being particularly susceptible because of repeated tillage and exposure of soil (Pimentel et al. 1995). Rates of erosion under farmland vary by region, with those in the United States at three times that of natural, non-cropped soils, while soils in China exceed seven times the natural rate (Nearing, Xie, Liu & Ye 2017). The erosion process is caused by energy transmitted from rainfall and wind, resulting in the dislodging of soil particles (Pimentel et al. 1995). The erosion process is exaggerated on sloping land, where rates can be several degrees of magnitude higher than on the flat ground. Practices that can increase the erodibility of soil include ploughing to conventional depths (conventional tillage) and exposure at times when no crop is in the field (Pimental et al. 1995). The immediate impact of erosion on crop production is a loss of nutrients from the site, while sediment adversely affects drainage channels and downstream watercourses (Amundson et al. 2015).

ii. Compaction

Soil compaction comes as a direct result of intensive farming practice, with an estimated 68 million hectares of land compacted from vehicle traffic alone (Flowers & Lal 1998). When soil is compacted, this leads to an increase in bulk density, by reducing gaps between soil grains and bringing these grains closer together (Soil Science Society of America 1996). Identifying that compaction is a problem requiring management is not always straightforward as, unlike erosion which shows visible signs of degradation, impacts on soil structure require physical monitoring and assessment before this can be detected and the extent, severity and cause determined (Hamza & Anderson 2005). Compaction is exacerbated by soils with low organic matter content and the use of heavy machinery when moisture content is high. Consequently, compaction leads to reduced plant growth, lower incorporation of fresh organic matter and reduced nutrient cycling and mineralisation.

iii. Soil organic carbon

Soil organic matter (measured as soil organic carbon (SOC)) is beneficial to numerous properties of soils, like the ability to store water, carbon and nutrients, to provide structure for adequate aeration and drainage, and to reduce susceptibility of topsoil to erosion (Reeves et al. 1997; Robertson et al. 2014).

The sequestration of carbon in soil results from, for example, a farming practice change increasing the soil carbon content, leading to a net removal of carbon dioxide from the atmosphere (UNEP 2017). The quantity of carbon in the soil is the balance of carbon inputs (e.g. resulting from litter, crop residue and manure) and carbon losses (primarily through respiration that increases with soil disturbance), meaning that practices aiming to increase inputs or reduce losses can promote sequestration (UNEP 2017).

SOC has received interest for its role as a sink of atmospheric CO2, due to its potential responsiveness to modification (Baker et al. 2007). In the top metre, global soils are estimated to contain 1,500 Gt of C (equal to 5,500 Gt CO2), with a further ±900 Gt C stored in the next metre (Kirschbaum 2000). These soil layers therefore contain ±2,400 Gt of C, which would be higher if it were not for the depleting effect of land-use change, resulting in a 60% decline in temperate regions and a 75% or greater decline in the tropics (Lal 2004). Although rates of sequestration vary based on land management practices, soil type and climate region, the technical potential for soil carbon sequestration is predicted to be around 4.8 Gt CO2e per year (Smith 2016). This depletion of C in soils coupled with the sequestration potential, presents an opportunity to recover lost carbon, through the deployment of soil management practices.

1.3. Problem statement

Recent investigations suggest that voluntary sustainability standards are often unable to verify that interventions intending to increase sustainability lead to improvements

(Blackmann & Rivera 2011). Agriculture is a dominant driver of global environmental threats, of which soil degradation is one (Global Land Outlook 2017). On review of Unilever's Sustainable Agriculture Code, I was unable to find a measure to assess the effectiveness of soil management practices.

1.4. Research aim and objectives

The associated research questions are as follows:

1. What are appropriate methodologies that could serve to measure the effect of soil health requirements of Unilever's Sustainable Agriculture Code?
2. What are the barriers to successful adoption of outcome-based measures?
3. Under a management framework, how would such measures be captured and administered?

1.5. Definition of terms

Agricultural management systems (AMS) are "the framework of policies, processes and procedures used by an organisation to ensure that is can fulfil all of the tasks required to achieve its objectives. In the case of an Agricultural Management System, this aims to ensure consistent practice across a group of farmers." (King 2018:4)

Carbon flux refers to the quantity of carbon exchanged between Earth's carbon pools, the oceans, atmosphere, land and living things, and is usually measured by units of gigatons of carbon per year (GtC/yr) (Melieres & Marechat 2015).

Certification schemes or food assurance schemes intend to offer consumers a broader range of information about the product assured, including how raw materials are grown, or an assurance that specific principles and requirements are met (Parliamentary business 2005).

Compost is degrading plant material that is added to soil to improve its quality (Cambridge University Press 2019)

Conventional tillage is the traditional technique whereby soil is prepared for planting by inverting it with a moldboard plough. Following this, other instruments are used to smooth the soil surface. Bare soil is usually left exposed to the weather for a varying duration of time (EPA 2019).

Cover crops are crops grown to protect the soil from erosion, mitigate losses of nutrients via leaching and runoff, and/or to provide biologically fixed nitrogen; they are generally not harvested (Clark 2007).

Crop residue is plant material left after harvesting, including leaves, stalks and roots (Environmental Indicators for Agriculture 2001).

Crop rotation is a method of farming whereby a variety of different plants are grown in succession on a field to maintain healthy and fertile soils (Cambridge University Press 2019a)

Cropped area is the area of land under production for the crop of interest and includes features along field margins like buffer strips and hedgerows (Cool Farm Tool 2019).

Key performance indicators (KPIs) are measures that organisations can use to evaluate their performance, to aid in determining the extent of success in achieving their objectives (Badawy et al. 2016).

Manure is organic material that is used to fertilise land, usually consisting of the faeces and urine of domestic livestock, with or without accompanying litter such as straw, hay, or bedding (Encyclopaedia Britannica 2009).

Monitoring and evaluation (M&E) is a process that helps improve performance and deliver results, to enhance the present and future management of outputs, outcomes and impact. M&E is typically used to evaluate the success of projects, institutions and programmes (UNDP 2002).

No tillage is a method of directly drilling seeds into previous stubble without any disturbance (Cool Farm Tool 2019).

Reduced tillage or conservation tillage is a system that leaves enough crop residue on the soil surface after planting to deliver a 30% soil cover, the quantity required to decrease erosion below tolerance levels (Balkcom et al. 2007)

Remote sensing is the gathering of information about the earth by aircraft and satellites (Cambridge University Press 2019c)

Soil health is the sustained ability of the soil to function as a vital living ecosystem that sustains plants, animals and humans, within ecosystem and land use boundaries (Doran & Parkin 1994; USDA-NCRS 2012).

Soil amendments are a materials which are worked into the soil to enhance the soil's physical properties (Agriculture Canada 1976).

Voluntary sustainability standards (VSS) are a set of guidelines for producing, selling and buying products in a sustainable way (IISD 2019)

1.6. Research design, methodology and methods

1.6.1. Research paradigm

This thesis finds its grounding at the nexus of pragmatic and post-positivist paradigms. I believe these paradigms constitute the 'best fit' for this research, given that they apply qualitative methods of enquiry to the assessment of mainly quantitively based cause and effect measures.

A pragmatist worldview places the topic of interest at the centre of inquiry and utilises whichever tools (qualitative or quantitative) best suit a satisfactory response to the problem (Creswell 2014). The research questions imply that an exploratory study is needed, so I have chosen a qualitative approach to assess quantitative methods. This outlook is deemed appropriate, given that the research applies to a company-own standard and the assessment itself relates to the exploration of predominantly quantitative measures.

Together with the pragmatic outlook, I identify with the post-positivist view, which applied a more deterministic method of objective experimentation (Creswell 2014). This links closely with the subject matter, which attempts to measure change through cause and effect pathways.

1.6.2. Research methodology

I believe the pragmatist and post-positivist paradigms are most effective in explaining my epistemological thinking and choice of research methods, since pragmatism advocates for the use of whichever methods (qualitative or quantitative) are most practically suited, while post-positivism understands that no research is totally objective. Through discussions with supervisors we determined that the subject matter would be best explored by considering the body of existing literature and as such a qualitative approach was used to explore quantitative subject matter. To this end, I conducted a narrative literature review to expound the research problem and multiple concepts drawn together by this thesis, followed by a systematic review of peer-reviewed and grey literature, as well as semi-structured interviews to gather and interrogate the research questions.

1.6.3. Research methods

Several methods were applied during the research process.

i. Review the USAC to target specific aspects of soil health for research

Requirements of the soil management chapter were reviewed and through discussion with supervisors, those relating to erosion, compaction and soil organic matter were selected as management issues to be addressed by this research.

ii. Benchmarking of standards deemed equivalent to the USAC

Following the review, a benchmark of standards deemed fully compliant with the principles and practices of the USAC[3] was performed, to determine the most commonly referenced practices for management of these aspects. These practices were then used to inform search criteria for the systematic review.

iii. Systematic review design and method

Systematic reviews are performed to answer well-defined question through a process that is both transparent and replicable (Gurevitch et al. 2018). The approach includes use of a set of formally documented steps, which defines rules around search criteria, study screening, data extraction, coding and where applicable, statistical analysis.

I chose to conduct a systematic review as the most suitable mode of research, given how well published the field of research is. Another incentive for its selection and use is the ability to minimise bias and improve the dependability of results (Petticrew &

[3] Unilever benchmarks other VSSs to widen the availability of raw materials grown in accordance with the principles and practices specified by the Sustainable Agriculture Code. Annex 1A of the USAC Scheme Rules lists the standards deemed fully compliant with those principles and practices.

Roberts 2008). I used Scopus as the search engine to identify literature for initial screening. However, the broader nature of search terms (e.g. Soil AND tillage) meant that thousands of results were generated. Discussions on how to refine the search terms with Dr Jan Kees Vis, Sustainable Sourcing Director at Unilever and co-supervisor of this research, determined that the addition of country limitations to the search terms would narrow the scope of enquiry and provide a means by which to compare and contrast findings. I selected the United States, Germany and China as countries to restrict the review by, given their importance as sourcing countries for Unilever and an evidence base presenting challenges with the management soil health (JK Vis 2019, personal communication, 2 April).

iv. Systematic searches for grey literature

Beyond the peer-reviewed literature I reviewed grey literature, to identify potential gaps in knowledge. I screened conferences associated with journals publishing studies selected in the systematic review to identify relevant literature relating to soil science and methodologies. Furthermore, I used the VSS evidence database Evidensia to locate research on barriers to adoption and the M&E system approach. I deemed it essential to include grey literature in this enquiry, because of the assumption that ‘white’ literature in peer-reviewed journals may exclude research on emerging or experimental methodologies for measuring soil health. In addition, grey literature contains evidence on the VSS sector, which was required so as to respond to research questions 2 and 3.

v. Interviews

Finally, I conducted semi-structured interviews with soil scientists, practitioners, standard holders and farmers, to acquire further insights. The interviews were loosely configured around several pre-defined questions, however the appropriateness of questions varied depending on the background and area of expertise held by the interviewee.

1.7. Rationale for the study

My work in Unilever’s sustainable sourcing team involves the benchmarking of VSS against requirements of the USAC. Through this exposure to numerous standards used globally or regionally, I have observed a wide-scale lack of quantitative measures to monitor and evaluate interventions made through these schemes. In addition, the annual trend analysis of farm measures (such as irrigation water use, nitrogen use and greenhouse gas emissions) reported by farmers in accordance with USAC drives my interest in quantifying performance, as this alongside other biophysical data can provide an indication of whether the environmental impact of participating farmers is increasing or decreasing. A limitation of these measures though, is their simplification of complex production systems operating within unpredicatble real-world conditions. Not discounting the validity of these measures or the pragmatic approach taken to express and measure continuous improvement, the ongoing development of monitoring and evaluation measures presents opportunities for better detection of the outcomes of practices ascribed in the code.

1.8. Chapter outline

The following section offers an overview of chapters 2-6 of this thesis.

Chapter 2 contains a narrative literature review of the selected soil health aspects and management practices. This gives an account on the current consensus among experts, including findings of meta-analyses and review papers. **Chapter 3** describes the methods chosen, in accordance with which this research was conducted. This accounts for steps taken during the systematic review and supplementary efforts to consolidate this analysis with interviews. **Chapter 4** details the results of the systematic review and interviews. **Chapter 5** contains the discussion of findings, addressing research questions posed. **Chapter 6** offers conclusions to the research and recommendations for further investigation.

1.9. Conclusion

In the opening chapter of this thesis, I provided a brief background of the challenges facing agriculture, cultivated soils and the VSS sector's ability to quantify impact (using the USAC as a case example), which I used as a rationale for the research. I have also clarified that my motivation for selecting this topic is attributed to my employment at Unilever. In the second half of this chapter, I have provided a description of the research design, methodology and methods underpinning this study. Finally, my rationale for choosing this research topic has been what I have observed to be a general lack of quantitative measures to monitor and evaluate interventions made through these schemes.

Chapter 2 – Literature review

2.1. Introduction

Chapter 2 provides a foundation on key topics, aiming to elicit a greater understanding of existing research and the debates surrounding these. The inclusion of a narrative literature review is considered necessary, because this research deals with a range of concepts spanning multiple disciplines. In writing this, I have gained a deeper understanding of certain concepts relating to soil science, a field I hold little previous knowledge on.

I begin by examining voluntary sustainability standards, their objectives and usage trends; followed by an enquiry into what evidence exists to suggest that these are resulting in the outcomes or impacts they intend to have. I then proceed to describe monitoring and evaluation systems as a possible framework through which to design and adopt methodologies to measure outcomes and impact. The second half of the chapter provides an explanation of key concepts regarding soil health and the management aspects of erosion, compaction and soil organic carbon, addressed by this thesis.

2.2. Voluntary sustainability standards

Voluntary Sustainability Standards are guidelines for producing, selling and buying products in a sustainable way, providing certainty that products meet desired social, economic and environmental standards (IISD n.d.). These are administered by certification schemes, which work to achieve their goals by combining standard-setting actions, capacity building and training of farmers and producers' organisations, as well as market interventions like price premiums (Oya et al. 2017). VSS also give those certified a common definition to communicate compliance with requirements spanning many thematic areas (J Rushton 2018, personal communication, 5 December). In Unilever's case, the term 'sustainably sourced' refers to material grown in accordance with the USAC's 12 thematic areas and over 150 individual requirements (King 2019). In a similar way, the labelling of products containing material certified against such standards gives consumers a quick and simple way to identify more ethical products without the need for expert knowledge themselves (Nielsen 2014).

Evidence of VSS' popularity is clear, with the area of land under certified production increasing significantly over the past decade (Lernoud et al. 2018). On a per hectare basis, certified products now cover approximately 11% of forestry plantations, between 25% and 45% of coffee plantations and 12% of oil palm plantations. Indeed, certified products no longer hold only a fraction of market share as they once did, with their growth now outpacing that of conventional products. Figure 1 demonstrates this trend depicting an impressive eight-fold increase of land area under certified practices achieved in just eight years.

Most of these commodities are dominated by a single standard directly targeting adoption within that specific sector, with the largest single end-user typically being consumer goods companies like Coca Cola and Unilever (Bonsucro 2019; Lernoud et al. 2018, Unilever 2018d). For example, Nestlé is the world's largest end-user of coffee, accounting for 22.7% of the global coffee market in 2013 (Lee 2013). In 2010, Nestle set a target to source 70% of the total Nescafé supply chain responsibly by 2020. In 2019, they reported that more than 56% of qualifying coffee volume came from farms that are Rainforest Alliance and Fairtrade certified. Driving overall demand is, of course, the consumer, with 66% reportedly willing to pay more for products or services from businesses committed to delivering positive social and environmental impact, according to a survey of 30 000 consumers across 60 countries (Nielsen 2015).

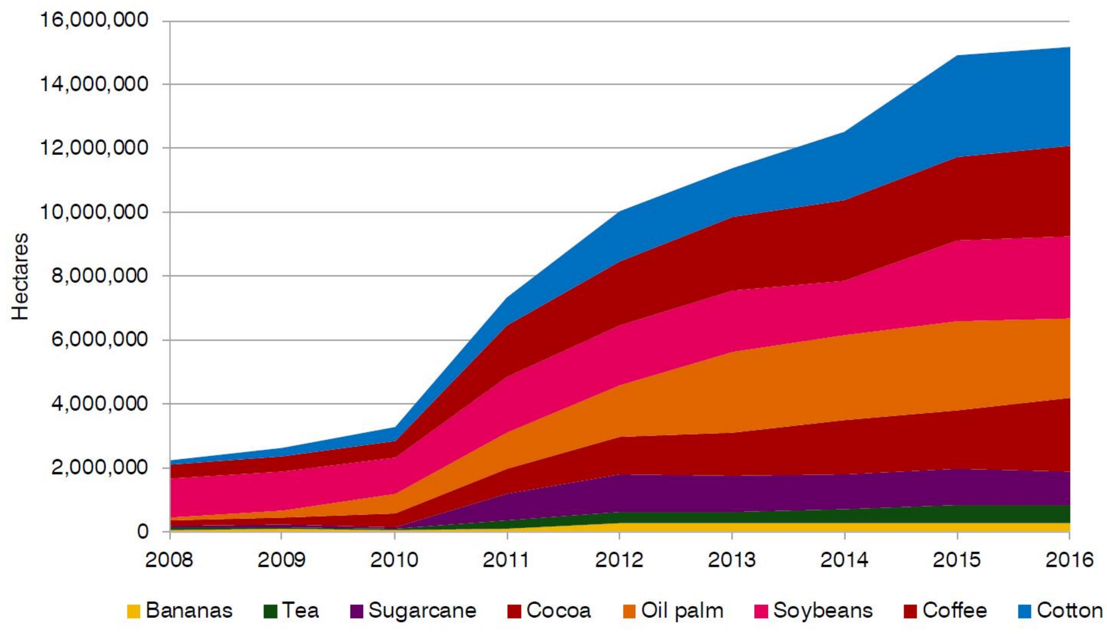


Figure 1 Selected commodities certified by VSS (Source: Lernoud et al. 2018)

This trend in figure 1 not only shows that significant adoption of sustainability standards has taken place over the past several years but implies growth will continue to occur. Yet, despite the success of VSS, the sector faces criticism on whether it is delivering material impact (Blackmann & Rivera 2011; Brad et al. 2018; Ruysschaert & Salles 2016). One case of criticism is put forward in a 2018 report, in which the NGO, Changing Markets Foundation, criticises palm oil, fisheries and textiles standards, stating that while certification can help drive the adoption of more sustainable practices, there is limited evidence to demonstrate that these have delivered a positive and measurable impact to the environment and people that they touch (Brad et al. 2018). In response, Porritt (2019) rebuffs this criticism, pointing out that the model of capitalism applied by western governments and businesses externalises the environmental and social costs of production, something which VSS attempt to address.

Perhaps as a response to criticisms, evidence of shifts away from certification schemes exist, as has been observed in the cocoa industry, with the emergence of company- and partner-led sustainability programmes, supported by monitoring and evaluation frameworks to measure outcomes (Cargill 2019; Cocoa Horizons 2019; Cocoa Promise 2019). Persistent challenges facing the sector include enforcement weaknesses among major cocoa certifying schemes Rainforest Alliance and Fairtrade and end-users like Mars and Nestlé failing to meet decade old pledges to combat child labour and trafficking (Cargill 2019; Cocoa Horizons 2019; Cocoa Promise 2019; Whoriskey & Siegel 2019).

2.3. Evidence of impact

Studies looking for evidence of impacts by VSS show mixed results. One measuring the impact of VSS on the well-being of farmers and workers in low- and middle-income countries found positive effects on producer prices and agricultural incomes, but no improvements for worker wages, household income and assets (Oye et al. 2017). Another study looking at the effect of Fairtrade on smallholder farmers' ability to adapt to climate change found that an increase in disposable income could facilitate spending on adaptive measures, whilst knowledge exchange would increase social capital and improve access to the international community (Borsky & Spata 2018).

Evidence of environmental benefits of VSS varies across the literature with two systematic reviews reaching different findings. Blackmann and Rivera (2011) found that, among 11 rigorous studies identified, only four showed evidence of environmental and economic benefits, with authors describing these as idiosyncratic or unevenly distributed. However, a 2018 report reviewing studies for evidence of positive conservation outcomes, concluded that Rainforest Alliance and the Roundtable for Sustainable Palm Oil (RSPO) schemes reduced deforestation rates, and increased plant and animal biodiversity on certified farms and/or plantations (Komives et al. 2018). As far as the organic schemes recgonised by the International Federation of Organic Agriculture (IFOAM) are concerned, Blackmann and Naranjo (2012) reported their adoption among coffee farmers in Costa Rica led to significant reductions in the use of chemical inputs, a trend that corresponds with IFOAM's guidelines to phase-out their use over three years. With regards to the greenhouse gas emissions from farming, a study of tomato farmers implementing Unilever's Sustainable Agriculture Code, measured a 25% decrease in the annual weighted mean carbon footprint over a three-year period, suggesting this may demonstrate the potential effectiveness of the USAC, although this causal link could not be drawn (Lam et al. 2018).

Looking beyond currently available evidence, a study predicting the environmental benefits of Bonsucro, the leading VSS for sugarcane, yielded striking results. Through an ecosystem services modelling and scenario analysis approach, researchers found that if adopted for all sugarcane production globally, compliance with the standard would result in irrigation water use savings of 65%, a reduction in nutrient loading of 34% and a decline in greenhouse gas emissions of 51% (Smith et al. 2018). Increased yields would further reduce the current sugarcane production area by 24%, whilst under a scenario of doubling sugarcane production, expansion would be restricted to existing agricultural land.

This evidence tells us that certification schemes are capable of generating positive social and environmental benefits, although this is not always guaranteed, with some studies finding limited benefits altogether. Some researchers have highlighted constraints that may undermine the effectiveness of certification schemes towards meeting their goals. Blackmann and Naranjo (2012) point out that schemes enrolling farmers who have already adopted higher standards may have fewer benefits to show.

The cost of certification is also recognised as an important barrier to entry, especially for poorer producers (Blackmann & Naranjo 2012; Oye et al. 2017). Moreover, the implementation of standards by scheme owners may vary, with the benefactors of outreach sometimes underrepresenting farmers and workers situated in remote areas and more vulnerable participants.

Gorter and Wojtynia (2017) believe that standards can adapt and improve in response to scrutiny by increasing sustainability performance and impact, moving from a system that accepts implementation of the scheme as a proxy for performance, to one which demonstrates results that respond more directly to the desired impact.

2.4. A methodological system for standards

Following an account of the successes and criticisms that VSS have had, it is useful to understand how these schemes could more proactively define, monitor and assess performance. An important voice within the global standards community is ISEAL Alliance, whose members include Rainforest Alliance, RSPO, the Better Cotton Initiative and Fairtrade (ISEAL Alliance 2019). The body sets credibility principles and codes of good practice, with a mission to help members demonstrate and enhance their impacts, improve their effectiveness, increase their adoption and define what credibility looks like for VSS (ISEAL Alliance 2014). ISEAL Alliance's current codes of good practice include their Standard-setting, Assurance and Impacts Codes, which instil confidence among benefactors of the effectiveness of the standards system as a whole.

VSS bodies can use the Impacts Code to guide the development of monitoring and evaluation (M&E) systems, which usually involve the regular collection of monitoring data for a range of indicators and the undertaking of outcome and impact evaluations (ISEAL Alliance 2014). ISEAL Alliance (2014) claims that, by adopting these M&E systems, VSS can define the impacts and outcomes they intend to achieve, strategies to get there and measure their progress, in a transparent and stakeholder-inclusive way.

Table 1 gives examples of several requirements for inclusion in the development of an M&E system (ISEAL Alliance 2014). By responding to each one, essential details about how the effectiveness of the standard can be measured are described, which provides the scheme owner with a blueprint to execute their plan to monitor and evaluate performance. As an example, the scheme owner of a VSS designed for use in the production of all crops may decide to limit the scope of the M&E system to the top five crops and countries on which it is commonly applied, to make the best use of resources. Furthermore, the scheme owner may decide to restrict M&E to a subset of topic areas that the standard strives to manage like biodiversity, soil and water. By articulating the scope and boundaries of the system, the scheme owner is able to manage the expectations of stakeholders by clearly stating what is included and excluded from scope.

Table 1: Examples of ISEAL M&E System requirements for scheme owners (Source: Adapted from ISEAL Alliance (2014))

Clause	Aspect	Outcome	Requirement
5. M&E system requirements			
5.2	Scope & boundaries	Ensure the standard system has the desired sustainability effects.	Define and frequently update records of the scope and boundaries; the system shall enable the scheme owner to monitor and evaluate its most significant sustainability.
5.4	Resources	Adequately resource the M&E system.	Appoint adequate, skilled staff or consultants, and budget to develop and implement the system.
5.7	Data confidentiality and use	Proprietary data is protected and legal requirements around confidentiality have been addressed to permit analysis.	Adopt measures to safeguard data and has sought to address any legal barriers.
6. Stakeholder consultation			
6.1 & 6.2	Stakeholder engagement	Identify stakeholders and provide them with opportunities to give input in design and occasional revision.	Identify categories of stakeholders and document this; provide stakeholders the opportunity to comment on the intended impacts and outcomes, unintended effects and the scope and boundaries of the system.
7. Defining the intended change			
7.1	Intended impact & outcomes	Define the sustainability impacts and outcomes the scheme intends to accomplish.	Describe and record the intended short-, medium- and long-term sustainability impacts of the system.
7.2	Causal pathways	Recognize how policies will support attainment of the intended impact and outcomes	Identify strategies and describe causal pathways that explain how strategies are expected to support outcomes and impact.
8. Monitoring & evaluation			
8.4	Performance Monitoring, Outcome & Impact Evaluation	The M&E system tracks progress towards outcomes and gives details on how standards are working and why it is or is not delivering its intended impacts	The M&E system has performance monitoring, as well as outcome and impact assessments.

Another useful requirement to have stated in the M&E system is the casual pathway or logical framework, a popular planning tool that can be adapted for use as the basis for

M&E in a project or programme (Intrac 2015). A logical framework is frequently used to describe the M&E system in bringing to life an organisation's theory of change - the shared vision of how an organisation creates change and reaches its goals (Gorter & Wojtynia 2017; Intrac 2015; ISEAL Alliance n.d). Figure 2 shows this using the steps defined by the UK Government's Department for International Development (DFID) (Intrac 2015). The pathway goes from left to right.

Inputs →	Activities →	Outputs →	Outcomes →	Impacts
Practices / Implementation			Results	

Figure 2 Logical framework (Source: DFID (2015))

Gorter & Wojtynia (2017) describe the logical framwork as a linear pathway showing the causal link between practices, direct results (outcomes), and long-term effects (impact). To give an example, a cooperative may depend on guidance documents and training on good agricultural practices from the VSS (inputs) to deliver training themselves to their farmers (activities), leading to a percentage of farmers receiving directions on how to implement these practices (outputs). As a consequence, these farmers improve their productivity (outcomes), ultimately resulting in greater prosperity among farmers and communities (impacts). When viewed in this way, dependencies can be easily understood and one is better able to distinguish between what an ouput, an outcome and an impact are.

Over the past few years, VSS have begun to incorporate M&E systems into their process. In 2019, the Rainforest Alliance (RA) scheme, an ISEAL Alliance member, undertook a stakeholder consultation process to back the development and update of a new sustainability standard. The new standard clearly outlines how each theme fits into the M&E system, with indicators to be reported at the time of each certification audit (Rainforest Alliance 2019). These indicators address a range of environmental, social and economic issues, for example:

- Output indicator: The percentage of farms with a Global Positioning System (GPS) point of their location; the number of men and women farmers attending training activities.

- Outcome indicator: The percentage of farmers applying an optimum quantity of fertilisers; the percentage reduction in water use compared with the previous year.

In this example, Rainforest Alliance have proposed to adopt indicators that help to address some of the key concerns of the standard. In taking GPS coordinates of certifying farms, this helps to achieve the outcome to manage the farm or farmer group "in an efficient, transparent, inclusive and economically viable manner" (Rainforest Alliance 2019: 17). Moreover, by collecting data on the number of men versus women farmers attending training activities, Rainforest Alliance are able to strengthen the position of female farmers and workers, which is another outcome they define.

Yet, while the ambition to incorporate M&E systems into VSS is becoming more evident, there are challenges that need navigating (Gorter & Wojtynia 2017). Giving recognition to stakeholders responsible for achieving the desired outcomes is essential if participants are to feel incentivised to continue with the scheme. Outcomes need to be globally relevant i.e. able to accommodate deviations in regions where these may be unattainable. Finally, there may be differences in capacity among farmers in their ability to deliver on indicators like a skills gap, as well as transition costs impacting the scheme owner, auditing bodies and producers and management groups being certified (Gorter & Wojtynia 2017). Although these factors need careful consideration when taking steps to improve standards, the M&E system are described by ISEAL Alliance's Impact Code does provide a well-recognised framework to produce rigorous evidence of the performance of standards and to demonstrate their benefits more effectively.

2.5. Soil health aspects and practices

This thesis is researching ways to measure the outcomes of soil health practices within VSS. Having explored VSS, the challenges these present in evidencing their effect and showcasing the M&E system as a potential solution, I will now provide a general overview of the relevant soil health aspects, practices and methodologies current available to measure these.

2.5.1. Soil organic carbon

Soil organic carbon is carbon that remains in the soil following fractional decomposition of any material derived from living organisms (FAO 2018). On a global scale, SOC forms an important component of the carbon (C) cycle, whilst in soil it is the primary constituent of soil organic matter. It supports multiple core soil functions, like the stabilisation of structure, the holding and release of plant nutrients, and the percolation and retainment of water (FAO 2018). As a result, changes in SOC concentration serve as a useful indicator of the occurrence of soil degradation.

In addition to its role in soil functioning and health, SOC also plays a key role in climate change. The earth's soils contain the largest global stock of organic carbon, approximately twice as much as the atmospheric C stock (Söderström et al. 2014). As roughly 12% of the soil C stock is held in cultivated soils covering around 35% of the world's land surface, the sequestration of SOC by the agricultural sector presents a significant opportunity to mitigate climate change (Söderström et al. 2014).

Global optimism in the potential role SOC could play towards mitigating climate change is already evident. Launched in 2015 at the United Nations Climate Change Conference, COP 21, the '4 per 1000' initiative seeks to galvanise action among public and private sector actors to transition towards a productive, extremely resilient model of agriculture that drives an annual growth rate of 0.4% in SOC stocks (Minasny et al. 2017). Another prediction is that the adoption of no tillage, cover crops, crop rotations and other practices will increase to 1 million acres by 2050, resulting in a total reduction of 23.2 gigatons of carbon dioxide equivalent, from sequestration and reduced carbon emissions (Project Drawdown 2019). Yet, present research has shown that sequestration is harder to achieve than previously anticipated (Powlson et al. 2014). The following section describes currently available techniques to measure SOC stock, and the challenges affecting accurate measurement.

The following section describes important pre-estimation parameters when measuring SOC and the currently available techniques to go about this.

2.5.1.1. In-field and laboratory

In their synthesis of best practice approaches to measure soil organic carbon, Nayak at al. (2019) provide a set of pre-estimation parameters for the design and collection of in-field soil samples, which must be considered to accurately estimate the carbon stock. Note that these are applicable to controlled experiments and not typically applied in real farm settings, because of their need to accommodate an experimental design with randomised sampling, to solicit unbiased results. This implies ‘locking’ land under controlled conditions for the duration of the experiment, while applying scientific and sampling procedures that are not typically within the capacity or expertise of farmers to meet. These are just two features of in-field experiments that render these unsuitable for application with farmers. Limitations aside, some of the pre-estimation parameters are useful to account for when contextualising results produced through other measurement pathways. These are described below along with associated observations of review papers on the effect of tillage and cover crop practices on SOC stock (Baker et al. 2007; Dimassi et al. 2014; Nayak et al. 2019; Powlson et al. 2014).

Nayak et al. (2019) states the importance of defining physical boundary lines to delineate the area included under the experiment, to contextualise results and to determine the average change per unit area (e.g. per hectare). Moreover, carbon accumulated in the soil prior to treatment should be excluded, which will help define a measurement boundary. Measuring the baseline SOC for all treatment and control plots prior to the experiment, is another parameter to be accounted for, as sequestration rates vary under land use change, management change, bulk density and other conditions (Nayak et al. 2019). In doing so, a comparison of carbon stock of soil under the same conditions, like soil type and slope, can be performed.

The sampling design and method are parameters also requires careful consideration, as they have direct implications on the validity of results and how these can be interpreted (Nayak et al. 2019). Stratified and random sampling approaches, that involve the random selection of plots, help to reflect the variability of carbon in soil and to obtain unbiased results. In addition, a sufficient number of samples are needed to estimate the average carbon stock with a greater confidence interval during statistical modelling. Scaling up SOC data to landscape or regional levels magnifies the error of estimation, so a greater number of sample is required to control for this. The actual method sampling can be chosen depending on the objective (i.e. short-term versus long-term change) and these include digging open pits, core sampling with a punch core and core drilling (Nayak et al. 2019).

The next parameter to document is the depth of sampling (Nayak et al. 2019). Baker et al. (2007), in their appraisal of tillage practices on SOC stock, observed bias in the sampling protocol of many results, as sampling is frequently performed to a depth of 30cm or less, despite crop roots often extending further. It was found that in studies which sampled at depths above and lower than 30cm, there was no steady accumulation of SOC, but rather a difference in vertical distribution, with higher concentrations near the surface under reduced or no-till experiments, and the same in deeper layers under conventional tillage. Such distinctions are thought to occur as a consequence of differences in thermal and physical conditions that impact root growth and distribution as a result of the tillage practice (Baker et al. 2007; Powlson et al. 2014).

The bulk density of soil is the next feature to account for, as management practices like tillage, lead to compaction at lower depths resulting in higher density, thus reducing their capacity to hold SOC (Nayak et al. 2019). Due to this variation in bulk density, estimations of a soils potential to accumulate SOC must be expressed as a mass or stock per unit area, rather than absolute concentration alone (Nayak et al. 2019, Powlson et al. 2014). For this reason, a review of research assessing the effect of tillage treatment on SOC found the majority of findings to be invalid (Powlson et al. 2014). This was substantiated by recalculating the results on an equal soil mass basis, which reversed the perceived increases in SOC under the soil depth comparison, instead of leading to a decline in SOC stock of 50% or more among studies.

Time is the final parameter to account for (Nayak et al. 2019). It affects the annual rates of accumulation, which declines when the soil nears a new equilibrium (Powlson 2014). This can take from 25 to over 100 years to reach, with often rapid rates of accumulation recorded in the initial years following a change in management (Dimassi et al. 2014; Powlson 2014). Time thus presents a challenge for studies measuring the change in SOC over a shorter duration, as they may fail to acknowledge what the expected rates of accumulation might be in future, assuming management practices remain in place (Dimassi et al. 2014). A meta-analysis of SOC stock responses to cover crop treatments, modelled the rate of change over time using the Rothamsted carbon model (RothC).

Their findings showed a new equilibrium would be reached after 155 years, with half of all accumulation achieved after 23 years. As such, the results from short-term studies (<10 years) should be interpreted in the knowledge that the trajectory of trends or the significance of comparative results may not be sustained in the mid- to long-term.

As far as laboratory analysis of samples is concerned, there are a number of techniques that measure SOC, the leading ones being wet digestion, loss-on-ignition and dry combustion in an elemental analyser (Nayak et al. 2019). Of these, the “Walkley-Black” wet digestion method is often used in developing countries, because it is cheap, provides rapid results and reliance on limited equipment. However, this only measures active carbon and therefore has a variable recovery percentage, requiring an adjustment factor be applied to results to compensate. While wet digestion has this crucial limitation, dry combustion methods using loss-on-ignition or analysis in an elemental analyser are more advantageous, because this exposure to high temperature decomposes all forms of carbon from few samples, over a short period of time (Nayak et al. 2019).

Although the parameters to measure SOC for scientific trials are stringent, there are more commercial, farmer-focused methodologies available in various countries. In the United States, Cornell University’s Comprehensive Assessment of Soil Health (CASH) offers farmers a protocol for measurement of 39 biological, physical and chemical indicators, from which results are determined through laboratory testing and reported back to farmers (Gugino et al. 2009). The percentage of soil organic matter is determined by the loss-on-ignition dry combustion method. Similar services offerings are available in European countries, like those provided by NRM Analytical Services in the United Kingdom (Measures 2017).

2.5.1.2. SOC models and other methodologies

In-field sampling and laboratory analysis techniques form the gold standard of fine-scale measurement of SOC stock, but these are not always suitable to measure change in open farm systems. Furthermore, where commercial laboratories offer these services, this can be costly, laboratories may be located far away from farms and require that soil samples be collected and stored in accordance with strict guidelines. In such instances, biophysical models serve as a useful alternative to estimate carbon stocks, as these rely on a limited range of input data.

A number of reliable global or ecosystem computer simulation models exist that have a capacity to predict the quantity of SOC in soils, a few of which are the Rothamsted Carbon (RothC), the CENTURY model and the Agricultural Production Systems sIMulator (APSIM) (Maas 2017). These have been applied at regional scales, as in the case of the CENTURY model to simulate the decline in SOM in the Great Plains of the United States (Cole in Powlson, Smith and Smith 1995) and the APSIM model to estimate SOC change and sequestration potential in wheat-growing regions of Australia (Luo et al. 2013). In the same way, models have been applied to evaluate SOC at the landscape, farm or plot level (Johnston et al. 2017; Maas et al. 2017).

As model objectives undoubtedly vary on aspects like scope, input parameters, and assumptions, these generate different results. For example, the CENTURY model includes monthly time step climatic data to simulate long-term (decades to centuries) SOM dynamics, the cycling of nitrogen, phosphors and sulfur, and plant growth. The RothC model on the other hand, is designed to simulate total organic carbon, microbial biomass carbon and active carbon and can be run on known inputs to calculate changes in SOM or inversely using known changes in SOM to calculate inputs (Coleman & Jenkinson 2014).

For the assessment of SOC using other methodologies like models, randomised sampling and sample number are also relevant to ensure results are representative of the farmer population.

Spectroscopy is a rapid technique for measuring and monitoring SOC through the use of instruments in a laboratory, field or via remote airborne platforms, by analysing the diffuse reflectance of visible near-infrared, shortwave infrared and mid-infrared (Nayak et al. 2019). For local measurements, portable field devices and laboratory techniques applied to soil samples are equally effective. For more regional assessments, aerial systems are also available, with platforms subject to different calibration and validation procedures and spectral imagery instruments (Nayak et al. 2019).

2.5.1.3. Broader challenges

Most carbon exists at northern latitudes, especially under permafrost and moist boreal ecoregions, in contrast with lower concentrations found in African and Asian soils, where the opportunity to increase SOC is greater (see Figure 3) (Zomer et al. 2017).

It is estimated that cropland worldwide could sequester between 0.9 and 1.85 picograms of carbon per year, which is 25-53% of the goal of the 4 per 1000 initiative that is to sequester 3.5 gigatons of carbon annually (Zomer et al. 2017). Yet, while the technical potential for sequestration of carbon into cropland soil is significant, this will vary geographically depending on available nutrients, the soil's physical properties, biomass productivity, the type of vegetation and water availability, among other factors (Zomer et al. 2017). Furthermore, strategies to increase the sequestration of carbon may carry with them tradeoffs for productivity, food security or hydrologic balances, as well as the risk of generating greenhouse gas emissions like nitrous oxide emissions from nutrients.

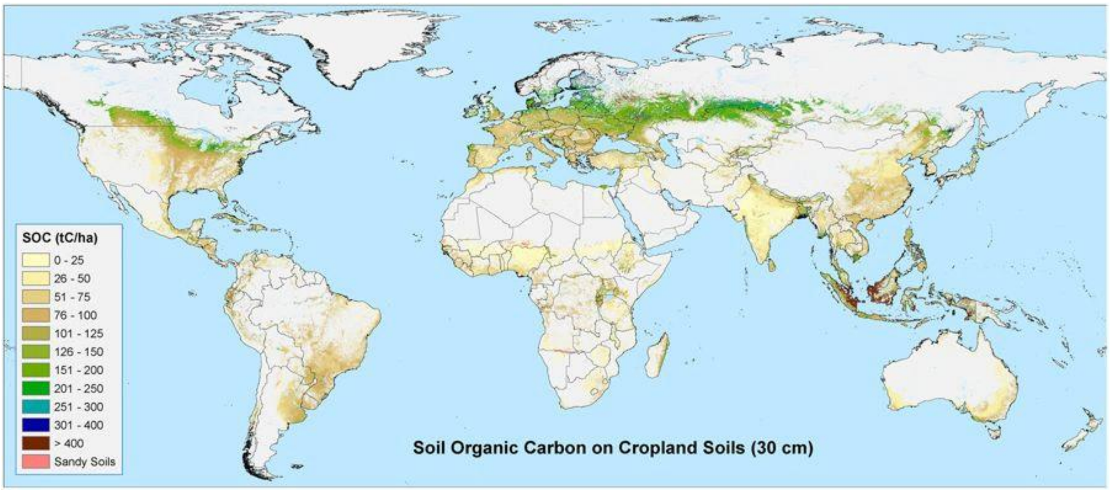


Figure 3 Global distribution of SOC stocks (Source: Zomer et al. 2017)

Although the issues described above point to variables effecting the accurate measurement of SOC, questions have been raised of how substantial the benefits of practices like no-till truly can be. Review literature on ploughing practices, such as no-till, have found limited to no benefit when measured at deeper soil depths (Powlson et al. 2014). Moreover, no-till strategies have to grapple with possible impacts on yield and carbon losses when soils are ploughed periodically, a common practice among farmers. Leaving crop residues in the field also presents a trade-off, where this would otherwise serve as livestock feed, as feed would otherwise need to come from other sources with its own carbon footprint. The availability of large quantities of nitrogen is another requirement to facilitate the increase of SOC but will limit the potential for sequestration where scarce (Searchinger et al. 2018).

2.5.2. Soil erosion

Soil is a vital natural resource to life on Earth, providing a host of benefits for soil biota, plant composition, runoff regulation, biodiversity and carbon sequestration, to name a few (Garcia-Ruiz et al. 2015). Erosion of fertile topsoil poses a major risk to soil's delivery of these benefits, making it a principal driver of soil degradation. Soil erosion can be defined as the detachment and loss of soil primary particles and aggregates from their point of origin, due to the energy transmitted by wind and water exposure, or mass wasting, the downward, gravity-induced loss of weathered and bedrock materials (Arriaga et al. 2017; Pimentel et al. 1995; Stetler 2014). In cropland, the direct down-slope movement of soil by tillage machinery redistributes particles within a field leading to what is called tillage erosion (FAO & ITPS 2015). Although the processing of soil loss sounds straightforward, many factors influence its occurrence, like soil physical, chemical and biological characteristics, degree of disturbance, the steepness of the slope, vegetation cover, and rainfall quantity and strength (Garcia-Ruiz et al. 2015; Pimentel et al. 1995; Montgomery 2007). As these conditions vary over space and time, the rates of erosion are different across the world.

In a model predicting the potential rates of soil loss by water erosion over 84.1% of the Earth's land surface, Borrelli et al. (2013) estimated 35.9 billion tonnes of soil was lost in 2012, equalling an average of 2.872 Mg per hectare. At a regional level, the highest proportion of land susceptible to severe erosion was attributed to South America (8.3%), followed by Africa (7.7%), Asia (7.6%), North America (4.3%), Europe (1.6%) and Oceania (0.8%). Unlike water erosion, global erosion rates for wind erosion are less defined, but it is estimated approximately 40% of the Earth's surface is vulnerable to it (FAO & ITPS 2015). One study by Shao et al. (2011) found that 25% of global dust emissions could be attributed to anthropogenic sources. However, contributions from anthropogenic sources varied significantly by region, with this making up just 8% of emissions in North Africa, but 75% of those in Australia. Concerningly, rates of erosion generally exceed that of soil formation, leading to a decrease in soil quality and increased production costs, declining yields and in extreme cases, the desertion of cropland (Montgomery 2007).

Slope steepness, higher rainfall and vegetative cover are considered as important factors in determining the rate of erosion (Garcia-Ruiz et al. 2015). As such, practices that reduce disturbance, while providing a protective cover of vegetation are seen as most effective in reducing the incidence and rate of erosion (Pimentel et al. 1995). Studies of annual soil loss from corn cropland under different tillage practices estimated loss to be 470 times greater on conventionally ploughed fields under continuous corn production, compared with that of fields under no-till practice with permanent soil cover (Pimentel et al. 1995). Other practices like cover crops and living mulches reduce runoff and erosion, because they provide vegetative ground cover during periods when a crop is absent, shielding the soil from energy that would otherwise detach particles (Hartwig et al. 2019). Furthermore, cover crops enhance soil structure by providing an additional source of organic matter, which groups soil particles into aggregates. This plant material is then processed by microbes that produce gums, which clump aggregates into peds, leading to improved soil permeability and aeration.

It is clear by this evidence that reducing erosion should be a key objective of farmers who wish to maintain productive, healthy soils. To do so, it is useful to assess what components of the soil can provide a yardstick of erodibility and which parameters are important to consider in the measurement of these components.

2.5.2.1. In-field and laboratory

I. Water erosion

Aggregate stability is a measure of the extent to which soil aggregates resist disintegrating or slaking when wetted and impacted by rain drops (Gugino et al. 2009). This process of slaking takes place through the compression of air contained within rapidly wetted aggregates, which Barthés and Roose (2002) linked to soil vulnerability to runoff and water erosion. The stability of aggregates in water is vital for sustaining soil productivity by serving to limit erosion, pollution and soil degradation (Fajardo et al. 2016). Several methods to measure aggregate stability have been devised, namely end-over-end shaking, wet sieving, raindrop impact or rainfall simulation, immersion techniques and ultrasonic dispersion, among which the wet sieving method is commonly applied.

The wet sieving technique involves a comparison of the Mean Weight Diameter of aggregates, by determining the difference between dry weight and wet weight, following wet sieving (Fajardo et al. 2016). This is conducted in a laboratory using a rain simulation device that progressively rains on a sieve holding previously measured, dry soil aggregates of between 0.5mm and 2mm in size (Gugino et al. 2009). In response to this process, unstable aggregates fall away and pass through the sieve. The soil fraction left behind is used to determine the per cent aggregate stability. Although the wet sieving method is simple and intuitive, it requires specialised equipment and time when processing a larger number of samples (Fajardo et al. 2016).

The in-field immersion method by Field et al. (1997), presents a simpler and faster approach to assess aggregate stability, by way of a scale to rank the extent of slaking, with 0 equivalent to non-disruption and 16 to full dispersion. With this method, Fajardo et al. (2016) developed an image recognition algorithm that when combined with a digital camera can measure the anticipated area of soil aggregates during the slaking process. The method was successful at evaluating the disaggregation process over time and could even explain drivers of slaking behaviour of soil aggregates and provide data for comparison of aggregate stability under different treatments (Fajardo et al. 1996). In 2018, Fajardo launched a smart phone application capable of measuring the change in area of soil aggregates immersed in a Petri dish full of water over time (Fajardo 2018). The application is compatible with smart phones operating on Android and is freely available for download from the Google Play app store.

II. Wind erosion

Wind erosion measurements can be conducted through field experiments, laboratory wind tunnel assessments or by using a portable wind tunnel in the field (Pietersma et al. 1996). The first two methods face challenges replicating a range of field conditions, making the portable wind tunnel a more suitable alternative. Independently simulating wind conditions in a tunnel facilitates rapid *in situ* measurement of soil loss on the soil type, under the treatments and cropping systems being tested. Portable wind tunnels have been used since wind erosion research begun, often in the development of empirical models, but require correlation with field conditions before use, making them more suitable to research trials rather than programmes with farmers in open farm systems (Hagen 2001).

2.5.2.2. Erosion models

I. Water erosion

Models provide a solution to estimate erosion potential from cropland via soil loss and runoff rates (Igwe et al. 2017). To effectively simulate the erosion process, these need to factor in slope steepness, slope length, plant cover, rainfall, soil characteristics and erosion control techniques. Igwe et al. (2017) describe three types of erosion models, namely empirical, conceptual and physics based. Empirical models rely on a limited set of historical data and parameter inputs, while conceptual models use sediment generating factors like rainfall and runoff as inputs and sediment yield as an output. Physical models offer an understanding of sediment producing processes and can access include spatial and temporal variations, like daily weather forecasts (Igwe et al. 2017). A review of available water erosion models found these varied in complexity and input requirements, as well as geographical applicability (Igwe et al. 2017). The most widely applied models among literature were the empirical Universal Soil Loss Equation (USLE) model and its successor, the Revised Universal Soil Loss Equation (RUSLE) model. A biophysical model, the Water Erosion Prediction Model (WEPP) was another that stood out from the group for its high degree of prediction accuracy.

The United State Department of Agriculture (USDA) developed the USLE model which was later updated to the RUSLE model (two versions of this now exist) (Foster 2013). The model predicts mean annual erosion loss using site-specific conditions based on input data of users interacting with background databases and mathematical equations (Foster 2013). It was designed for ease of use, robust enough to account for input data uncertainties and to provide evidence to support decision-making. A review of studies using models to assess erosion found the USLE model was better suited in the prediction of long-term averages, rather than specific events. Furthermore, one study found the RUSLE model to be more sensitive to land use and land cover variables, predicting results similar to those observed (Igwe et al. 2017).

Moving from an empirical to a more accurate biophysical model, the USDA along with institutional partners, developed the WEPP model (Field to Market 2018). Advantages of the WEPP over the RUSLE model include a higher confidence in erosion estimates, the facility to estimate in-field gully erosion, the inclusion of daily weather updates and better simulation of crop growth. With the launch of the WEPP model, the USDA have halted further maintenance and updates to the RUSLE model. For this reason, it makes little sense to apply the RUSLE model for measurement of soil loss, if not part of a wider model to compensate its omissions. At this time, the RUSLE model forms a component of the spatially explicit Sediment Retention model, which maps sediment generation and delivery to a stream (Sharp et al. 2015). However, the tool is designed for use at the landscape level rather than at farm, modelling sedimentation of water catchment areas for reservoir management and instream water quality. More suited to farm or plot-level assessments, the Field to Market FieldPrint Calculator is a farmer-facing platform providing sustainability metrics for use in the United States (Field to Market 2018). The Soil Conservation Tool is one of these. One such indicator is the Soil Conservation metric that combines the USDA's WEPP and the Wind Erosion Prediction System (WEPS), which both apply the same parameters and weather database.

II. Wind erosion

There are fewer wind erosion models as there are water, but of these the most widely accepted one is the Wind Erosion Equation (WEQ) and the Revised Wind Erosion Equation (RWEQ), counterpart to the USDA's USLE and RUSLE models (Favis-Mortlock 2017; Stout n.d). WEQ was found to be a highly reliable model when making long-term predictions of soil loss, while RWEQ has been used to demonstrate good agreement with observed yields of soil loss when compared with in-field sampling techniques (Borrelli et al. 2017). Designed in a similar way to the RUSLE model, RWEQ uses mathematical algorithms and related parameter values to predict soil eroded and carried by wind from the surface to a 2-meter height (Favis-Mortlock 2017). Although the model has been developed for application in the United States, it has been adapted for use in other regions (Borrelli et al. 2017).

In keeping with their approach of moving from an empirical to biophysical model to estimate water erosion, the USDA developed the Wind Erosion Prediction System

(WEPS). Unlike its predecessors, WEPS is a process-based, ongoing, time-step model that accounts for weather, field conditions and erosion for use in the United States, but easily adaptable to other parts of the world (USDA-ARS 2010). Funk et al. (2004) conducted a comparison of the WEPS model with in-field measurements based on single erosion events in Germany cropland, finding good agreement between these on soil loss and the spatial and temporal variability of soil transport. Together with the WEPP model, the FieldPrint Calculator Soil Conservation metric relies on the WEPS model to evaluate soil loss from wind erosion (Field to Market 2018).

Despite their usefulness as a method for measuring soil loss, there are several cautionary factors that need considering when selecting and applying models. Firstly, most models are scale-specific and thus rely on input data to fit this design (Van Rompaey & Govers 2002). For example, in the case of a regional model, input data must sufficient reflect variability within the geographical area to provide a sensible prediction of reality. Moreover, a high level of data quality is needed to produce credible results, especially as error can propagate through the model, yet in reality this is sometimes technically or financially infeasible to gather. For this reason, some models like USLE have been simplified, classifying variables like slope angle and land cover as low, medium or strong. However, a model that is too simple may be of limited value, so in selecting a model, it should be sufficiently complex to predict soil loss with limited uncertainty, while ensuring that input data are not too numerous to jeopardise data quality and invalidate the results (Van Rompaey & Govers 2002).

2.5.3. Soil compaction

Heavy machinery, traffic or tillage on wet soils and shorter crop rotations that are synonymous with intensive agriculture have led to increasing compaction of cultivated soils (Hamza & Anderson 2005; Moebius-Clune et al. 2017). Estimates suggest 68 million hectares of soil is compacted from heavy vehicles alone, while compaction has caused the degradation of 33 million hectares in Europe. It is defined as a process whereby soil particles are rearranged and brought closer together, leading to increase bulk density (Soil Science Society of America 1996). It is also associated with soil aggregates as it effects the spatial configuration, size and shape of soils (Hamza & Anderson 2005). Compaction is more severe when organic matter is lacking, influences the mineralisation of SOC and nitrogen, and can reduce root growth, restrict water infiltration and increase sensitivity to drought (Hamza & Anderson 2005; Moebius-Clune et al. 2017). Despite its problematic nature, compaction is difficult to detect through observation, as it does not present physical signs of degradation like erosion would. For this reason, it is often misdiagnosed and goes untreated (Hamza & Anderson 2005).

Bulk density is a parameter commonly used to measure the level of compaction, because it is measured as the mass of dry soil per unit volume (Hamza & Anderson 2005). Soil strength is also used as it denotes a soil's resistance to root penetration. Lastly, a soil's water infiltration rate may also be used to assess compaction, since water can infiltrate soils that have well-aggregated soil particles more rapidly than it can those that do not (Hamza & Anderson 2005). Solutions to combat compaction include adding of organic matter to effect soils, introducing controlled traffic systems that restrict the movement of machinery and vehicles and the selection of a rotation that includes plants with strong tap roots to helps.

Appropriate methodologies to measure change in soil compaction are field based, as models are deemed less suitable because most require a number of mechanical parameters and have been developed using a limited set of conditions, showing disparity between simulations and observations. (Hamza & Anderson 2005). The most common measure of compaction is to determine the cone index value using a static penetrometer instrument, which is designed to measure the force used to shove the probe through the soil at a constant rate (Herrick & Jones 2002). This provides a measure of surface and subsurface hardness, at depths of 0 to 6 inches and 6 to 18 inches respectively (Moebius-Clune et al. 2017). The limitations of such devices are that these are costly, they need to be moved through the soil at a steady rate, they must be recalibrated regularly and they can handle a limited range of resistance, unless a more industrial grade, expensive version is used (Herrick & Jones 2002).

2.6. Conclusion

In this chapter I reviewed the literature on key topics associated with this research enquiry. I began with a description of VSS, sector growth in recent decades and how companies have modelled their sustainability strategies in accordance with these standards. Despite continued growth in the sector, a review of studies attempting to measure the impact of VSS found mixed to limited evidence of positive impacts. Yet I determined that challenges in measuring performance are perhaps in-part due to the absence of M&E systems, to systematically collect evidence and to evaluate and report achievements. As a means to address this, I described ISEAL Alliance's guidance on M&E systems and the logical framework as tools by which standards could effectively communicate their theory of change.

In the second half of this chapter I sought to provide some explanation of the soil health features covered by this research, including how common practices like tillage impacts on these, and methodologies used to measure the effect thereof. Of these soil health features, measuring changes in SOC present the biggest challenges for measurement, due to factors like to high spatial variability and a slow and unpredictable rate of change. Comparatively, the measurement of soil erosion and compaction is more straightforward, as these present physical characteristics as opposed to changes to the chemical composition of soil. Methods for measurement of SOC and erosion include both in-field sampling and laboratory analysis, as well as the use of available models to predict change based on relevant activities and biophysical data. Dissimilarly, the measurement of compaction is restricted to in-field procedures only.

Chapter 3 – Research design and methodology

3.1. Introduction

Having provided some depth into key concepts addressed by this research in Chapter 2, I will now explain what methods were used and the ensuing approaches taken to answer the research questions.

The objectives of this chapter are to articulate how the research enquiry was performed; knowledge that is crucial to understanding on what basis evidence has been generated, what strengths and weaknesses underpin this research and to appreciate how results have been interpreted.

Chapter 3 begins with a description of the research problem statement, followed by the research objectives this thesis intends to address. This is followed by a description of the methodological approaches and paradigms used to deduce findings and why these were chosen. Finally, the research methodologies used to collect information and to generate and analyse results are explained.

3.2. Research problem statement

Although their objectives vary, Voluntary Sustainability Standards (VSS) typically seek to drive the adoption of good agricultural practices to reduce environmental impact, safeguard human rights and increase the economic prosperity of the rural economy. The management of soils erosion, compaction and organic carbon are issues commonly addressed by VSS and compliance against a minimum set of practices ensures these risks can be managed and in cases, avoided. Unilever’s Sustainable Agriculture Code (USAC) is one such standard that aims to, amongst other objectives, help farmers produce crops with high yields and the efficient use of resources, while minimising the adverse effects of agricultural activities on soil fertility, water and air quality, and biodiversity.

Despite the continued global increase in land area certified against VSS, research seeking to assess the outcomes and impacts of these schemes has yielded mixed results, with some review studies finding limited evidence of their ability to deliver on their objectives. The same applies to the detection of improvements to the soil health of cropland, which at a global scale has been in decline due to poor management practices and other human pressures.

In response to this problem, this research has sought to explore methodologies to assess the outcomes of good soil management practices obligated by the USAC, a company-own standard with which I work. Through a systematic review and the conducting of interviews with experts and practitioners, this research considered methodologies currently available to measure change, which would be appropriate for use with farmers implementing a standard like the USAC. These methods are presented through the framework of a monitoring and evaluation system, which could be operated in tandem with the USAC as a way to monitor and track performance of farmers for a range of indicators.

3.3. Research aims and objectives

The USAC defines a minimum set of requirements for farmers to comply with, which include criteria relating to soil health, namely erosion, compaction and soil organic carbon. Practices frequently recognised as beneficial in the management of these soil health aspects are composting, cover cropping, crop rotation, and reduced or no tillage. These practices have been selected to help hone the scope of this enquiry. With these soil health aspects and management practices in mind, this research maintains the following objectives:

i. What are appropriate methodologies that could serve to measure the effect of soil health requirements of Unilever’s Sustainable Agriculture Code?

ii. What are the barriers to successful adoption of outcome-based measures?

iii. Under a management framework, how would such measures be captured and administered?

3.4. Research approach/paradigm

The choice of research questions and methods, as well as the interpretation of research findings, is a reflection of a researchers’ epistemological understanding, or point of view of the world (Feilzer 2010). This understanding is demonstrated through adherence to a particular paradigm, which may also be viewed as an “accepted model or pattern" (Kuhn 1962:23). A paradigm thus allows the researcher to be prescriptive with the research methods that they select and exclude (Feilzer 2010).

The pragmatic paradigm is a perspective that avoids dealing with the difficult issues of truth and reality, instead focusing to resolve practical problems in the real world, using objective, subjective or a combination of approaches (Creswell 2014, Feilzer 2010). As this research applies qualitative methods of enquiry to quantitative subject matter that seek to measure cause and effect, the pragmatic paradigm explains this form of enquiry well. Moreover, the pragmatic paradigm maintains a similar commitment to the outcomes of practice, aiming in interpret each idea against its practical implications, because it recognises that the world is layered with ambiguity, uncertain possibilities, and the ability to predict and control these outcomes (Dewey 1925). By nature of the relative open-endedness of the research questions, an exploratory study is called for, employing qualitative approaches to assess quantitative methods.

Together with pragmatism, post-positivism is second paradigm that helps describe this research endeavour, because of its pursuit for objectivity, recognising that truth can be based on probabilities rather than certainty, by verifiable observation and measurement (Crotty 1998). It argues that "no matter how faithfully the scientist adheres to scientific method research, research outcomes are neither totally objective, nor unquestionably certain" (Crotty 1998:40). Unlike positivism which emphasises the use of quantitative methods, post-positivism deems both quantitative and qualitative methods as valid tactics (Taylor & Lindlof 2011).

3.5. Research methodology

A qualitative approach was selected to respond to the research questions, as discussions with supervisors determined the subject matter would be best explored by considering the body of existing literature. A narrative literature review was performed to expound the research problem, followed by a systematic review and interviews to gather and interrogate the research questions. This range of desktop approaches were deemed most appropriate, given the already wide body of research available on these topics.

3.5.1. Narrative literature review

A literature review entails the objective, detailed synthesis and critical evaluation of evidence that is deemed relevant to the topic under investigation (Hart 1998). This serves to inform the reader of the latest available literature on the topic and to justify future research (Cronin et al. 2008). A narrative literature review adheres to the definition, but is selective in the material it references, as has been the approach taken to identify relevant literature for inclusion in Chapter 2 of this thesis (Cronin et al. 2008). As a starting point, pertinent literature was identified through the use of academic databases available to me, namely the Stellenbosch University library and Scopus. Search results were ordered by highest to lowest number of citations, which were perceived as a measure of influence within each topic area. From these papers, further relevant concepts and associated papers were identified. Typically, the abstracts of articles were scanned to gauge their relevance, before proceeding to identify, summarise and synthesise pertinent information into this thesis.At times, seminal literature and concepts were brought to my attention by supervisors. Other times, relevant literature was identified by considering the citations of accessed literature.

3.5.2. Systematic review

Gough, Oliver and Thomas (2012:5) define a systematic review as "a review of the research literature using systematic and explicit accountable methods." Unlike traditional narrative reviews wherein the process of literature selection and inclusion or exclusion is not typically documented, systematic reviews explain the process of identifying literature, data collection, and analysis, so that researcher bias can be observed, the approach may be replicated if required and readers may evaluate the evidence-based on merit (Gurevitch, Koricheva, Nakagawa & Stewart 2018; Petticrew & Roberts 2008). The process of reviewing evidence systematically involves the 'mapping' of literature by identifying and describing it, the methodical evaluation of the evidence, and finally, the synthesis of the findings into a concise statement (Gough, Oliver and Thomas 2012).

The Cochrane Collaboration is an internationally renowned charity whose work aims to provide a synthesis of evidence that can support decisions about health care (Higgins and Green 2011). Among key objectives, the group maintain guidelines against which researchers conduct their systematic reviews. Although originally developed for the medical science community, the guidance has been adapted for use in social, behavioural, and educational disciplines (led by the Campbell Collaboration) and environmental sciences (led by the Collaboration for Environmental Evidence or CEE) (Dicks et al. 2017). I applied the CEE's guidelines and standards as the basis for my systematic review, which have been developed for application to environmental management and the kinds of data and study designs most common among environmental research (CEE 2018). The guidelines provide instructions from how to conduct the initial search, eligibility screening, data coding and extraction, to identifying source of bias, a process for selecting the method of synthesis and the interpretation of results.

Although these guidelines were applied to the systematic review, several criteria were not met because these were deemed to exceed the normative boundaries of a master's thesis. These include registering a research proposal with CEE, publishing a notice of intent of this project to the scientific community and documenting specific information in formal templates (CEE 2018).

A general characteristic of the systematic review is that it relies on a review team, consisting of multiple researchers who review each other's decisions, such as whether to include or exclude from scope a particular study. In spite of this, this review was performed entirely by me, although results were shared with the supervisors to determine whether they agreed with decisions made during the eligibility screening process.

3.5.2.1. Pre-systematic review preparations

Prior to embarking on the systematic review, the scope of this enquiry was refined by way of three activities; a review of the USAC, the benchmarking of soil management practices listed in VSS deemed as equivalent in the USA scheme rules, and the selection countries in which to restrict the review.

As this research seeks to address soil health in accordance with the USAC, this served as a sensible place to start. The USAC contains several requirements within its soil management chapter, which when considered in discussion with supervisors, led to the selection of three; concerned with the management of erosion, compaction and soil organic matter; as described in table 2 below (Unilever 2018e).

Table 2 Extract of selected soil management requirements from the USAC (Source: Unilever (2018e))

Number	Requirements	Description
F28	Management of erosion risks	Unless the risk of soil erosion is assessed as insignificant (see guidance), the risk must be managed. This includes identifying areas of the farm particularly susceptible to erosion, and putting in place management plans, grazing and cropping systems that reduce the risk. Monitoring soil cover and effectiveness of land management systems in place (drains, bunding, terracing, contour planting, windbreaks, cover crops etc.) to minimise erosion must then be incorporated into the management plan.
F29	Management of compaction risks	Unless the risk of soil compaction is assessed as insignificant (see guidance). The risk must be managed. Compaction risks need to be reduced from methods that deal with the symptoms for minor compaction problems, e.g. breaking soil caps and subsoiling, to methods the deal with the causes, e.g. controlled traffic, conservation tillage.
F30	Soil Organic Carbon/ Organic Matter	Management practices must be put in place that maintain or enhance Soil Organic Carbon/ Organic Matter.

Next, a benchmark of VSS recognised as equivalent to the principles and practices of the USAC was performed (see Annex 1a) (Unilever 2018). This evaluation served to determine the most frequently cited practices for use in the management of these aspects, so as to restrict the scope of the systematic review to subset of research of a manageable quantity. Of these, only standards intended for use in the production of annual crops were included, as the USAC is used predominantly for the production of annual row crops like tomatoes, onions and potatoes. Moreover, annual crops are known to be more problematic for soil health than perennials or permanent crops, because of their comparatively lower root growth, shorter growing seasons, annual removal and exposure of bare soil and greater dependency on farm machinery, all of which makes soils more susceptible to erosion and lower their capacity to store carbon (Zhang et al. 2011).

Table 3 lists the practices referred to three or more times by nine of the ten standards reviewed, with the aspect that each standard claimed the practice would address, abbreviated to a capital letter in the body of the table. This analysis found that tillage practices (7) cover cropping (6), composting (6), and crop rotation (5) were most frequently cited for the management of compaction, erosion and soil organic matter. Only three of the nine standards reviewed (Rainforest Alliance SAN 2017, Proterra and ISCC) had requirements covering all three management areas.

Table 3: Benchmark of soil management practices among USAC recognised VSS

Count	Management practices	A. USAC	B. Fair Trade	C. For Life	D. IFOAM	E. ISCC	F. ProTerra	G. RFA	H. SAI FSA	I. SCS	J. UTZ
7	Tillage practices	C			E	E		C	E	C,E	
6	Cover cropping	E			S			S	E	E	E
6	Composting					S	S	E,S		E	E
5	Crop rotation				S	E		S		C,E	
5	Controlled traffic	C				C,E		C	C		
5	Crop residues & groundcover			E	E		C,E	E			
4	Terracing	E						E	E	E	
3	Timing around wet soils					C			C		C
3	Tyre pressure					C		C	C		

Key
C. Compaction. **E.** Erosion. **S.** Soil organic matter

Names of standards summarised above
A. Fair Trade Certified - Agricultural Production Standard (Version 1.0.0). **B.** For Life (Version April 2019). **C.** The IFOAM NORMS for Organic Production and Processing (Version 2014). **D.** ISCC 202 Standard on Sustainability Requirements for the Production of Biomass (Version 3.0). **E.** ProTerra Standard (Version 3.0). **F.** Rainforest Alliance Sustainable Agriculture Standard (Version 1.2). **G.** SAI Platform Farm Sustainability Assessment 2.0. **H.** SCS Sustainably Grown (Version 2.1). **I.** Unilever Sustainable Agriculture Code (2017). **J.** UTZ Certification Protocol (Version 4.1)

Prior to the formal initiation of the systematic review, mock searches were performed in Scopus, to determine how many papers would be called up. When applying search strings with terms like ‘erosion AND tillage’, a significant number of results were generated (over 3000 in this example). In discussion with supervisors, it was decided that a limiting variable would be included to reduce the search results to more manageable proportions. This was to reduce the enquiry from a global to a country-level enquiry. Countries were selected by considering where the largest concentration of raw material volume from USAC suppliers is grown, and where the greatest number of farmers implementing the USAC are located. To inform this, an analysis of Unilever 2018 raw material volume produced in accordance standards listed in table 2 (Unilever 2018). An aggregation of data by country of production was made for all annual crops,[4] from which a list of the top ten countries by order of volume was derived. Next, this list was cross-checked against a database of USAC farmer locations, to ensure the countries selected would be among those with the highest number of farmers participating in the programme. In doing so, this would ensure that the research could be applied to the largest group of farmers possible (Unilever 2018a).

China, Germany and the USA featured in both lists and were selected for the systematic review, because these were among the top five countries by both farmer participation and volume and reflected three distinct geographical jurisdictions. Figure 4 depicts the top ten countries featuring in both lists and shown here in alphabetical order. However, during the inclusion/exclusion process (described below), it was decided to remove Germany from the study, as searches generated batches of literature a fraction of the quantity generated for China and the USA, meaning any comparison of the three would underrepresent literature from Germany. A review of literature from more than one country was selected in the hope that this would offer more diversity among the literature, and the opportunity to compare and contrast findings (JK Vis 2019, personal communication, 2 April).

[4] An FAO classification of crops as annual versus permanent was used to group area accordingly (FAO 2010).

Tonnage of raw material volume by country				Count of farmers implementing the USAC by country
Belgium				Argentina
Chile				China
China				France
Germany	→	Selection of countries for inclusion in the systematic review	←	Germany
Greece				India
India				Italy
Italy				Poland
Spain				Spain
Turkey				Turkey
United States				United States

Figure 4 Top ten countries by raw material volume and USAC farmer implementation

3.5.2.2. Conducting a search

The CEE (2018) explains that, to accomplish a robust synthesis, searches should be transparent and replicable while limiting bias. This section provides a step-by-step overview of the search process performed, summarised in tables.

I. Choice of a search database

Selection of a search database that holds the largest number of applicable articles and which provides the abstracts of articles for better understanding of relevance is considered best practice (CEE 2018). The systematic review was performed using Scopus, an abstract and indexing database with 22,800 titles (Elsevier 2017). Scopus was chosen over Web of Science, the alternative academic database, which holds around 12 000 titles (Wagner 2015). The database has an extensive geographical coverage, with 60% of titles coming from countries other than the USA (Burnham 2006). This was considered an important attribute for ensuring search results delivered a balanced range of articles for China, despite around 23% of these publications being in Chinese. From a searchability standpoint, Scopus lets users conduct enquiries based on a variety of criteria (e.g. key words, title, language, etc) and to export results to reference managers like Mendeley or a programme like Microsoft Excel for further processing (Elsevier 2017). This was found to be particularly useful in facilitating the aggregation and initial review of titles and abstracts for inclusion or exclusion.

II. Developing the search strings

Generating search strings that retrieve relevant results while limiting the inclusion of irrelevant ones (CEE 2018), required that I test out search string combinations. Words used in the search strings included the soil management aspects (e.g. erosion) and practices (e.g. tillage) described under 3.2.1. Initial searches were conducted in April of 2019, but once eligibility screening of these papers had been complete, it became clear that some methodologies identified during the narrative were not represented. This led a second search performed on the 24th of June 2019 to allow to use of several new search terms. Notably, the methodologies described by Nayak et al. (2019) to measure soil organic carbon were used, as this recent study evaluated both established and emerging techniques. The methods used in search terms were eddy covariance, inelastic neuron scattering, lifecycle assessment (LCA), Laser-Induced Breakdown Spectroscopy (LIBS) and spectroscopy. Other more generic search terms included were ‘monitor’ and ‘methodology’. Table 4 shows the words and phrases used in search strings under the headings Part A-D. These strings used ‘AND’ between each part to form the desired syntax, as well as quotation marks to couple words into phrases where needed (e.g. “cover crop” or “eddy covariance).

III. Search criteria

Several limiting factors were applied when setting up the search, resulting in Boolean phrases that are shown in Appendix A The search string was applied to ‘Article title, Abstract, Keywords’, to only call up articles that contain these words in these fields. The ‘Date Range’ was restricted to documents published in ‘2015 to Present’, or later reduced to those published in ‘2018 to Present’ (see section 3.5.2), given the high degree of homogeneity among methodologies applied by authors (see Chapter 4 for further details). The ‘Document Type’ was restricted to the ‘Article or Review’ option to only include peer-reviewed articles and review articles. For ‘Language’, only articles published in ‘English’ were selected. Finally, for ‘Subject Area’ only articles attributed to the Agricultural and Biological Sciences were included.

Table 4: Search terms and limiting factors applied when using the Scopus database

Part A	Part B	Part C	Part D	Search date
soil	compost	‘country’	-	14/04/19
soil	cover crop	‘country’	-	14/04/19
soil	crop rotation	‘country’	-	14/04/19
soil	tillage	‘country’	-	14/04/19
soil	compaction	methodology	‘country’	24/06/19
soil	erosion	methodology	‘country’	24/06/19
soil	eddy covariance	‘country’	-	24/06/19
soil	inelastic neuron scattering	‘country’	-	24/06/19
soil	methodology	‘country’	-	24/06/19
soil	monitor	‘country’	-	24/06/19
soil	LCA	‘country’	-	24/06/19
soil	LIBS	‘country’	-	24/06/19
soil	spectroscopy	‘country’	-	24/06/19

Searches were conducted on the 14th of April 2019 and the 24st of June 2019, with the Boolean operators shown in table 3. The total number of articles both searches generated was 619. All search results were downloaded and consolidated into Microsoft Excel files, group by country. Articles searched for on the 24th of June 2019 were reviewed to remove articles published after the 14th of April 2019, to align the date range for both searches. This led to the removal of six articles. Appendix A provides the complete list of Boolean operators used in the search.

3.5.2.3. Eligibility screening

Prior to initiating the eligibility screening, duplicate results were removed, aided through the use of conditional formatting and highlighting features available in Microsoft Excel. This was followed by eligibility screening, a process of including or excluding articles based on their applicability to the research questions (CEE 2018).

The list of inclusion and exclusion criteria was drafted to ensure the same screening decisions were applied to both the China and USA searches. As a basis for inclusion, articles needed to reflect the application of one or more of the management practices under consideration (compost, cover crop, crop rotation or tillage) to manage one of the aspects (compaction, erosion, soil organic carbon). Other criteria determining the inclusion of articles included application to ‘temporary’ or annual crops (FAO 2011) and experiments relating to field-grown crops rather than those produced in a greenhouse or a laboratory. This to ensure that experiments reflected similar conditions to those anticipated under field cultivation.

The screening process was initiated by applying search filters to the column containing article titles and later the abstracts. If, after reviewing both the title and abstract, the eligibility of a paper was still unclear, the full text was reviewed (CEE 2018). In parallel, the list of inclusion and exclusion criteria was updated, as more factors were considered and accommodating criteria added. Table 5 shows the final list of inclusion and exclusion criteria. To check decisions made on eligibility, the portion of these articles resulting from the initial search conducted on the 14th of April 2019, were shared with Dr Jan Kees Vis, who agreed with the decisions made (JK Vis, personal communication, 24 April).

Table 5: Inclusion and exclusion criteria

Aspect	Included	Excluded
Language	English	Non-English
Research conducted on	United States, China	Other countries (including comparisons with USA and/or China)
Published between	1 January 2017 – 14 April 2019	Dates outside this time period
Experiment location	In-field trials	Greenhouses or lab-based
Topic criteria (search conducted on 14 April 2019)	Soil AND compost/ "cover crop"/ "crop rotation"/ tillage AND "China"/ "United States" for the management of compaction/ erosion/ soil organic carbon	Does not conform with the topic inclusion or serve to manage compaction/ erosion/ soil organic carbon. Focused on water management, weed and pest management, heavy metals and contamination.
Crop type	Relates to 'temporary' crops which are sown and harvested in the same agricultural year (FAO 2010). Examples include cereals, vegetables, oilseed crops and root crops.	Relates to 'permanent' crops that occupy land for several or more years (FAO 2010). Examples include cocoa, coffee, rubber, fruit and nut trees. Livestock-related production systems. Relates to a comparison of temporary crops with permanent crops. Relates to production of biofuels, tobacco, hemp, cotton or feed crops.
Land use	Relates to cropland	Relates to other land uses like forestry, pasture, wetlands, prairies, rivers and urban land.
Other	-	Studies not accessible via Scopus, Google Scholar or the Stellenbosch University Library. Studies relating to historical assessments, system dynamics, thermal energy, yield, comparison of conventional tillage methods rather than tillage systems (e.g. conventional vs no-till) and those baselining soil conditions without experimenting with a practice change.

3.5.2.4. Amendments of the process

The initial search on the 14th of April 2019 was performed using the date range 2015 to present. However, this generated over 200 articles for review, an unrealistic quantity, so publication year of 2017 to present was used to select a smaller group of articles (JK Vis, personal communication, 24 April). It was not thought that this would lead to the exclusion of specific concepts or methods, as the articles remaining pertained to experiments that had been conducted over an average of ten years.

3.5.2.5. Data coding and synthesis

Data coding and extraction involves the systematic removal of relevant information from articles, whereby coding is the documenting of study characteristics (e.g. location, date) and extraction refers to the results of the study (CEE 2018). Data on bibliographical, geographical, climatic, management, methodological and agronomic variables were coded where deemed useful for aggregation and relevant to other reviews relating to soil health (Adams et al. 2017, Luo et al. 2010 and Nayak. et al. 2019). The CEE (2018) require that any coded data be cross-checked by at least two independent reviewers, however this step was not fulfilled. The data tables are included in Chapter 4.

3.5.3. Grey literature

To expand on the systematic review of peer-reviewed articles and review articles, a search for grey literature sources was performed. Grey literature is made up of evidence that exist outside of peer-review processes synonymous with publication in scientific journals and includes conference papers, newsletters, unpublished reports and presentations (Adams et al. 2016). A grey literature review was conducted to identify information not found in the peer-reviewed literature, such as that gathered from experimental and applied research fields (Adams et al. 2016).

Conference proceedings associated with the journals containing articles featured in the systematic review were used to identify and locate relevant literature, which typically came in the form of presentations and posters. The websites of 21 journals linked with articles drawn during the systematic review were searched, of which only the Soil Science Society of America Journal was affiliated with an annual conference. This conference is in association with the American Society of Agronomy (ASA), the Crop Science Society of America (CSSA) and the Soil Science Society of America (SSSA). The conference proceedings of two conferences were considered, namely the ASA, CSSA Annual Meeting of 2018 and the ASA, CSSA and SSSA Annual Meeting of 2017. Both of these conferences had programmes on land management and conservation, which contained most of the research relating to soil health, so searches were conducted in these section only.

Table 6 provides a summary of the inclusion criteria applied with screening evidence located in proceedings related to this programme. The conference archive folders were accessed on the 4th of October and a total of 212 documents in the form of presentations or posters with supporting abstracts were contained within these folders, of which six were deemed to be relevant for inclusion. A key distinction between this review and the systematic review was the exclusion of research relying on traditional in-field sampling and laboratory analysis techniques, since this had featured so prominently in the previous review.

Table 6 Conference proceedings inclusion criteria

Aspect	Included	Excluded
Language	English	Non-English
Research conducted on	United States, China	Other countries (including comparisons with USA and/or China)
Presented between	2017 and 2018	Dates outside this time period
Topic criteria	Barriers or challenges to adoption of soil health methodologies, soil health assessment methodologies.	Traditional in-field sampling and laboratory analysis methodologies
Crop type	Relates to 'temporary' crops which are sown and harvested in the same agricultural year (FAO 2010). Examples include cereals, vegetables, oilseed crops and root crops.	Relates to 'permanent' crops that occupy land for several or more years (FAO 2010). Examples include cocoa, coffee, rubber, fruit and nut trees. Livestock-related production systems. Relates to a comparison of temporary crops with permanent crops. Relates to production of biofuels, tobacco, hemp, cotton or feed crops.
Land use	Relates to cropland	Relates to other land uses like forestry, pasture, wetlands, prairies, rivers and urban land.

A second source of grey literature was the online database on the sustainability impacts of VSS, called Evidensia (Evidensia 2019). The purpose for conducting a seach within this database was based on a need to consider other sources of information to better respond to the research objectives 2 and 3, namely to identify potential barriers or challenges to adoption of soil health methodologies and the question of how such methodologies would be captured and administered. Evidensia is a collaboration of organisations that play a role in the VSS sector like the World Wildlife Fund (WWF), who have helped establish VSS and ISEAL Alliance, who support scheme owners to operate against best practice standards. The database recognises a range of evidence relating to jurisdictional approaches, public or quasi-public sustainability standards, national plans, policies and platforms, and VSS instruments, among others.

A search was conducted in the database on the 4th of October. Instead of using search terms though, filters were applied to locate the relevant evidence. Firstly, the date of publication of the evidence was restricted from January 2017 to January 2019, to ensure recent studies were included. Next, 'agriculture' was selected from the filter 'Sectors & Products', to exclude evidence relating to other sectors.

Table 7 Evidensia inclusion criteria

Aspect	Included	Excluded
Language	English	Non-English
Published between	January 2017 and January 2019	Dates outside this time period
Topic criteria	Barriers or challenges to adoption of soil health methodologies, soil health assessment methodologies or other environmental methodologies.	All other topics
Type of literature	Grey literature, not published in peer-reviewed journals	Research published in a peer-reviewed journal
Sector	Agriculture	Others

As table 7 shows, all peer-reviewed literature published in journals was excluded from the selection, as the objective of this enquiry was to prioritise grey sources of evidence. With these studies excluded, the remaining papers were reviewed, looking for any that addressed the topics of interest.

3.5.4. Semi-structured interviews

Given that this research enquiry is partly concerned with emerging methodologies to measure changes in soil health, it was deemed necessary to interact with experts in relevant fields of specialisation, that could share insights on approaches that may not yet reflect among scholarly literature or who themselves are or work with stakeholders that are more closely associated with the application of science.

Semi-structured interviews were chosen as a suitable way to elicit knowledge from a group of pre-selected participants. Longhurst (2010: 103) describes these as "a verbal interchange where one person, the interviewer, attempts to elicit information from another person by asking questions." The process is facilitated by way of a list of predetermined questions, which loosely guides the direction of enquiry, while providing enough flexibility for participants to explore concerns they believe to be salient. This approach to questioning was fostered to allow the participants space to not only respond to questions, but to build on them or introduce new ideas.

Purposeful sampling, described as the selection of information-rich cases for study, was used to select participants for interview (Patton 2002). Their selection was therefore not meant to be representative, but to rather provide a sample of specific people and knowledge to provide insight regarding the research topic. The persons interviewed were identified through colleagues and were themselves practitioners or researchers in the fields of VSS, sustainable agriculture, remote-sensing, agronomy and soil science. Figure 5 provides the list of questions asked during the interview.

Interviews were conducted via the telecommunications application Skype. These typically ran for between 30 to 45 minutes, with information captured in Microsoft Excel. All participants were asked to sign a consent form, confirming their willingness to participate. To analyse findings, data were categorised according to theme and described.

1. Introduction to research and participant

a: Please describe your current role and work relating to cultivated soil.

b: How would you define a healthy soil?

2. Recommended soil monitoring techniques

a: What are the most practical (affordable, widely available, user-friendly) monitoring techniques you would recommend for use in monitoring change in SOC, erosion and compaction?

b: Should any of these be used in combination?

c: Can you estimate the cost of deploying such a technique (e.g. equipment, software, manhours)?

d: If you were to prioritise the use of one measure over another, which would this be and why?

e: Which stakeholders should be engaged to effectively plan for and implement this?

f: Are there any new or emerging technologies you believe could be effective in monitoring the health of cultivated soils?

3. Constraints in effectiveness of a monitoring technique and outcome when implemented

a: What are the limitations of using this methodology and how would this effect the result?

b: How might these constraints be mitigated?

4. Sources of grey literature

a: Is there any grey literature you would recommend reviewing providing alternative, less conventional views?

b: Are there any other people you would recommend I speak to with knowledge or experience in this field?

Figure 5 Interview questions

3.6. Conclusion

In this chapter I described the research problem as one whereby evidence demonstrating the impact of VSS is scant and which lacks consensus among researchers. With this framing, I centre my research on the USAC, a standard I have experience working with in my role at Unilever. Focusing on the soil management requirements of this standard, I have defined three research objectives, asking what appropriate methodologies to measure the effect of soil management practices are, what the barriers to successful adoption of such measures are, and what type of framework can be used to capture and administer these measures. I defined my point of view as practical, looking to interpret each idea against its practical implementation (pragmatism), and objective, recognising that truth is based on probabilities rather than certainty (post-positivism).

I then described the methodologies I have applied to this research: literature reviews and semi-structured interviews. I selected a narrative review approach as the basis for gathering knowledge for chapter 2. To address my research objectives, I used a systematic review approach, restricting the scope of enquiry to research conducted in the United States and China, as these are two important sourcing geographies for Unilever. I described the steps taken to perform the systematic review, from choice of Scopus as the search database and developing search strings using appropriate key words; to setting search and screening criteria and the data coding approach, thus allowing for the exclusion of irrelevant literature and synthesis of information. A description of the grey literature review to extract evidence on novel methodologies was then provided. Lastly, I explained my choice to conduct semi-structured interviews, the purposeful sampling approach taken and the questions around which these were conducted. This engagement was considered essential to seek out knowledge on emerging methodologies, to understand the effectiveness of tools currently applied on farms and barriers to their adoption.

Chapter 4 – Results

4.1. Introduction

This chapter presents the results obtained from the various methods of enquiry laid out in chapter 3. It describes the findings of the systematic review, grey literature review and interviews, summarising data in charts and tables. The chapter opens with the results of the systematic review search and eligibility screening process, followed by a description of the data coded and extracted from the eligible literature. Next, findings of the grey literature review are described, followed by a description and categorisation of interviews and common themes emerging from these.

4.2. Systematic review

4.2.1. Search and eligibility screening

A systematic review was conducted on the 14th of April 2019, to identify studies conducted in China and the United States. The results from the search and eligibility screening process are illustrated in figure 6, showing the quantity of articles each step represented in relation to the original search yield. The initial results for searches on China and the United States generated 389 articles, 194 (49%) and 195 (51%) respectively. This showed a nearly equal quantity of articles relating to soil health were published during the selected years in each country. Next, 113 intra- and inter-country duplicate articles were removed, 25 (13%) and 88 (45%) for China and the United States respectively. This highlighted a difference in the sensitivity of Boolean searches conducted, with the United States' searches generating almost four times more duplicate results in the title of these articles, indicating these articles were addressing multiple practices.

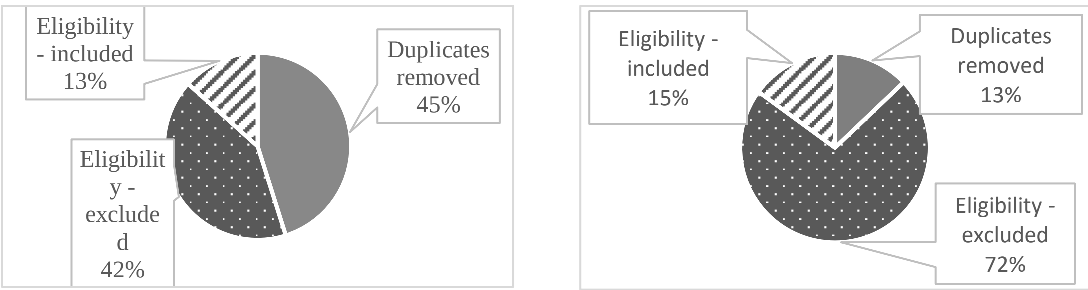


Figure 6 The proportion of articles per step of the systematic review

The eligibility screening applied a series of inclusion and exclusion criteria to cut the list of articles down to only those which met the inclusion criteria. The basic rule of eligibility was the paper needed to involve an experiment applying crop rotation, cover crops, soil amendments (including organic inputs) or tillage to manage compaction, erosion or SOC. These practices could be implemented in combination with other treatments, for example, the study could consider what the effect of alternative tillage and nutrient sources (synthetic versus organic) might be on SOC accrual. An inability to meet this criteria led to the exclusion of 140 (72%) and 81 (42%) of articles from the China and United States searches respectively. Figure 7 lists the main reasons for excluding articles. The largest group, *'Study does not relate to erosion, compaction, SOC'*, contains articles that did not meet the basic rule explained above, otherwise addressing physical, chemical, biological or mechanical properties of soil. Where the motive for exclusion could be clearly attributed to a single feature, like where the objective was to manage pest or weed management, these were separated out.

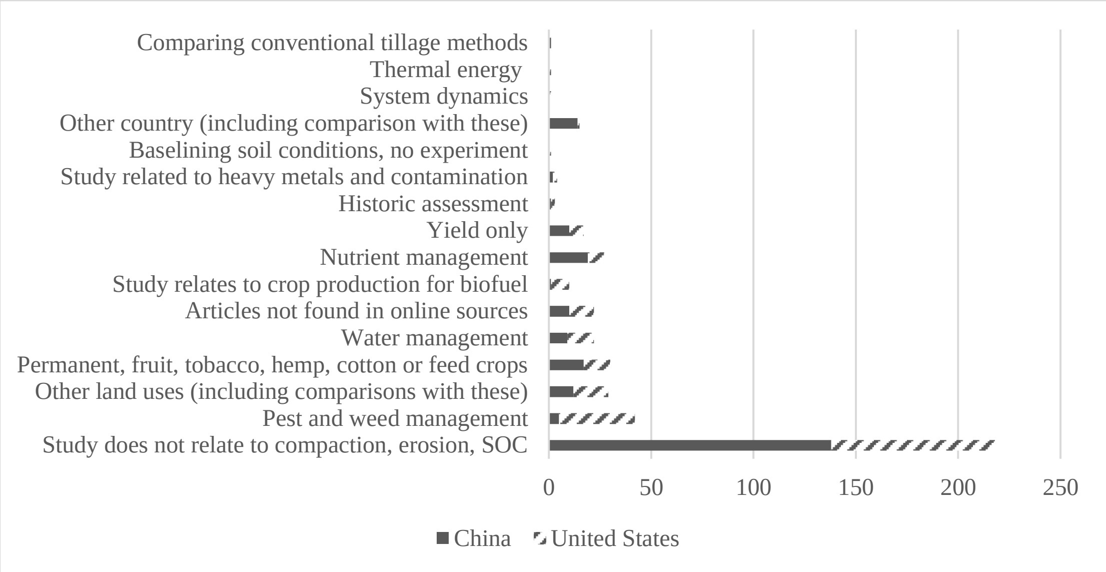


Figure 7 Reasons for excluding articles and count

4.2.2. Articles included

On completion of the eligibility screening, 60 peer-reviewed articles remained. These were the combined work of 274 authors, 231 (84%) of whom contributed to one paper and the remaining 43 (16%) authors contributing towards two or more. Although in the minority, the latter group were associated with 39 (61%) of the articles included in the systematic review. Twelve of these authors were attributed to three or more articles.

Table 8 lists these prominent authors and the associated journals and institutions they are affiliated with. Notably, there was a concentration of authors among the Chinese articles, with 34 of the 43 authors contributing to two or more articles linked to those generated from the Chinese searches. Several institutions were frequently affiliated with authors of the 60 articles; most notable of these were state organisations: the Chinese Ministry of Agriculture with ten attributions, the Chinese Academy of Sciences with eight attributions and the United States Department of Agriculture and Chinese Academy of Agricultural Sciences with eight attributions. Prominent universities affiliated with authors were the Northwest A&F University of China and the Ohio State University, each attributed to five authors.

Table 8 Prominent authors

Author	#	Journals	Article subjects	Institution affiliation(s)
Lal, R.	3	*Land Degradation and Development; Journal of Soil and Water Conservation; Field Crops Research*	Effect of crop residue and tillage treatment of SOC stock	Carbon Management and Sequestration Center, School of Environment and Natural Resources, Ohio State University
Sun, B.	3	*Field Crops Research, Geoderma*	Effect of crop rotation, soil amendments and tillage on SOC stock	Key Laboratory of Mollisols Agroecology, Northeast Institute of Geography and Agroecology; University of Chinese Academy of Science
Wang, H.	3	*Field Crops Research, Land Degradation and Development, PloS ONE*	Effect of tillage on SOC stock	Research Institute of Agricultural Resources and Environment, Jilin Academy of Agricultural Science; Key Laboratory of Crop Ecophysiology and Farming System in Northeast China, Ministry of Agriculture
Yang, X.	3	*Field Crops Research, Land Degradation and Development*	Effect of soil amendments and tillage on SOC stock	College of Agronomy, Northwest A&F University

Twenty-five different journals were attributed to the articles selected. Most prominent were *Soil and Tillage Research* (13 articles), followed by *Field Crops Research* and *Geoderma* with six articles each. Both *Soil and Tillage Research* and *Geoderma* are concerned primarily with soil science research, while *Field Crops Research* aims to publish articles relating to crop ecology and physiology (*Geoderma* 2019; *Field Crops Research* 2019; *Soil and Tillage Research* 2019). As international journals, these tended to maintain a balance of articles originating from studies conducted in the United States and China. Figure 8 visualises the prominent journals with the size of each bubble determined by the number of articles in this selection published therein. The number of articles is also shown within each of the larger bubbles. The colour gradient indicates the impact factor (Source Normalised Impact per Paper (SNIP)), a contextual measure of journal significance calculated by dividing the journal articles cited by the total number of citations for that subject field (Elsevier 2017). This demonstrates that the most prominent journals have the highest impact, as is illustrated here in dark brown.

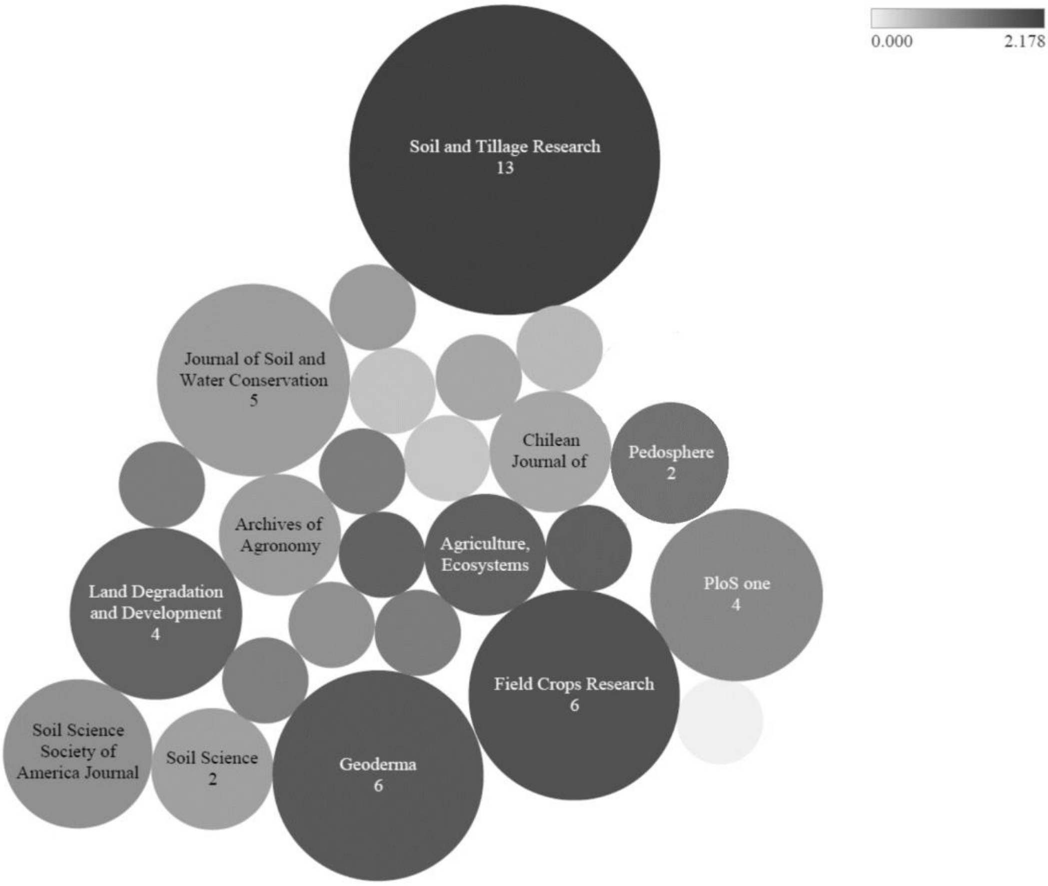


Figure 8 Journals weighted number of articles and SNIP score

4.2.3. Article yield by country

One of the key inclusion criteria was the selection of studies conducted in China or the United States. On completion of the eligibility screening, 60 articles remained and were coded into an Excel sheet for analysis. These articles overwhelmingly sought to assess the effect of a practice on soil organic carbon, generally in combination with other soil parameters like total nitrogen or production measures like yield. Fifty-one articles addressed SOC, while eight looked at erosion and only one at compaction, with a breakdown by country provided in figure 9.

The dominance of articles addressing SOC is in keeping with that observed in the initial search results, prior to eligibility screening. This summary shows that all but two articles from China were addressing SOC, while those from the United States contained papers on erosion and compaction, albeit a small number in comparison.

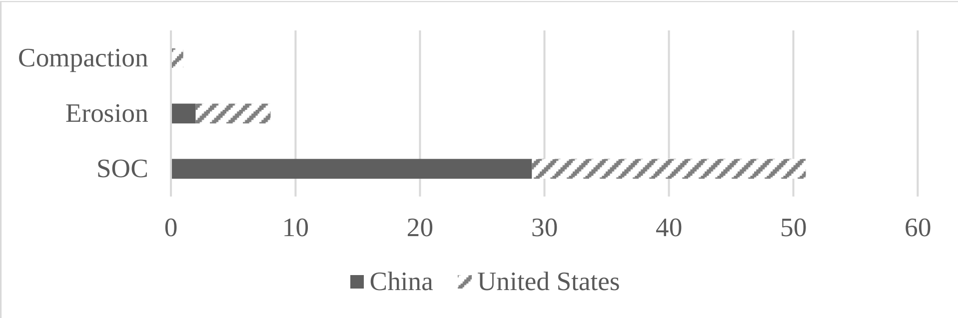


Figure 9 Soil health aspect by country

Nearly two-thirds of the research trials described in articles experimented with two or more treatments compared with alterative treatment(s). Most common of these was a crop residue and tillage combination, observed in 11 articles, crop rotation and soil amendments in nine articles, and crop rotation and tillage in nine articles. Tillage was the most common treatment conducted independently and observed in nine articles. When presented individually, as shown in figure 10, it can be observed that tillage treatments were the most commonly experimented for management of SOC, followed by crop rotations and soil amendments. Cover crop treatments were tested in studies conducted in the United States, but not in China. The term soil amendments is used here in place of compost, as related experiments tended to test a variety or organic and synthetic amendments, with those evaluating effects of compost often doing so in combination with fertiliser or crop residues. Crop residues were another treatment typically applied in combination with soil amendments and because of its frequent occurrence in the literature, has been recognised as a distinctive treatment type in figure 10.

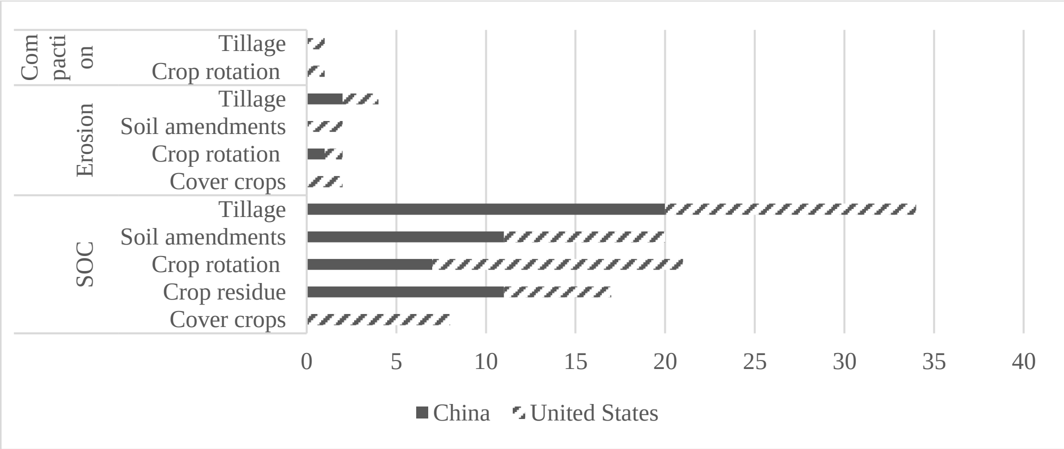
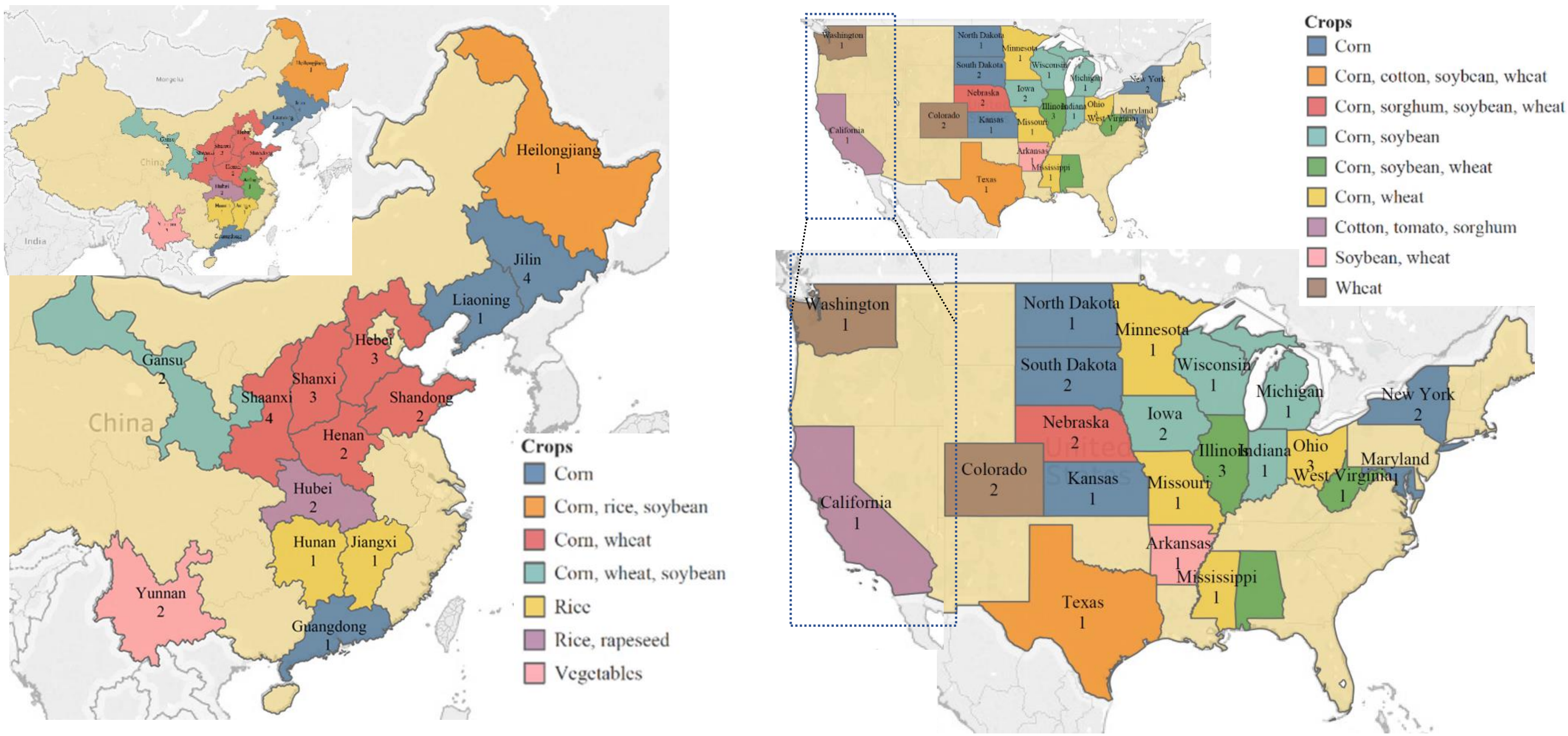


Figure 10 Soil health aspect split by treatment and country

4.2.4. Study locations and crops

Studies were conducted across a number of states in each country, with no clear concentration in any particular one. When viewed at a country-level as shown in figure 11, it becomes apparent that studies were conducted in states often considered as the most productive in each country (Central Intelligence Agency 1986; USDA 2019). Similarities among cropping systems were common across articles, with particular crops dominant in the crop sequence and rotation of experiments. Corn was the main crop in 73% of studies (44 of 60), cropped as continuous corn in 20% of studies and in rotation with wheat 20% of the time. Soybean occurred in rotations in 28% of the studies. The prominence of these crops among experiments aligns with their dominance as top commodities by tonnage output in both countries (FAOSTAT 2019).

Figure 11 provides a spatial representation of studies by state, with colour shading according to the crop or combination of crops in experiments. Although the range of colours suggest a diversity among crops, corn is present in most of these, giving an indication of how widely cropped this is geographically, featuring in studies in 18 of 21 included states in the United States and 10 of 15 provinces in China.



China **United States**

Figure 11 **Spatial representation of studies and crops under trials in China and the United States**

4.2.5. Methodologies applied in literature

Table 9 and 10 provide an overview of the methodologies applied among papers to assess the impact of management practices on compaction, erosion and soil organic carbon. All but one of the Chinese studies used traditional field and laboratory methods with which to collect data and analyse SOC. Studies conducted in the United States contained more methodologies, in part because these also included experiments addressing compaction and erosion. Apart from field and laboratory methods, models were applied in three studies, with two of these utilising data collected from in-field sampling. Although these results depict methodologies attributed to three soil health aspects, most of these studies did apply what King et al. (2017) describe as a whole-systems approach to the experiment, so as to not isolate particular management practices and to emulate what would occur on farms (King et al. 2017).

Table 9 Methodologies for monitoring soil health in China

# Studies	Aspect	Typology	Duration (years)	Sample depth (cm)	Method of collection	Method of analysis
7	SOC	Field & laboratory	9	26	Disturbed or undisturbed soil cores	Dry combustion method
17	SOC	Field & laboratory	8	28	Disturbed or undisturbed soil cores	Walkley-Black method
4	SOC	Field & laboratory	8	26	Disturbed or undisturbed soil cores	Wet digestion method
1	SOC	Field & laboratory	2	40	Disturbed soil cores	Spectral analysis

Note: One study was excluded from this list, as the method of laboratory analysis was not stated. A second study was excluded as this was a meta-analysis, as this was not comparable to other studies. All values were rounded up to whole numbers.

Table 10 Methodologies for monitoring soil health in the United States

# Studies	Aspect	Typology	Duration (yrs)	Sample depth (cm)	Method of collection	Method of analysis
2	Compaction, erosion, SOC	Field & laboratory	20	30	Disturbed soil cores, Penetrometer	Dry combustion
1	Erosion	Field & laboratory	128	9	Undisturbed soil cores	Aggregate stability test using wet sieving technique, single-drop soil splash detachment test, undrained soil shear strength test, bulk density
1	Erosion	Field & laboratory	1	3	Disturbed soil cores	Residue cover, silhouette area index, random roughness, Revised Wind Erosion Equation to measure sediment flux
1	Erosion	Modelling	-	-	-	Agricultural policy/ Environmental eXtender (APEX) model
16	SOC	Field & laboratory	13	33	Disturbed or undisturbed soil cores	Dry combustion method
2	SOC	Field & laboratory	31	30	Disturbed or undisturbed soil cores	Loss on ignition method
1	SOC	Field & laboratory	2	15	Disturbed or undisturbed soil cores	Wet digestion method, Dry combustion method
1	SOC	Field & Modelling	-	-	-	RothC model
1	SOC	Field & Modelling	10	220	Disturbed soil cores	APSIM biochar model
Note: All values were rounded up to whole numbers.						

Tables 11 and 12 provide a breakdown of literature addressing soil organic carbon, showing attributes identified by Nayak et al. (2019) as the essential pre-estimation parameters to accurately assess SOC. A discussion of these results will follow in the next chapter.

Table 11 Articles assessing SOC in China

In-text reference	Treatment	Cropping system & sequence	Research design	Boundary	Baseline	Duration	Sampling method	Sampling depth (cm)	Equal soil mass	Laboratory test
Yang et al. 2017	Crop residue, soil amendments	Continuous corn	RCBD[5]	Plot	Yes	3	Multi-grade sampling strategy	20	No	Dry combustion
Kubar et al. 2019	Crop residue, tillage	Rice-rapeseed	RCBD	Plot	No	9	Undisturbed cores	40	No	K2CrO7[6] oxidation
Si et al. 2018	Crop residue, tillage	Continuous corn	RCBD	Field	Yes	7	Not specified	60	Yes	K2CrO7 oxidation
Wang et al. 2018	Crop residue, tillage	Corn-wheat	RCBD	Plot	Yes	8	Not specified	60	Yes	K2CrO7 oxidation
Wu et al. 2017	Crop residue, tillage	Corn-wheat	RCBD	Plot	No	4	Disturbed cores	20	Yes	K2CrO7 oxidation
Xue et al. 2018	Crop residue, tillage	Corn-wheat	Randomised, plots side by side	Plot	No	5	Disturbed cores	50	No	K2CrO7 oxidation
YIN et al. 2018	Crop residue, tillage	Continuous corn	RCBD	Plot	Yes	11	Disturbed cores	10	No	Lab spectrometer

[5] Randomised Complete Block Design

[6] Walkley-Black method

Tang et al. 2017	Crop rotation	Rice-rice-ryegrass; rice-rice-vetch; rice-rice-potato; rice-rice-rape; rice-rice-fallow	RCBD	Plot	Yes	11	Disturbed cores	20	Yes	Dry combustion
Bughio et al. 2017	Crop rotation, soil amendments	Corn-wheat	RCBD	Plot	No	20	Disturbed cores	160	Yes	Dry combustion
Dou et al. 2017	Crop rotation, soil amendments	Corn; corn-soybean	RCBD	Plot	No	25	Disturbed cores	20	No	Dry combustion
Zhang & Ni 2017	Crop rotation, soil amendments	Broccoli–zucchini–wheat; broccoli–zucchini–fallow	Fully Phased Factorial Design	Plot	Yes	2	Disturbed cores	10	No	K2CrO7 oxidation
Zhang et al. 2017	Crop rotation, tillage	Corn-wheat	Not randomised	Plot	Yes	9	Disturbed cores	40	No	K2CrO7 oxidation
Zhang et al. 2018	Crop rotation, tillage	Continuous corn	RCBD	Plot	Yes	12	Disturbed cores	30	Yes	Chemical lab analysis
Kubar et al. 2018	Crops residue, tillage	Rice-rapeseed	RCBD	Plot	Yes	9	Undisturbed cores	40	No	Wet digestion
Li et al. 2018	Crops residue, tillage	Corn-wheat-soybean	RCBD	Plot	Yes	10	Disturbed cores	10	No	K2CrO7 oxidation
Xu et al. 2019	Crops residue, tillage	Corn-wheat	RCBD	Plot	Yes	10	Disturbed cores	20	Yes	K2CrO7 oxidation
Bibi et al. 2018	Soil amendments	Corn-wheat	RCBD	Plot	Yes	23	Disturbed cores	20	No	Wet digestion
Chen et al. 2017	Soil amendments	Rice	RCBD	Plot	Yes	31	Disturbed cores	20	No	K2CrO7 oxidation
Hu & Xia 2018	Soil amendments	Corn-wheat	RCBD	Plot	Yes	11	Disturbed cores	20	Yes	K2CrO7 oxidation

Liu et al. 2018	Soil amendments	Corn-wheat	RCBD	Plot					No	
Xie et al. 2017	Soil amendments	Corn-wheat	Not specified	Plot	Yes	21	Undisturbed cores	20	Yes	K2CrO7 oxidation
Li et al. 2018	Soil amendments, tillage	Corn-wheat-soybean	RCBD	Plot	No	11	Disturbed cores	10	No	K2CrO7 oxidation
Zhang et al. 2017	Soil amendments, tillage	Continuous corn	RCBD	Plot	Yes	2	Disturbed cores	20	No	Wet digestion
Asenso et al. 2018	Tillage	Continuous corn	RCBD	Plot	Yes	2	Not specified	40	No	Not specified
Du et al. 2017	Tillage	Wheat	RCBD	Plot	Yes	15	Disturbed cores	20	No	Dry combustion
Liu et al. 2018	Tillage	Continuous corn	RCBD	Plot	No	14	Disturbed cores	15	Yes	Dry combustion
Zhang et al. 2018	Tillage	Corn-wheat	RCBD	Plot	Yes	3	Disturbed cores	40	Yes	K2CrO7 oxidation
Zhao et al. 2018	Tillage	Corn; soybean; rice; potato	Not randomised to account for topographical features	Plot	Yes	1	Not specified	20	No	Dry combustion
Zheng et al. 2018	Tillage	Continuous corn	RCBD	Plot	Yes	31	Disturbed cores	60	Yes	K2CrO7 oxidation

Table 12 Articles assessing SOC in the United States of America

In-text reference	Treatment	Cropping system & sequence	Research design	Boundary	Baseline	Duration	Sampling method	Sampling depth (cm)	Equal soil mass	Laboratory test
Nunes et al. 2018	Crop rotation, cover crops, tillage	Continuous corn, grass; corn-ryegrass, red clover, crimson clover, hairy vetch mix	No Data	Plot	No	24	Not specified	15	No	Loss on ignition
Aller et al. 2018	Crop rotation, soil amendments	Continuous corn; corn-soybean; corn-soybean-triticale/ soybean; corn-corn-corn/ switchgrass-switchgrass-switchgrass; continuous switchgrass	RCBD[7]	Plot	Yes	10	Disturbed cores	220	No	N/A
Maas et al. 2017	Tillage	Continuous corn		Plot	Yes	53	RothC Model	25	Yes	RothC Model
Wang et al. 2017	Cover crops	Corn; forage radish	RCBD	Plot	Yes	2	Disturbed cores	105	No	Dry combustion
Beehler et al. 2017	Cover crops	Corn-soybean; cereal rye	RCBD	Plot	No	4	Disturbed cores	60	No	Dry combustion
Mitchell et al. 2017	Cover crops, tillage	Tomato-cotton; sorghum; garbanzo beans	RCBD	Plot	Yes	133	Disturbed cores	30	Yes	Dry combustion

[7] Randomised Complete Block Design

Kazula et al. 2017	Crop residue, crop rotation	Corn; corn-soybean; sorn-soybean-wheat	RCBD	Plot	Yes	49	Disturbed cores	60	No	Dry combustion
Desrochers et al. 2019	Crop residue, tillage	Wheat-soybean	RCBD	Plot	No	13	Disturbed cores	10	N/A	Dry combustion
Kinoshita & Schindelbeck 2017	Crop residue, tillage	Continuous Corn	RCBD	Plot	N/A	40	Disturbed cores	60	Yes	Loss on ignition
Nawaz et al. 2017	Crop residue, tillage	Wheat	RCBD	Plot	No	26	Disturbed cores	15	No	Dry combustion
Aller et al. 2017	Crop rotation	Continuous corn; corn–soybean; corn–soybean–triticale/ soybean–corn–soybean –triticale/ soybean; corn–corn–corn/ switchgrass–switchgrass –switchgrass–switchgrass; continuous switchgrass	RCBD	Plot	Yes	8	Undisturbed cores	10	No	Dry combustion
Romano et al. 2017	Crop rotation, cover crops, livestock grazing of cover crops, soil amendments	Corn-soybean-wheat-kale; grass/ legume	Not specified	Plot	No	14	Disturbed cores	10	No	Dry combustion
Rorick & Kladivko 2017	Crop rotation, cover crops, tillage	Corn-soybean; cereal rye	RCBD	Plot	Yes	4	Disturbed cores	60	No	Dry combustion
Calderón et al. 2018	Crop rotation, soil amendments	Wheat/ pea blend	RCBD	Plot	No	5	Not specified	30.5	Yes	Dry combustion

Blanco-Canqui et al. 2017	Crop rotation, soil amendments	Corn-sorghum-soybean-wheat/ alfalfa	RCBD	Plot	N/A	40	Disturbed cores	100	Yes	Dry combustion
He et al. 2019	Crop rotation, soil amendments, tillage	Corn; corn-wheat; soybean; soybean-wheat	RCBD	Plot	No	6	Disturbed cores	20	No	Dry combustion
Zuber et al. 2017	Crop rotation, tillage	Continuous corn; corn-soybean; corn-soybean-wheat; continuous soybean	RCBD	Plot	No	18	Disturbed cores	20	No	Dry combustion
Alhameid et al. 2017	Crop rotation, tillage	2-year corn–soybean; 3-year corn–soybean–wheat; 4-year corn–soybean–wheat–oat	RCBD	Plot	Yes	23	Disturbed cores	60	No	Dry combustion
Nicoloso et al. 2018	Soil amendments, tillage	Continuous corn	RCBD	Plot	Yes	20	Undisturbed cores	30	Yes	Dry combustion
Stewart et al. 2017	Tillage	Continuous corn	RCBD	Plot	Yes	11	Not specified	120	Yes	Dry combustion

4.3. Grey literature

Grey literature reviews were conducted with the objective to include a wider range of evidence, further to that gathered in peer-reviewed literature. This was performed using two distinct sources: the conference proceedings pertaining to land management and conservation at the 2017 and 2018 ASA, CSSA and SSSA annual conferences in the United States, as well as a sustainability impacts database called Evidensia, the product of a collaboration between organisations including ISEAL Alliance, Rainforest Alliance and WWF.

4.3.1. Evidence derived from conference proceedings

A total of 221 presentations and posters were reviewed, from which six relevant articles were identified, which are listed in table 13.

Table 13 Conference proceedings papers

Session	In-text reference	Title of research	Reason
Symposium--Collaborative Program to Advance Soil Health for Productivity, Economic and Environmental Benefits	Elias (2018)	Market-Driven Adoption of Science-Based Soil Health Practices	Addresses topics of relevance to research question 2
Building Soil Health with Cover Cropping and Crop Rotational Diversity Oral	Zuber & Kladivko (2018)	Using Commercial Soil Health Assessments to Quantify Impact of Cover Crops in Indiana	Addresses topics of relevance to research question 1
Agricultural Management and Soil Health Poster	Singh, Jagadamma & Walker (2018)	Suitability of Current Soil Health Assessment Approaches for the Agricultural Soils of West Tennessee.	Addresses topics of relevance to research question 1
Agricultural Management and Soil Health Oral	Stewart, Jian, Gyawali, Reiter, Badgley, Thomason & Strickland (2018)	What We Talk about When We Talk about Soil Health.	Addresses topics of relevance to research question 1
Agricultural Management and Soil Health Oral	Case-Cohen (2018)	Understanding the Soil Health Knowledge of Farmers in the Yakima Valley	Addresses topics of relevance to research question 2
Soil Health for Agroecosystems Oral	Schonbeck et al (2017)	Soil Health – 15 Year Review of USDA OREI/ORG and OFRF Research	Addresses topics of relevance to research question 2

Two of these studies, Zuber and Kladivko (2018) and Singh, Jagadamma and Walker (2018), assessed the suitability of commercially available assessment approaches in the United States to measure soil health indicators like aggregate stability and soil organic carbon, but found these were not always sensitive to treatments or effective in their interpretation of results back to farmers. Stewart et al. (2018) performed a meta-analysis using the Soil Health Institute's Research Landscape Tool to identify which indicators were most frequently used in cover crop studies to measure change in soil health. They found that while 42 indicators had been used across studies, uncertainty exists over a lack of consensus among studies of what, when and where to measure, while clear baseline measurements were often missing.

Schonbeck et al. (2017) evaluated the results of SOM research conducted on organic farms between 2002 and 2014, finding that more reliable and practical measurement tools to detect the outcomes of management practices are required, as are practical recommendations for farmers by geographical region, on optimum SOM levels in accordance with the soil type and texture, climate and production system.

The remaining three studies contained a description of some of the barriers preventing farmers from adopting soil health practices, some of which can be transposed for consideration in the context of a VSS-led initiative. Elias (2018) explained the importance of incentives to encourage rental farmers to adopt soil health practices, as while both non-operator landowners and farmers had positive attitudes towards soil health, a mechanism to facilitate adoption was missing.

In a study to investigating the soil health knowledge of farmers in the Yakima Valley in Washington State, Case-Cohen (2018) distinguishes between two distinctively different epistemologies in how scientists and farmers accumulate and interpret knowledge. In this framework, farmers are considered to hold implicit knowledge, gained through trial and error experiences, and shared between generations and communities. With this consideration, it becomes clear that if farmers are to embrace science-based practices and methods to measure change, these need to be provided in the form of accessible resources and demonstrated for farmers to visualise the effects of such practices and to interact with one another in an informal way.

4.3.2. Evidence derived from Evidensia

A total of 80 studies were generated by applying filters for the date of publication and limiting the scope of the search to studies relating to the agricultural sector. From here, the inclusion criteria as listed in table 6 were applied, to remove studies that did not comply with these, which left just one paper in scope. The absence of research to measure the outcomes of soil health was the primary issue resulting in this limited finding. Furthermore, much of the evidence is concerned with measuring adoption of practices as a measure of impact rather than outcomes, while the focus of research tended to be around social issues. In the cases where environmental issues were in scope, these related primarily to deforestation.

The study that was identified was a systematic review by Petrokofsky and Jennings (2018) assessing the effectiveness of standards to encourage the adoption of sustainability practices. Although this study did not try to measure outcomes of practices, barriers to adoption of VSS were described. The most important of these was when there existed a gap between existing practices and requirements of the standard, especially among smallholder farmers and those in developing countries, where access to technical, financial and institutional support may be lacking. This issue was no doubt have implications for the adoption of soil health practices, and is thus considered relevant to this research.

4.4. Semi-structured Interviews

Interviews were conducted to obtain the opinion of practitioners and experts in the field of soil science, persons who work in the standards industry and those involved with setting of agricultural measurement decision-support tools. This engagement was motivated by the need to triangulate trends observed in the literature featured in the systematic review. It also served to uncover the perspectives of persons operating outside of academic circles, where experimentation of emerging techniques may be underway. Table 14 provides a list of participants and a non-exhaustive description of their area of expertise.

Table 14 Interview participants

Participant	Role	Organisation	Area of expertise
Carlson, S	Strategic Initiatives Director	Practical Farmers of Iowa	Field trials, cover crops, agronomy
Jiang. Feng	Procurement manager, North Asia	Unilever	VSS, sustainable sourcing
Kulak, M (Dr)	Sustainable Investing Analyst (former Environmental Sustainability Scientist at Unilever)	RobecoSAM	Modelling and simulation, life-cycle assessment, corporate sustainability

Kuneman, Gijs	Director (former Director at Centrum voor Landbouw en Milieu (CLM)	Bosgroep Midden Nederland	VSS, farm decision-support tools
Ma, M	Consultant (former Director of Solidaridad China)	Scofield Consulting	VSS, sustainable sourcing
Millie Grant, S	Senior Manager: State Government Relations & External Affairs	Unilever	Multi-stakeholder initiatives
Morgon, C (Dr)	Chief Science Officer	Soil Health Institute	Soil science (hydrology, soil, soil security)
Rushton, J	Farm Sustainability Assessment Programme Lead	SAI Platform	VSS, farm decision-support tools
Thomson, A	Science & Research Director	Field to Market	Modelling and simulation of farm environmental impacts, field trials
Wilcox, A	Sustainable Sourcing Manager	Unilever	Remote sensing

Interviews were conducted with participants over Skype and loosely followed a predefined sequence of questions to elicit opinions and uncover new information. The focus of these conversations varied depending on the participant's knowledge area. In this way, questions were used as a starting point, to explore topics in further depth. Table 15 denotes the topics that each interview participant gave insights on, illustrating how varied the focus of each interaction was. A summary of key insights is provided in the following sections (4.3.1 to 4.3.4).

Table 15 Classification of knowledge exchanged during interviews

Participant	**Research Question 1: Methodologies**					**Research Question 2: Barriers to adoption**
	In-Field & Lab Analysis	**Modelling**	**Remote-sensing**	**Smartphone Application**	**VSS & Assurance**	
Carlson, S		x				x
Jiang. Feng					x	x
Kulak, M (Dr)		x				
Kuneman, Gijs		x				x
Ma, M					x	x
Millie Grant, S						
Morgon, C (Dr)	x			x		
Rushton, J					x	x
Thomson, A		x				
Wilcox, A			x			x

4.4.1. Model of assurance

When asked what methods participants would recommend for measuring the effects of management practices on soil health, this question was framed in the context of farmers implementing the Sustainable Agriculture Code, or other Voluntary Sustainability Standard. With this perspective, Andrew Wilcox, Gijs Kuneman and Joe Rushton were of the mind that modelling tools may be most appropriate for calculating the effects of practices, validated every few years with in-field sample and laboratory analysis (A Wilcox 2018, personal communication, 16 November; G Kuneman 2019, personal communication, 9 January; J Rushton 2018, personal communication, 5 December). In this way, a research programme could be designed to simulate the effect of interventions for a greater number of farmers, permitting investigations to be conducted at scale, across one or multiple landscapes.

4.4.2. Out of field methods

During interviews, participants pointed to several tools to measure and estimate change in crop and soil variables. Wilcox pointed to the existence of a geospatial tool, the Soil Moisture Active Passive (SMAP) satellite (A Wilcox 2018, personal communication, 16 November). SMAP is a NASA instrument that measures the amount of water content in the top 5cm of soils globally every three days, providing the early warning detection of droughts and floods and predictions of agricultural productivity (Enrekhabi *et al* 2014). The tool has also been modelled to show how the earth seasonally takes up and releases carbon (Alaska Satellite Facility SAR DAAC 2014). In addition, Morgon identified the SLAKES mobile application for assessing wet aggregate stability, a measure of the erodibility of soil.

Sarah Carlson is the technical lead on Practical Farmers of Iowa’s (PFI) cost-share cover crop programme being executed with soybean farmers on behalf of Archer Daniel Midland, Unilever and partners (S Carlson 2019, personal communication, 2 July). In this project, remotely sensed imagery is used to count the area under cover crops. Elsewhere, PFI is trying to calibrate the signature to the height of the cover crop, to estimate biomass, with the results of this experiment yet to be determined.

Several predictive models are available to measure soil erosion, with global or regional applications. During his interview, Dr Michal Kulak provided the example of the open-source software tool, called InVEST – the integrated valuation of ecosystem services and tradeoffs (M Kulak 2019, personal communication, 16 June). These spatially explicit models combine mapping with programming language, to return estimations of average annual soil loss or retention at multiple scales. When used in a project setting, this tool can be deployed to produce time-sensitive estimates of change in response to different management practices. For example, by uploading satellite imagery depicting a land parcel under different crops or by adjusting input variables like tillage and nutrient sources, the model will calibrate the soil loss avoided accordingly.

Carlson gave examples of further open-source models for application (S Carlson 2019, personal communication, 2 July). The Revised Universal Sol Loss Equation or RUSLE2 model developed by the United States Department of Agriculture, estimates erosion at field-level based on user inputs regarding climate, soil, topography and land use. caused by rainfall (USDA 2016). While this static tool is available for download and use independently, the Daily Erosion Project's adaptation of the WEPP Model by Iowa State University, provides daily updates of erosion potential to interested parties, via their web-based platform. One limitation Carlson identified with the RUSLE2 model was that it does not take into consideration how plants effect the soil as much or differently to tillage. As such, the model would fail to reflect the benefit from applying cover crops, for example (S Carlson 2019, personal communication, 2 July).

Thomson described two predictive models in the Fieldprint Calculator that assess soil carbon and erosion, adapting tools developed by the USDA ARS for use by farmers (A Thomson 2019, personal communication, 12 July). The Soil Conservation tool measures soil lost to erosion from water and wind, reported as tons of soil lost per acre. Dissimilarly, the Soil Carbon model is more simplistic, predicting the likelihood of carbon increase, decrease or stability using a directional unitless scale.

LCA models for predicting change in soil carbon are also available, such as the RothC Model referred to by Gijs Kuneman (G Kuneman 2019, personal communication, 9 January). The model estimates the turnover of organic carbon in aerobic soil based on soil type, temperature, moisture and crop (Nayak *et al* 2019). Dr Kulak also referred to the carbon sequestration section of the Cool Farm Tool, a greenhouse gas accounting tool from farmers. This section models the carbon impact of cover cropping, tillage and land use change, should any of these parameters have changed in the last 20 years and is thus able to attribute an estimated value to this action. However, both Kulak and Carlson acknowledged challenges in accounting for the impact of spatial and temporal anomalies on carbon accrual, saying it would be difficult to measure accurately in open cropped systems, where farmers are not restricting their management decisions to a fixed set of experimental factors. Carlson commented that efforts to manage soil health would be better served reducing sources of impact, thus building organic matter and protecting soils from erosion, which should as a consequence increase carbon (Personal communication, 2 July).

Neither Ma nor Jiang, two participants interviewed for their knowledge of VSS and sustainable sourcing in China, were aware of tools developed for the Chinese market that could be used as methods to measure the outcomes discussed in this thesis.

4.3.3. Soil health measurements and VSS

Four interview participants have experience working with the Sustainable Agriculture Initiative (SAI) platform’s Farm Sustainability Assessment (FSA), an industry-harmonised assessment and assurance tool to market aligned sustainable agriculture practices. Joe Rushton, the FSA Programme Lead, spoke about the increasing level of awareness on issues effecting soil health among the FSA member base (J Rushton, personal communication, 5 July).

When asked whether methodologies to measure changes in soil health could be incorporated into a standard framework, Rushton indicated that although some standards do require the testing of soil parameters, the soil management practices addressed by this research are not typically required as a precondition to compliance. It therefore stands to reason that uptake of these management practices would need to be promoted through initiatives that go beyond basic compliance with a standard. Still, if they were to be administered to some extent by VSSs, Rushton indicated that measurement could be taken for a sample of farmers implementing management practices. He further added that a pragmatic approach to sampling from a smaller, less representative sample but to a higher degree of accuracy, would be preferable to sampling from a larger, more representative sample to a lower degree of accuracy.

4.3.4. Barriers to adoption of practices

When asked what the principal barriers to adopting soil management practices are, Carlson said incentives. She elaborated saying there is ample agronomic support available to farmers growing crops, but to adopt cover crops or other best practice approaches, farmers require as much if not more support. However, at the moment there is no economic incentive for the private agricultural sector to provide technical support to facilitate this adoption. As such, farmers are receiving limited support from other farmers, membership organisations like PFI, government programmes or University extension services where available.

In the context of VSS, Rushton suggested that instead of emphasising environmental benefits to inspire the adoption of soil management practices among farmers, economic benefits, like higher yields and cost-savings achieved by applying fewer inputs, may be more effective. As a consequence, the environmental improvements would materialise as a secondary outcome.

4.5. Conclusion

In this chapter, I explained the findings of the systematic review, grey literature review and semi-structured interviews. This opened with a description of the systematic review process whereby, through a process of eligibility screening and the removal of duplicate results, the number of papers was reduced from 389 to 60. This result was predicated on a rule that, to be included, a paper needed to apply one or a combination of crop rotation, cover crops, soil amendments or tillage soil management practices for the treatment of soil organic carbon, erosion or compaction. Of the 60 papers, 51 applied treatments for the management of soil organic carbon (SOC), while eight were concerned with managing erosion and the final one related to compaction. Nearly two-thirds of experiments involved two or more treatments, with crop residue and tillage management most combined. When considering the four practices of interest, treatments involving tillage practices were most commonly applied, of which 34 papers used this to manage SOC. When considering the methodologies used to measure the effects of soil management practices, most of the papers applied traditional in-field soil sampling techniques and laboratory analysis approaches, while a few applied models to predict change to soil parameters. All the studies were of field trial experiments, most frequently conducted within controlled settings, like a university research station. In all cases, the primary objective was to assess the effectiveness of treatments in managing a soil feature, like erosion, rather than comparing methodologies most suited to measuring this.

I also described the grey literature review of conference proceedings, examining 221 presentations and posters, from which six relevant articles were identified. Two studies assessed the fitness of commercially available assessment methods in the United States to measure soil health indicators. A meta-analysis of measurement tools for cover crops found a lack of consensus among studies of what, when and where to measure; while a fourth study evaluating the findings of research on soil organic matter concluded that practical recommendations for farmers on the optimum SOM by geographical region was needed. The remaining three studies dealt with barriers to farmer adoption of soil health practices, with the need for incentives, knowledge and resources to understand the benefits of unfamiliar or novel practices. In addition to conference proceedings, an evidence database for VSS called Evidensia was reviewed, from which a systematic review assessing the effectiveness of standards to encourage the adoption of sustainability practices was identified. This highlighted barriers to adoption of sustainable practices, as gaps in technical, financial and institutional support.

Finally, I conducted ten interviews with subject matter experts to triangulate trends observed in the literature and to obtain the opinions of practitioners working directly with farmers and farmer-centric programmes. Several topics were discussed, ranging from how methodologies to measure outcomes could be coupled with VSS and suitable predictive modelling tools to estimate change, to barriers to adoption. All together the research enquiry yielded a rich layer of evidence, reflective of academic literature, as well as literature and perspectives from practitioners working more directly with farmers.

Chapter 5 – Discussion

5.1. Introduction

This research explored methodologies to evaluate soil management practices and their effect on compaction, erosion and soil organic carbon. To investigate the range of available methods, a systematic review was performed but showed the application of a relatively narrow set of in-field sampling and laboratory analysis methods, primarily measuring soil organic carbon. Since the review was conducted using peer-reviewed literature, the majority of studies related to field trials performed under controlled experimental conditions. These studies tended not to explain the reasons for selecting one methodology over another, as their objectives were to assess the effect of practices or a combination thereof on the physical or chemical parameters of soil. Resulting from this enquiry are insights that apply to field trials, but not necessarily to the use of methodologies that are appropriate to a real-world farm setting or VSS applications.

A systematic review of grey literature formed the second line of enquiry, providing information on recent and emerging research and experiments, presented at conferences and documented in reports.

Finally, interviews conducted offered an invaluable bridge between theory and practice, through the engagement of experts on measurement tools, standards, soil science and farmer engagement. Although originally intended to provide a secondary source of knowledge to gain insight to findings of the systematic review, interviews facilitated the exploration of measurement tools underrepresented or absent from the literature, namely models.

This discussion interprets these findings and their implications for managing soil in the context of a standard like Unilever's SAC. The limitations of the research methodology and subsequent results are described, to point out gaps in knowledge and assumptions made. With this accumulated knowledge, recommendations are made and measures are presented in a logical framework format in accordance with a monitoring and evaluation system. This chapter is structured by order of the research questions, to consolidate findings from the systematic review, grey literature and interviews.

5.2. Methodologies for measurement of soil organic carbon

The primary research question of this thesis sought to establish methodologies that can be used to detect the outcomes of good soil management practices. One of three soil aspects in the scope of this enquiry is soil organic carbon, to be discussed in this section. The systematic review showed 85% of studies were concerned with experiments to manage soil organic carbon and rarely other chemical, biological and physical parameters. The prominence of soil organic carbon may be a consequence of the contemporary publication years selected, during a period of heightened awareness of the mitigation potential soils could offer against climate change (Zomer et al. 2018). Indeed, nearly a half of the literature drew this connection, signalling it could be a motivating factor of the research.

When comparing studies conducted in the United States and China, similarities were observed among crops under production, with corn featuring in 73% of studies, indicative of its dominance as one of the most commonly grown crops in both countries (FAOSTAT 2019). Treatment combinations were more numerous in US studies than in Chinese studies, with 12 and eight combinations, respectively. As a consequence, the US studies may prove to better emulate a real-world farm setting, where farmers typically introduce more than one new practice simultaneously (S Carlson 2019, personal communication, 2 July). Apart from literature in the systematic review, interviews identified alternative methods for monitoring SOC, in the form of models.

Of the methodologies used in studies selected through the systematic review, those conducting in-field sampling and laboratory analyses were most prevalent. This finding is perhaps unsurprising, as these are tried and tested techniques, accepted by the scientific community and commonplace to soil science research trials. Unfortunately though, no discussion as to why particular methods were used over others was given in papers, with authors merely stating the method applied. Despite this lack of explanation, the prominence of a few techniques gave credence to their status as reliable methods, as did their use in articles published in peer-reviewed journals. The following sections describe methodologies for measurement of SOC in further detail.

5.2.1. In-field sampling and laboratory analysis of SOC

For the assessment of studies conducting in-field and laboratory analyses, pre-estimation parameters as defined by Nayak et al. (2019) were used. This is because the study is a recent publication, investigating current and emerging methodologies with which to measure SOC and is therefore is assumed to reflect the latest body of science. The pre-estimation parameters referred to are a set of variables required to adequately predict the carbon stock of soil. These parameters are deemed critical in understanding the robustness of research to ensure this complies with best practice approaches for measurement of SOC and that results are be interpreted correctly.

In gathering this evidence, the parameters least reported on were the baseline value of SOC prior to the experiment and whether bulk density corrections had been applied in calculation of the SOC stock. In the United States, 44% of studies did not report a baseline value, compared with 27% among Chinese studies. Despite this, some of these studies compared the effects of multiple treatments against each other, thus eliminating the need for a baseline value. As for the reporting of equal soil mass, the opposite was true, with more studies from the US failing to report bulk density corrections (48%), compared with 30% among Chinese studies. These exclusions present gaps in knowledge when interpreting the results, leaving room for assumptions that could otherwise have been avoided. Nevertheless, the exclusion of these parameters does not invalidate their findings, as they are to be read within the limits of the research design.

In-field samples were performed by way of disturbed or undisturbed soil cores, with undisturbed cores taken to prevent contamination between soil layers, while disturbed samples were permissible to determine physical parameters like aggregate-size distribution (Nicoloso et al. 2018). For the measurement of SOC, these core methods are commonplace, for their time efficiency over other methods like open pit sampling, allowing for more samples to be collected with greater accuracy, especially in spatially diverse sites (Davis et al. 2018 in Nayak et al. 2019).

The other parameters described by Nayak et al. (2019) were frequently addressed by studies. The research design approach used in nearly all experiments in both countries was randomised complete block design with replicates, which reduces the effect of spatial variation and the risk that results are the product of chance (Rzewnicki 1992). All studies defined the boundary of the experiments, with all but three taking place on plots at research stations. The duration of studies varied significantly, with Chinese studies averaging 15 years versus 28 years for those from the United States. This significant difference can be attributed to the presence of four longitudinal studies ranging between 40 and 133 years among the USA literature. Dissimilarly, the longest duration among Chinese studies is 31 years. Study duration is an important factor among parameters effecting SOC sequestration, as has been discussed in chapter 2. This is because the rate of accumulation changes over time and the point at which soils reach a new equilibrium under management practices can vary from 25 to over 100 years. As a result, while studies often do measure the SOC stock at varying time intervals, it should not be assumed that these rates of accumulation can be sustained indefinitely.

Another distinction between the USA and Chinese studies were the method of analysis chosen. The wet chemical oxidation method, or Walkley-Black method, was utilised by 57% of Chinese studies but found to be absent among USA studies. Unlike the wet and dry combustion methods, Chen et al. (2015) describe the Walkley-Black method as rapid and requiring limited equipment, making it the most widely reported procedure for several decades. However, this approach has been attributed to widely variable recovery of SOC and requires the use of hazardous chemicals. Dissimilarly, 85% of USA studies reported use of the dry combustion method, which is characterised as simple and accurate, yet more expensive given its reliance of machinery and consumables (Chen et al. 2015). Moreover, the dry combustion method simultaneously measures nitrogen and sulphur. For these reasons, Chen et al. indicated the Walkley-Black method is being replaced by the dry combustion method in many countries, which may explain its absence from USA studies. Other methods of laboratory analysis used were the loss-on-ignition technique (Kinoshita & Schindelbeck 2017; Nunes et al. 2018), the wet oxidation method (Bibi et al. 2018; Kubar et al. 2018; Zhang et al. 2017; Zhang et al. 2018) and the use of a spectrometer (Yin et al. 2018).

Beyond this consideration of the direct research design features underlying in-field sampling and analysis and the implications thereof, contextualising the results in relation to the sequestration potential for the region helps researchers understand their implications (Zomer et al. 2017). Unfortunately, studies often neglected to do this, perhaps due to a focus on comparing treatment outcomes within the boundaries of a defined plot under fixed conditions. Although, by not contextualising these results in light of spatial thresholds, studies fail to acknowledge the role this inhibiting factor could have on the future sequestration response of soil under such treatments in that region.

A global assessment of SOC distribution shows it predominantly exists at northern latitudes, chiefly in permafrost and moist boreal ecoregions (Zomer et al. 2007). Since SOC accumulation is lower in hotter and drier climates, the western half of the United States tends to hold lower concentrations of it than does the eastern half which experiences a cooler, wetter climate. Similarly in China, the western half of the country sustains lower concentrations of SOC compared with the eastern half (Zomer et al. 2017). However, concentration of SOC in the top 30cm of cropland soils does vary considerably, with tonnes of carbon per hectare among the eastern states of the United States ranging from 51 to 100 and higher rates accruing among north-eastern States. To this point, Thomson argued that if farmers were to adopt measures to increase SOC, they would need knowledge of what levels could realistically be attained, to set goals accordingly (A Thomson 2019, personal communication, 12 July).

In discussing available methodologies to measure SOC, Carlson stated that while the in-field measurement of carbon may be suitable for field trials at research stations, replicating such experiments on a working farm would be challenging, as these would not be designed and executed to the same level of rigour (S Carlson 2019, personal communication, 2 July). She explained that in reality, farmers usually trial multiple new treatments simultaneously, without following strict methodological procedures. This means that any observed findings may be affected by biases, since the influence of spatial variation among soil parameters (e.g. bulk density) and features of the field (e.g. slope) may not have correctly been accounted for, if at all. Furthermore, conducting experiments under controlled conditions of a sufficient duration to detect changes in SOC would be challenging, as farmers may have competing priorities that would not permit such time-bound commitments.

In discussing the appropriateness of in-field methodologies, experts were sceptical of whether these could be applied within a standards system (G Kuneman 2019, personal communication, 9 January; J Rushton 2018, personal communication, 5 December; S Carlson 2019, personal communication, 2 July). Given that standards already require that farmers adopt a broad suite of agronomic, management, social and environmental practices, burdening them with additional data collection obligations may present challenges, like how to finance the measurement and analysis of soil samples, the need for capacity-building, the deployment of systems in which to report data and questions of how to assure and validate the data. Instead, Kuneman put forward the idea of using models to estimate change in SOC, which could be validated through in-field soil sampling and analysis for a representative sample of farms. The use of models for SOC measurement was thought to be much more suitable and is discussed further below.

Although conducting scientific field trials in open farm systems is an unsuitable option, there are frameworks that have adapted scientific methods for practical application, such as the Cornell University's Comprehensive Assessment of Soil Health (CASH). This offers farmers a multi-indicator package designed to help evaluate the monetary value of land, identify management practices to improve performance and to educate farmers on soil management and protection (Schindelbeck et al. 2008). A step-by-step training manual highlights strategies for managing soil health, by using a scoring framework to assess the condition of physical, chemical and biological features of the soil. Farmers are given a protocol against which to take soil samples and these are sent for laboratory analysis. The service is offered through several packages, of which the basic package analyses five indicators including soil organic matter at $60 per sample (Cornell n.d; Gugino et al. 2014).

Apart from assessing the state of soil parameters, CASH provides a series of resources to help farmers select practices that target indicators of soil health and resources to interpret returning test results. Yet, despite their accessibility, studies to assess the sensitivity of these integrated assessment frameworks have found they are not always sensitive enough to differentiate between the treatments (Singh, Jagadamma & Walker 2018, Zuber & Kladivko 2018). In the study by Zuber and Kladivko (2018), soil samples were collected from fields under cover crop plus no-till treatments and those only under no-till treatments, and sent to four commercial soil health assessment laboratories for comparison of the results. A range of biological, physical and chemical indicators were tested, with different combinations measured by each commercial laboratory. Overall, results showed limited significant change between the baseline year and subsequent years, which could be because laboratory tests are not sensitive enough to measure differences between treatments, or that soil improvements in response to treatments had occurred before the experiment was conducted. Alternatively, climatic variations and a lack of consistency among indicators assessed by each laboratory could also be responsible for the limited overall results (Zuber and Kladivko 2018). A second study assessing the suitability of soil health assessments found that the Haney Soil Health Test scores for biological parameters provided inconsistent responses to treatments and were unable to differentiate between tillage treatments (Singh, Jagadamma & Walker 2018). These findings do cast doubt over the suitability of various soil health assessments, with no clear indication on whether one may provide more sensitive results than the other.

In their appraisal of in-field and laboratory based research measuring improvement in soil organic matter in response to soil health practices, Schonbeck et al. (2017) concluded that, to improve performance, more reliable and practical measurement protocols are needed for farmers, along with practical guidelines that provide optimum levels specific to the soil type and texture, climatic conditions and the production system.

5.2.2. Modelling SOC

Although the systematic review predominantly contained literature on experiments predicated on in-field and laboratory analysis techniques, two studies utilised models to test their hypotheses. Dissimilar to direct measurement approaches, models require only a limited range of input data (e.g. kg of fertiliser applied), to predict the relative effect of a practice or practices on the variable in question, like carbon dioxide equivalent greenhouse gases emitted per hectare of cropped area (Nayak et al. 2019).

Maas et al. (2017) used the Rothamsted Carbon model (RothC) to process soil data from research plots under different tillage regimes together with climate data, to project future SOC content in agricultural soils using low- and high-emissions climate change scenarios (Coleman & Jenkinson 2014). The model calculates total organic carbon, microbial biomass carbon and SOC over various timescales, with only several input data points needed, which are all readily available. It is one of several available computer simulation models to contain a soil carbon cycle component, but RothC was found to have a high number of citations among published studies, giving integrity to its output (Maas et al. 2017). The model can predict change at intervals as little as a month apart through to wider time steps of a year or more, ideal for modelling change in SOC, considering the slow pace of change (Coleman & Jenkinson 2014). Moreover, it can be applied globally, using input data specific to the plots at the study location.

During interviews, experts spoke of the suitability of models for programmes designed for the engagement of farmers, given their adaptability, accessibility and ease of use (A Thomson 2019, personal communication, 12 July, A Wilcox 2018, personal communication, 16 November; G Kuneman 2019, personal communication, 9 January). Several internet-based tools with the capacity to estimate changes in SOC exist and are free to use, like the RothC model, the CENTURY-5 model and the Field to Market Soil Conditioning Index (A Thomson, personal communication, 12 July; S Carlson 2019, personal communication, 2 July). These range in spatial relevance, methodology and design. For example, the Cool Farm Tool greenhouse gas calculator models the effect of changes in land use, tillage and cover crops in the calculation estimation of a farm's carbon footprint (Hillier et al. 2011). Dissimilar to the Cool Farm Tool's life-cycle assessment approach, the Field to Market Soil Conditioning Index is a dedicated soil carbon tool that utilises a qualitative and directional approach. The distinctions between tools identified during interviews are discussed below.

5.2.2.1. Cool Farm Tool

The Cool Farm Tool's greenhouse gas calculator is a lifecycle assessment decision-support tool for farmers, built using several empirical greenhouse gas quantification models, leveraging hundreds of peer-reviewed studies (Aryal et al. 2015). It relies on input data on climate and soil characteristics, agronomic inputs, energy use and other management practices, to produce a context-specific footprint per crop under production. The calculator accepts input data for an extensive range of management practices, including cover cropping, reduced or no tillage and residue management (Cool Farm Institute 2013). For changes to land use, tillage and cover crops, the tool has a cut-off period of 20 years, beyond which it will not calculate results. The tool also requires that input data be given as the percentage of the field affected, to reflect cases where changes affect a portion of the cropped area only.

As the tool models the full suite of on-farm activity, it can be used to calculate the total kilograms of carbon dioxide equivalent (kg CO2e) emitted or sequestered (M Kulak, personal communication, 16 June). Moreover, the tool provides a breakdown of emissions by source, with the aim to help farmers identify key drivers of emissions to prioritise in emission reduction initiatives. It is therefore possible to conduct trend analyses and the calculation of directional change in kg CO2e, for example a five-year trend may show that the adoption of reduced tillage led to a 20% reduction in emissions. Although the scientific approach for accurately modelling change in soil carbon is still developing, the Cool Farm Tool can model change in SOC for the practices investigated in this thesis (D Malin, personal communication, 24 July). Moreover, Unilever already mandates its use by suppliers and their farmers implementing the USAC, making this an appropriate tool for measuring the effect of soil health practices on SOC, using the unit of kg CO2e as a proxy for this.

5.2.2.2. Fieldprint Calculator Soil Carbon metric

The Field to Market's Fieldprint Calculator contains a range of sustainability measurement decision-support tools for use by farmers in the United States. These include the Soil Conditioning Index (SCI), which was originally developed by the USDA National Resource Conservation Service (NRCS). Thomson explained that when investigating available models to measure soil carbon, the challenges to accurately quantify SOC led to Field to Market's selection of a qualitative tool providing a directional measure of SOM (A Thomson, personal communication, 12 July). The SCI is a predictive tool to estimate whether management practices lead to the loss, maintenance or gain in SOM (not SOC) at the field level (Soil Quality Institute 2003). The tool is based on three main components: the organic material factor, the field operations factor, and the erosion factor, as well as other considerations. To perform a calculation, it requires data on field location, soil texture, crops in rotation, the yield for each crop, the application and type of fertiliser treatments, any additional organic matter applied and the rate of wind and water erosion. In response, the tool returns values for each factor, as well as a combined SCI.

If the tool produces a negative value, the level of SOM is forecast to decrease under the production system, while the opposite applies if a positive value is generated (Soil Quality Institute 2003). Values close to zero imply that SOM will be sustained near the present level. Unitless scores along a continuum of -1 and 1 are calculated, with higher scores giving greater confidence that a trend in SOM will be significant. However, the results do not predict the quantity of organic matter nor the rate of change. Nevertheless, the tool can help farmers to better understand the likely benefit of adopting good soil management practices. It therefore serves as a viable tool to engage farmers with but is unable to quantify the effect of practices on soil carbon.

5.2.2.3. InVEST Carbon Model

Stanford University's integrated valuation of ecosystem services and tradeoffs (InVEST) Carbon model is another tool that was mentioned for its potential relevance to measure SOC storage at farm level (M Kulak 2019, personal communication 16 June). However, on investigation the tool was determined to be for use at ecosystem-level assessment of carbon storage densities, under different land uses and land covers, making it unsuitable for simulating change at the farm or field level (Sharp et al. 2015).

5.3. Methodologies for measurement of soil erosion

Compared with the findings of the review for SOC, just seven studies were located that related to soil erosion. Five of these applied to research conducted in the United States and two to China. Of the seven, five were conducted through research trials at a plot level (Acikgox et al. 2017; Adeli et al. 2017; Zhang et al. 2018; Sharrat & Schillinger 2018; Pi & Sharratt 2007), one modelled the costs and environmental benefits of cover crops to reducing erosion (Roth et al. 2018), while another was a meta-analysis of the effects of reduced and no-till in controlling water erosion in China (Jia et al. 2019). Further to this, interviews identified landscape and field-level models, with applicability to the United States or globally.

5.3.1. In-field sampling and laboratory analysis of erosion

5.3.1.1. Scientific field trials

Although only seven studies in the systematic review addressed erosion, all of the soil management practices investigated were present among these. In six of these, erosion was the central issue of concern, while the remaining study dealt with erosion in a minor capacity. For all studies, the same pre-estimation parameters of Nayak et al. (2019) collected for SOC were applied in the extraction of evidence. In terms of the focus of these studies, three were distinctly concerned with wind erosion, one with water erosion and the remainder with the erodibility of soil.

Four studies were designed around field trials that conducted in-field sampling to gather data for further analysis. These studies used different soil properties to assess erosion under different management practices. Acikgoz et al. (2017) took undisturbed soil cores to measure aggregate stability, soil splash detachment, bulk density and soil strength in response to different continuously cropped systems. Each component reflected a particular physical characteristic of the soil, like aggregate stability, which is the measure of a soil's ability to resist degradation from external forces like wind, water or the mechanical actions of tillage (Amézketa 1999). Moreover, interactions between these are useful to understand, like the relationship between shear strength and bulk density, which can affect water infiltration and runoff (Acikgoz et al. 2017).

Similar to Acikgoz et al. (2017), the experiment conducted by Adeli et al. (2017) sought to improve soil structure, although this was attempted through a change in tillage and the application of poultry litter. Soil properties measured included both physical and chemical parameters, like bulk density, pH, penetrative resistance, organic matter and aggregated stability, with values calculated through in-field apparatus and laboratory analysis. In addition, the dry matter yield of crops was sampled. This combination of variables was measured to determine whether the soil amendments would lead to improved productivity of eroded soils. On hillslope smallholdings of southwest China, Zhang et al. (2018) tested the effect of different manual hoe tillage depths on soil translocation, the transfer and displacement of soil by tillage. The magnetic tracer method uses iron powder that adhere to soil particles to differentiate topsoil from subsoil layers under different tillage conditions. Formulae were then applied to determine the average displacement distance, soil flux and erosion rates for tillage treatments of different depths.

Unlike SOC, the measurement of soil erosion is not complicated by the multitude of methodological challenges, like considerations of time on the rate of accumulation (Nayak et al. 2019). Although each of these studies maintain different objectives, they all applied strict in-field sampling designs, under controlled experimental conditions. As is the case with literature measuring SOC, such fixed experiments would prove too inflexible for commercial farms, which would likely be unsuitable, as influencing variables would not be sufficiently controlled for, nor would results be objectively obtained through randomised sampling procedures.

Nevertheless, there are less constrained alternatives which forego the stringent methodological requirements of a scientific study but can provide farmers with the evidence required to inform decisions leading to an improvement in soil health parameters.

5.3.1.2. CASH and Slakes measurement tools

Aggregate stability is a good indicator of soil erosion, because it measures soil's resistivity to erosion, while gauging the health of soils more broadly, given the effect that organic matter content and biological activity have on it (Flynn, Bagnall & Morgan 2019). CASH has been mentioned above as a commercially available tool for farmers in the United States to assess soil organic matter of their soil. Aside from this indicator, CASH also includes a test for wet aggregate stability, which as described in chapter 2, can be used as a measure of the erodibility of soil (Schindelbeck et al. 2008). The CASH framework can therefore serve to track improvements in soil aggregate stability following the adoption of soil management practices that are beneficial to increasing aggregate stability, such as cover crops. This will prove particularly helpful where incorporated as part of a monitoring and evaluation system, which lays out important variables to account for if credible claims are to be made (e.g. a baseline measurement and a timeframe over which to track change) (ISEAL Alliance 2014).

However, even the CASH framework can be considered somewhat complicated, time consuming and due to the requirement for specialised equipment, inaccessible (Fajardo et al 2016). It is for these reasons that SLAKES, a recently launched free smartphone application that uses an image recognition algorithm to measure aggregate stability, has the potential to disrupt the use of traditional laboratory testing methods.

SLAKES has been described as a simple, rapid and affordable way to assess aggregate stability and determine a numerical score for soil health (Flynn, Bagnall & Morgan 2019). This is done by placing between three and five pea-sized aggregates under the suspended smartphone camera to take a reference image. Next, the aggregates are transformed to a petri dish filled with water and simultaneously in the application a button is pressed to record the aggregate dispersion. The programme measures the expansion of aggregate area from an initial reference image as it disintegrates in water, providing a unitless score after ten minutes of disaggregation.

An experiment to test the sensitivity of SLAKES at measuring the aggregate stability of soils on several farms under conventional-tillage fields, no-tillage fields and perennial fields was performed (Flynn, Bagnall & Morgan 2019). The study found that SLAKES was effective in determining the difference in aggregate stability between soils impacted by each management practice. To validate the sensitivity of these results, the same soils were tested using a more traditional technique, the Cornell wet aggregate stability test. Of the two, SLAKES was able to differentiate between the effect of each management practice on aggregate stability at a much higher level of significance, making it more sensitive to measuring the outcome of different management practices. SLAKES can therefore be recommended for use by farmers participating in an M&E programme for its sensitivity to measuring change, ease-of-use and accessibility.

5.3.2. Models for measuring soil erosion

Several models that measure soil erosion were identified during the systematic review and interview process. One systematic review paper used models to simulate the effect of experiments on soil loss from wind erosion.

Pi and Sharrett (2017) assessed the effectiveness of the Revised Wind Erosion Equation (RWEQ) and Wind Erosion Prediction Models (WEPS) at modelling particulate matter (PM10) loss and soil loss compared with actual sampled data. In the experiment, wind erosion was simulated through the use of a portable wind tunnel and ancillary apparatus, while input data required for each of the two models was collected adjacent to the wind tunnel. The RWEQ model for estimation of soil loss required 13 data points to run, while the WEPS model relied on 36, to estimate soil loss and PM10 loss. In the WEPS model, wind speed conditions within the wind tunnel experiment could be recreated because of daily time-step intervals, while the surface area within which the model was assessing erosion could be adjusted to reflect the same scale as that in the simulation. Unlike the WEPS model, the RWEQ model did not factor in daily time-step wind speed intervals, as it was developed to rely on fewer input data. In comparing the likeness of results from the models with that of the wind tunnel experiment, the WEPS results showed good agreement with the measured soil loss for two of the four tillage treatments and PM10 loss for all treatments, while RWEQ only produced similar soil loss estimates for one treatment. The authors concluded that while the models could be improved by adjusting parameters or calibration, they were unable to reflect the complex nature of erosion processes in the field.

5.3.2.1. Fieldprint Calculator Soil Conservation metric

Thomson described the Field to Market Soil Conservation tool, which estimates soil lost to erosion from water and wind, expressed as tons per unit of land area (A Thomson, personal communication, 12 July). It does this by simulating crop growth, water flow over the field, and sediment runoff, using the USDA NRCS Integrated Erosion Tool (IET). The IET relies on two models, the Water Erosion Prediction Program (WEPP) and the WEPS. Previously, the water model used was the Revised Universal Soil Loss Equation (RUSLE2), however this was replaced with the WEPP model given its greater accuracy in estimating erosion, the ability to estimate in-field gully erosion, and the use of newer weather datasets (Field to Market 2018).

To calculate soil loss, the tool requires data on the location (e.g. field boundaries), field (e.g. slope), soil (e.g. texture) and crop. Once the score is calculated, lower values are preferable as these denote less soil being lost, while a score of 0 equates to zero soil loss. The tool can be applied to any farm within the United States, and because it forms part of the Fieldprint Calculator, is widely recognised among industry and farmers in the country.

5.3.2.2. InVEST Sediment Retention Model

The Stanford University InVEST sediment retention model was identified as a model to assess soil erosion (M Kulak, personal communication, 16 June). The model predicts the ability of a land parcel to retain sediment using data on geomorphology, climate, plant coverage and management practices. The model relies on the RUSLE2 water erosion sub-model, which is no longer receiving further development by the USDA, so this tool will cease to reflect the latest science without modifications. Furthermore, much like the inVEST carbon model, it is intended to be applied for ecosystem assessment of land use change, so is unsuitable for use for assessment of soil loss at the field or plot level.

5.4. Methodologies for measurement of soil compaction

Soil compaction was measured in one of the systematic review studies, using a cone penetrometer (Hernándex et al. 2019). Unfortunately, unlike soil organic carbon and erosion which can be measured using out of field methodologies, compaction is best measured using a penetrometer in the root zone directly in the field instead of in a laboratory or otherwise (Gugino et al. 2014). Where farmers are using a penetrometer to assess compaction, they should aim to measure a representative sample of points within the field or plot to avoid statistical inference error, since compaction is highly variable over space (Hernándex et al. 2019).

Aside from measuring compaction, it is possible to avoid or lessen the magnitude of it. Timing operations to fall outside of precipitation events is a practical way to avoid undue compaction, as soil moisture content is a crucial influencing factor. Furthermore, the machine axel load on wet soils determines the magnitude of compression, so this can be adjusted when moving over waterlogged soils to reduce the extent of impact.

5.5. Challenges impacting the adoption of measures and success of programmes

In this section, I discuss the barriers to adoption of outcome-based measures and programme success. In reality, these exist across all stages of the M&E system, from the selection of methodologies during the programme design stage that meet budgetary thresholds and scientific rigour, to providing the right incentives and knowledge to receive the commitment of farmers. These barriers were identified from grey literature and interviews and do not represent an exhaustive list.

5.5.1. Creating incentives for farmers

In the United States, high levels of rented farmland in some counties may create barriers to investing in practices that can improve soil health. Approximately 40% of farmland in the United States is rented, while in the Mid-West where there are higher rates of nutrient loss, this number is greater (as much as 83% of land is rented in some counties in Illinois) (Elias 2018). Farmers renting land are half as likely to adopt soil management practices than farmers who own the land, because soil conditions can be slow to change and they do not have security of land tenure, making it hard to justify or guarantee a return on investment (Elias 2018).

A survey by The Nature Conservancy and partners in Iowa, Indiana and Illinois, investigating the perceptions of non-operator landowners regarding the conservation of their land, the management of soil quality held similar significance as did the need generate income from the land (Elias 2018). Of the farmer, landlords indicated the importance of them being good stewards of the land. Moreover, landlords did not perceive any significant barriers to working conservation practices into their lease agreements, signalling a willingness to address soil health practices with their tenants.

One mechanism that could incentivise adoption of soil health requirements into lease agreements is a tax credit. For landowners to receive tax benefits they would need to be materially involved in financial decisions related to the land, such as through a crop-share agreement (Elias 2018). If state-level assessments were to be conducted and to show a sufficient enough societal benefit to managing soil health to warrant a tax deduction, this might be grounds to propose a credit system in cases where tenancy agreements require certain soil management practices be applied. However, this is unlikely to be a political endeavour that could be easily embarked on by Unilever.

When asked what the main barrier was to encourage the adoption of soil health practices among all farmers (renting or otherwise), Carlson said too much support for the status quo, with no economic incentive for the private sector to help farmers in this endeavour (S Carlson 2019, personal communication, 2 July). In response to the same question, Kuneman said that a farmer's commitment would be encouraged by offering incentives, as good soil management in the short-term costs money, but in the long-term bears results (G Kuneman 2019, personal communication, 9 January). Under such circumstances, offering financial incentives to farmers that adopt soil health practices is one solution that has shown promise, as is the case with the "40 x 40" cover crop programme in Iowa, United States. Launched in 2018, Unilever together with the farmer membership organisation Practical Farmers of Iowa (PFI) and partners, offered farmers who sell soybeans to Archer Daniels Midland and who have never planted cover crops, a financial incentive of $40 per acre for up to 40 acres of cover cropped land.

Crucially, this project gives farmers the flexibility to choose from a variety of cover crops species and provides technical support in the form of PFI membership and the attendance of field demonstrations, workshops and guidance (Jones 2019). By doing so, farmers are given opportunities to gain further knowledge on the benefits of planting cover crops, can choose to plant whichever cover crops would support their commercial objectives and experiment, while any pre-conceived risks perceived that come with modifying the cropping system are hedged by the guarantee of a finacicial incentive. In turn, Unilever are able to attribute any measurable environmental benefits gleaned from data reported by participating farmers against metrics in the Fieldprint Calculator, to their Sustainable Soy Programme. Hence, by establishing a partnership model with local interest groups like PFI and encouraging the adoption of soil health practices by way of a financial incentive, the potential hurdle that rental farmland may otherwise pose is sidestepped.

5.5.2. Education and awareness

The act of knowledge-sharing may be another crucial lever towards driving the adoption of soil management practices, as farmers may lack sufficient information to assess the implications that such changes may have on their business (A Thomson 2019, personal communication, 12 July). Furthermore, the method of exchange of information between soil scientists and agronomists on the one side and farmers and land managers on the other requires consideration, as it is often unclear how effectively this information reaches the latter group (Case-Cohen 2018). One study investigating how farms accrue soil health knowledge, found that the most common method was through trial-and-error and practical experience (Case-Cohen 2018). As a result, it was suggested that farmers would be more likely to adopt new practices if they observed these through a demonstration or in-person training, rather than grappling with the concept on paper or through other means. Indeed, this formed a key strategy to recruit farmers into the “40 x 40” programme, whereby farmers were invited to attend PFI arranged field days, to learn from each other and observe the effects of cover crop adoption on a working farm (PFI 2019). Others factors like farmer philosophies (often materialised through the type of production system, such as conventional versus organic), a risk aversion to change and a preference for working with familiar partners (e.g. from their community versus a consultant travelling from another state) may also influence a farmer’s knowledge on soil health. Although existing knowledge on soil health or lack thereof could influence a farmer’s willingness to adopt soil health practices, well-conceived education and awareness initiatives could go a long way towards remedying this.

While educating farmers is needed to facilitate their adoption of practices, so too must they receive support on how to interpret, collect and report data on which the methodology measuring the outcome may rely. Data quality is of particular importance, be this for in-field sampling or as input into a biophysical model, if methodologies are to accurately measure or predict change. For farmers, understanding how to interpret the results is also essential, if these interventions are to drive changes in behaviour (A Thomson 2019, personal communication, 12 July).

5.5.3. Technical, financial and institutional support

In a systematic review looking at the effectiveness of VSS in driving adoption of sustainability practices, Petrokofsky and Jennings (2018) emphasised that a key barrier to adoption of practices was a gap between existing practices and requirements of the standard, often found among smallholder farmers, where access to technical, financial and institutional support may be lacking. Equally so, this issue would apply to farmers participating in a project that encourages the adoption of soil health management practices. In such cases, the VSS would need to broaden access to various forms of support, to ensure farmers have the sufficient capacity to perform management practices according to technical guidelines, have the financial means to meet the programme demands and access to technical advice and instruction, especially if farmers are required to collect and report data themselves.

5.5.4. Standardisation of methodologies

When it comes to the selection of methodologies to measure changes in soil health, a decision to be made is whether to choose one standard approach to be applied everywhere, or whether to recognise a toolbox of different methods that may better suit the conditions characterising a particular farmer group.

To demonstrate the scale of an initiative, it may be necessary to select a single methodology that allows for aggregation of data to a programmatic level. This approach also affords the interrogation of data to identify similarities or differences, as data conform to the same methods along with all of the assumptions, pros and limitations these harbour (A Wilcox 2018, personal communication, 16 November). Dissimilarly, where data are not uniform, this may discourage judgements based upon aggregation or likeability, as data are derived from different methods. Nevertheless, selecting a single method may be inappropriate if the programme extends over multiple jurisdictions, where farmer knowledge, cropping systems, access to resources and level of mechanisation (as examples) may vary considerably.

For example, the “40 x 40” programme requires that participating soybeans farmers in Iowa complete the Fieldprint Calculator Soil Conservation metric and the USDA NRCS’ Resource Stewardship Evaluation Tool, which to perform effectively, would require farmers to collect input data, participate in training and maintain a proficient level of computer literacy to operate software programmes. The same type of tool may not be suitable to a group of smallholder farmers in China, as they may lack access to computers and the skills to use software programmes effectively. Moreover, roles and responsibilities may fall with another actor in the supply chain, such as Unilever’s direct supplier, as is the case for implementation of USAC. In such instances, Unilever and partners provide training and support to the direct supplier, who cascades this down to their farmers, under which circumstances may necessitate the consideration of a different, simpler methodology that relies on fewer input data points. Important factors determining whether to standardise a methodology to one or to opt for a few approaches would include defining the geographical scope of the programme and determining the presence of local organisations to provide technical support.

5.5.5. Balancing scientific rigour with practical considerations

A consideration raised by Wilcox was that, at the point of selecting a methodology, trade-offs between what is perceived most practical and scientifically sound may arise (A Wilcox 2018, personal communication, 16 November). For example, models to estimate the loss of soil from a field would be less accurate compared with in-field sampling and laboratory analysis approaches. This is because the model relies on a limited range of input variables and therefore makes several assumptions to calculate a value, something which can be avoided through in-field measurement and laboratory analysis, by directly recording this evidence instead. Still, while the preferred scientific method would be the collection and analysis of soil samples, there is often limited consensus within academic circles on what the best method to measure soil parameters is, as well as the lack of a common measurement approach, so even this type of measurement is subject to its own challenges (Stewart et al. 2018). It may also be too expensive to finance if a large farmer group are participating. In this case, a compromise may be to use models to estimate soil loss and to validate these results with field measurements for a sample of farmers (G Kuneman 2019, personal communication, 9 January).

5.6. A framework to track and report progress

Having considered methodologies to measure the outcome of soil management practices, as well as barriers to adoption and the success of programmes, I will address the third research question: how the logical framework would be used to capture and administer methodologies. In this section I demonstrate the necessity for this structured approach to monitoring and evaluating a project by using a theoretical example.

The application of clear, logical thought when responding to complex and evolving challenges, permits sensible planning, monitoring and assessment. This describes the purpose of the logical framework, which is a project management staple of aid agencies and the international development community (Crawford & Bryce 2003). Its value has not gone unnoticed by the global standards industry member organisation, ISEAL Alliance.

ISEAL Alliance refer to it as a causal pathway, which they define as "the logical and causal relationships between inputs, activities/support strategies, outputs, outcomes and impacts" (2014: p.6). In a logical framework, these various strategies are defined and measured at every stage, allowing managers to monitor and assess progress, apply assurance checks where necessary and to learn and drive change as the programme is executed (Gorter & Wojtynia 2017). They should in effect provide any person, novice or expert, with a clear description of what components go into achieving the desired impacts and outcomes, as well as what these key performance indicators are.

When used as part of the M&E system linked to a VSS, the logical framework provides the scheme owner with an understanding of how the strategies they implement are anticipated to contribute to their desired impacts and outcome (ISEAL Alliance 2014). As the logical framework summarises the causal pathway of strategies from one to the next, the strategies themselves would need to be expanded on in further detail elsewhere (Intrac 2015).

Table 16 gives an example of a logical framework, describing the basic information of a programme to reduce compaction and the erodibility of soil. Each stage is explained using a question for ease of interpretation, as posed by Parsons, Gokey and Thornton (2013). This structure is similar to a logical framework already applied by Unilever, so its layout was thought to be most suitable (Ida 2018).

The framework provides headline information, starting with a description of the resources required to commence with the project, the inputs. In this example, these are the materials, information and tools needed to initiate work with participating farmers and other role-players, such as the weather forecast application. Next, the activities are explained to describe in what way the inputs will be applied. At this stage, the farmers monitor the weather forecast application to plan farm activity around heavy rainfall events to avoid movement of machinery over waterlogged soils. The outputs indicator gives a measure of what the project produces, with the example providing the percentage and number of farmers participating in the programme and in turn using the weather forecasting application. Together, these three strategies describe the practices and implementation activities required to deliver results, in the form of outcomes the project is intended to achieve and the ultimate impact this will hopefully lead to (Gorter & Wojtynia 2017). In this example, the outcome describes the quantifiable change these strategies will hopefully lead to, which is a measurable reduction in compaction. On achieving this outcome, the impact measure of improving soil health, as defined by this conceptual framework, will have been achieved.

As the logical framework is merely a summary of strategies, it excludes granular detail about the scope and boundary of a project, roles and responsibilities and how data are managed, among other aspects. The ISEAL Alliance Impact Code provides a helpful description of all the essential components for establishing an M&E system that supports the objectives of the VSS. Mostly importantly, baseline requirements form the minimum viable set of criteria to ensure the M&E system meets ISEAL Alliance’s ten credibility principles, which address issues like impartiality, transparency, accessibility and truthfulness. Therefore, the logical framework provides a simple way to capture and visualise methodologies, while giving them context, by describing strategies in this causal pathway structure.

Table 16 Example of a logical framework for programme to reduce compaction and the erodibility of soil

Inputs (What resources are required?)	Activities (What does the project do?)	Outputs (What does the project produce?)	Measurement (How is the outcome measured?)	Outcomes (What does the project achieve?)	Impacts	Means of Verification	Risks/ Assumptions
• Training manuals and technical support • Biochar for farmers • Download of a mobile-enabled weather app and the SLAKES aggregate stability app onto the farmer's smartphones • Data collection sheets • Baseline measurements of compaction using a hydraulic penetrometer on a sample of participating farms, as well as an assessment of aggregate stability using the SLAKES app.	• Farmers use a weather app to avoid movement of machinery over waterlogged soils • Farmers use the SLAKES application to measure change in aggregate stability • Farmers apply biochar with the aim to increase organic matter content of soil • Farmers document the application rate, timing, frequency of application, etc	• % and # of farmers participating in the programme • # hectares under the management practice	• A penetrometer is used to measure resistance (kg/cm$_2$) • The SLAKES application to assess the aggregate stability of soils (unitless scale)	• Farmers reduce the compaction of their soils by xx% over xx years • Farmers increase the aggregate stability of their soils by xx% over xx years	Soil health is improved, by reducing the impact of machinery and improving soil structure, making it more resilient to heavy rainfall events	• Penetrometer field measurements are taken by project partners annually • Aggregate stability readings taken every 6 months following sampling guidelines	• The sampling protocol delivers a representative sample of aggregate stability readings • Farmers comply with the sampling guidelines for aggregate stability

5.7. Conclusion

In this chapter, I interpreted the findings from the systematic reviews and interviews on what appropriate methodologies can be used to measure the outcomes of soil management practices, what the barriers to adoption are, and what framework can be used to capture and administer measured results.

In addressing the first research objective on methodologies, approaches can be grouped as those involving in-field sampling and laboratory analysis, those that involve the use of predictive models and pre-defined framework-based tools, that in part utilise the first approach. In order of accuracy of results, in-field sampling and laboratory methods provide a higher degree of confidence than models, because they rely on physical evidence like soil samples, rather than an estimation of change using input data and model approximations. In the case of SOC though, the measurement of changes over time requires a long-term strategy, with practices to be sustained over decades, whilst accounting for varying rates of accumulation and being realistic about storage potential based on climatic features. Comparatively speaking, in-field measurement of the erosivity of soil and compaction is much simpler, because these diagnose a physical condition of soil rather than a chemical one.

Yet, from a scientific standpoint, applying the same experimental rigor on working farms as that required of a research trial is considered unrealistic, as management decisions change based on multiple drivers, beyond the health of soil, like economic incentives (e.g. demand for a particular crop), climatic (e.g. drought cycles) and agronomic (e.g. ensuring a plant physiological needs are met to achieve expected yields). Further still, designing for such measurement in support of a VSS would be challenging, because of the necessary burden of proof, the need for capacity-building and cost implications.

For these reasons, interviewees recommended the use of biophysical models like the globally relevant Cool Farm Tool and US-based Fieldprint Calculator, given their adaptability, accessibility and ease of use. Indeed, the USAC has for several years required suppliers to calculate the greenhouse gas footprints of farmers, so there is a precedent for these types of tools to be used in support of the objectives of a VSS. In the case of the Fieldprint calculator's Soil Carbon metric, the calculation of a unitless score along a continuum of -1 to 1, based on input data like the field location, soil texture, crops in rotation, fertiliser treatments and yield, gives farmers an indication of whether current practices are likely resulting in an increase or decrease of soil organic matter. For the modelling of erosion, sophisticated biophysical models that incorporate a daily timestep of climatic data are already available and used, like the Fieldprint calculator's Soil Conservation metric, which expresses soil lost as tons per unit of land area. Lastly, a novel new tool called SLAKES was identified by an interviewee to measure the erosivity of soil. It allows anyone with a smartphone device to assess the aggregate stability of soil, by suspending a smartphone camera over soil aggregates before and while applying water, to calculate a score based on the rate of disaggregation.

Next, challenges effecting the adoption of measures and success of programmes were discussed. Both interviews and grey literature provided a great deal of context and information to respond to this research area. Providing incentives for farmers is emphasised as pivotal, if the expectation is for farmers to introduce a practice change. This is especially important where farmers occupy rented farmland and may not have a guarantee of how long they will be custodians of this land for. Economic incentives and technical support are essential, if farmers are to shift from current patterns of production to include practices that are also beneficial for the soil health. Providing education and awareness opportunities through farmer-to-farmer knowledge-sharing is another technique to demonstrate the benefits of these practices.

To address the third research objective of how to capture and administer methodologies under a VSS, I looked to the ISEAL Alliance, a recognised standard-setting body in the industry. The Alliance supports the logical framework or causal pathway model as a structure through which to define strategies and measure change at every stage, providing a means to monitor and assess progress. Inputs, activities, outputs, outcomes and impacts are captured and reported on through the causal pathway, providing a clear and articulated means to communicate outcomes with stakeholders. For these reasons, the logical framework is considered a suitable structured through which to capture and administer the measurement of outcomes resulting from soil management practices.

Chapter 6 – Conclusion

6.1. Introduction

This is the final chapter of my thesis, which includes a summary of the main findings, gives recommendations and describes limitations of the research. While in previous chapters I discussed particular phases in the research process, this conclusion summarises the body of work in totality, drawing attention to pertinent findings.

As a reminder, the principle objective of this research has been to explore methodologies for assessing the outcome of soil management practices, in the context of Unilever's Sustainable Agriculture Code. Although the origin of this enquiry finds its basis in the SAC, the research was performed with all VSS in mind, as the SAC's questions and coverage of soil management issues are similar to that of other industry standards. From this, two further questions emerged, namely, to identify the barriers to adoption and programme success and to describe how such methodologies might be captured and administered for a programme setting, like that of the SAC. I will now summarise the main body of work, emphasising key learnings for consideration.

6.2. Understanding of key concepts

In Chapter 1, I provide an overview of the research problem, explaining my research questions and touching on key concepts. This is succeeded by Chapter 2, a narrative literature review on VSS, soil science and methodologies, to bring clarity to these broad-ranging concepts being dealt with. Herein, VSS are described as standards for producing, selling and buying products in a sustainable way that results in positive environmental, social and economic impacts. Their rise in popularity is indicative of increasing demand among consumers, yet VSS face criticism on whether they are achieving their sustainability questions and studies do not always show this to be the case. Nevertheless, it is argued that scrutiny can be curtailed if VSS move from an approach that relies on implementation as a proxy for performance, to a monitoring and evaluation system that is designed to demonstrate outcomes and impact through instruments like the logical framework.

As the research is looking to find ways to measure outcomes of soil health practices within VSS, a review was conducted on selected soil health aspects – compaction, erosion and SOC. Soil organic carbon, a product of the decomposition of living organisms, is an important indicator of soil degradation because of its role in supporting core physical, biological and chemical functions of soil. SOC sequestration in cultivated soils has received considerable attention as a potential route to reducing the accumulation of atmospheric carbon and therefore abating the impacts on climate change. However, while direct measurement approaches and other estimation tools like models are available to measure sequestration, these approaches face challenges in accurately predicting change. One challenge facing in-field investigations is to account for the variable rate of SOC accumulation among soils, which can decrease in initial years, then increase and eventually plateau once in a state of equilibrium. As this change is slow, field investigations of a short timeframe are unable to measure the effects of treatments on SOC over the long-term.

Soil erosion is another soil health aspect chosen because it drives the detachment and loss of soil particles and aggregates from cropland. Slope steepness, increasing rainfall and change in vegetative cover are important factors determining the rate of erosion, making beneficial soil management practices vital in safeguarding this resource. Unlike the measurement of SOC, erosion is more straightforward and both in-field measurement and models are suitable methodological approaches to measuring soil loss. Soil compaction, the third soil health aspect addressed, is a process whereby soil particles shift and move closer together under the weight of heavy machinery and traffic. Unlike SOC and erosion, approaches to measure compaction are limited to in-field techniques.

6.3. Describing the research design and methodology applied

Having provided further background on key concepts addressed in this thesis, Chapter 3 delves into the research design and methodology, describing the research paradigm and the various methodologies used. I chose the pragmatic and post-positivist paradigms to explain my epistemological thinking and the selection of research questions and methods, as these advocate for the selection of whichever method (qualitative or quantitative) is most practically suited to addressing the outcome (pragmatism) and recognise that no research is entirely objective or certain (post-positivism), which is a good perspective to have when measuring outcomes that are often based on assumptions and limited evidence.

The qualitative research methods selected for use were considered most suitable given the existence of research available on this topic and to compensate for my limit knowledge on soil science. As such, a systematic review using systematic and documented methods formed the basis to addressing the research questions. Guidance developed by CEE was selected as the basis for the review, for its relevance to environmental management and the types of data and methods most commonly applied in environmental research. The systematic review is characterised by a series of steps that identify search terms and combinations (strings), determine criteria to include and exclude literature, screen literature to remove non-conforming results, extract data in a formalised way and analyse the results.

Before this commenced, a review of the SAC and similar standards was performed to identify a range of commonly recommended practices that could be applied to manage compaction, erosion and SOC. This led to the selection of compost, cover crops, crop rotation and tillage as practices for inclusion. These were used in the search strings of the systematic review to help narrow the focus. To this end, an analysis of Unilever's supply chain data led to the selection of the United States and China as countries to further focus the enquiry, due to these being key markets for sourcing agricultural materials. The timeframe between which results were sought was 2017 to 2019, chosen in an attempt to solicit results reflective of both traditional and emerging methodologies for measuring outcomes of soil health. To build upon the findings from the systematic review of peer-reviewed literature, a grey literature search of conference proceedings linked to literature selected in the systematic review was performed. Finally, semi-structured interviews were performed to engage a range of experts on the topic areas covered and to elicit information potentially missing from the systematic review literature.

6.4. Findings of the research enquiry

The systematic review generated 621 results, which were reduced to 60 articles meeting the eligibility criteria, like a requirement for the scope of studies to be on annual or temporary crops that are harvested annually or more frequently. A requirement which resulted in the exclusion of many articles, was that the experiment needed to include treatments of composting or other soil amendments, cover crops, crop rotation and tillage, or a combination of these for the management of erosion, compaction or SOC.

Of these 60 studies selected, 51 sought to assess the impact of practices on SOC, while eight addressed erosion and one dealt with compaction. The emphasis on SOC was equally high for both countries. Nearly two-thirds of articles implemented two or more treatments in combination, the most common of which was crop residue management and tillage. On a per practice basis, tillage was the most common treatment applied, in nearly two-third of the studies. In terms of the location of research conducted, this was spread across many states in both countries and applied to a similar set of cropping systems, with corn featuring most frequently either on its own or in rotation with other crops, commonly wheat and soybean. In terms of methodologies applied, the majority were classified as in-field and laboratory emoirical trials, taken under field trials subject to scientifically rigorous approaches, considered unsuitable for open-farm systems like those growing crops for Unilever. Overall, studies did not provide a reason as to why a particular sampling method or laboratory analyses technique was applied over another.

The semi-structured interviews generated a variety of information on methodologies applied on commercial farms, discussions on barriers to adoption of soil health practices by farmers and how VSS could incorporate methodologies into their strategy and operations. A clear findings that emerged was the unsuitability of conventional in-field and laboratory scientific methods and instead the role that models could play in estimating change, which could be validated using in-field and laboratory techniques to ensure credibility and accuracy of results.

Regarding methodologies for measuring SOC, several participants mentioned that the science is still evolving and therefore methods available to open-farm systems are currently limited to frameworks like Cornell's Comprehensive Assessment of Soil Health. Considering the three soil health aspects, it was recommended to prioritise management of soil erosion, to protect soil from loss, before attempting to improve SOC sequestration. Regarding the assessment of compacted soil, it was advised the only viable method is in-field sampling using a penetrometer.

6.5. Discussion of the findings

6.5.1. Research Objective 1: What are appropriate methodologies that could serve to measure the effect of soil health requirements of Unilever's Sustainable Agriculture Code?

In Chapter 5, I have discussed the findings, interpreting the results to answer the research questions. In response to the primary research question to identify methodologies to measure the outcomes of soil management practices, a clear set of recommendations emerged.

For the assessment of SOC, interview participants considered in-field sampling and laboratory analysis to be unsuitable for use in open-farm systems, such as those in the supply chains of Unilever. There are obvious methodological features to scientific field trials which would be incompatible with the objectives of a working farm, such as setting aside land for the purpose of experimental multi-year trials, which would otherwise fall under crops for commercial sale. This essentially nullified the results of the systematic review, as in nearly all cases, studies were conducted under such conditions. As an alternative, biophysical models were recommended to estimate change in the SOC stock. Although credible models like the RothC and CENTURY-5 models were applied in two studies within the systematic review, it was during interviews that models designed for use by farmers were identified. For farmers in the United States, the Field to Market Fieldprint Calculator offers bespoke metrics to quantify impact of farming activity, including a directional and unitless scale to estimate whether management practices are leading to an increase, maintenance or loss of soil organic matter (SOM), from which SOC is derived. Furthermore, the Field to Market team who administer the Fieldprint Calculator, offer programme support to ensure that farmers are able to interpret the result correctly. Unfortunately no comparable tool was identified for use in China.

The Cool Farm Tool greenhouse gas calculator was another tool suggested for use in estimating the effect that management practices like cover cropping and reduced tillage would have on the carbon footprint. Although the unit output from the calculator is different from that typically used in measuring change to SOC directly, the tool offers users the option of simulating their footprint against a range of management practices and the algorithm that calculates the footprint is equipped to model carbon sequestration. Furthermore, farmers implementing Unilever SAC already use the tool to calculate their carbon footprint, so it would be a suitable solution against which to collect data and model the effect of soil health management practices on the overall farm footprint. The tool has been designed for global use.

As was the case for the measurement of SOC, interview participants identified several alternative approaches to conventional in-field sampling and laboratory analysis, which they deemed unsuitable for use in open-food systems, unless facilitated through a tool such as Cornell University's CASH, which provides soil analysis along with capacity building and awareness-raising resources. The Fieldprint Calculator was again referred to for its soil conservation metric, a biophysical model which estimates soil loss by water and wind and incorporates daily weather data to simulate a more accurate estimate. The tool relies on a range of input data on soil conditions and management activities to estimate the quantity of soil lost from a field. It can therefore be used to model the effect of different management practices to estimate the loss of soil, thus allowing for trend analysis as the basis for potential claims.

Perhaps the most interesting methodology to measure soil erosion with is the SLAKES tool, because of its accessibility as a freely available application for download to a smartphone. The tool assigns a score for wet aggregate stability, following a ten-minute period, during which the app compares imagery of dry soil aggregates from a reference photo, against the deterioration of these same aggregates in the presence of water. With this comparison, the model assigns a score against a unitless scale that is indicative of high through to low aggregate stability. When compared for its sensitivity, it was found to be more accurate than an in-field sampling and laboratory analysis technique. Positively, this tool can be used globally, so is relevant to farmers in both the United States and China.

The final soil health aspect addressed in this thesis was compaction, however as previously mentioned, interview participants recommended this only be sampled using a penetrometer in field. Based on these findings, table 17 summarises the recommended methodologies for measurement of compaction, erosion and SOC.

Table 17 Proposed methodologies to measure the change in compaction, erosion and SOC

Aspect	Instrument	Apparatus & parameter	Parameter & unit	CHN	USA
Compaction	Field device	Penetrometer – soil strength	kg/cm$_2$	x	x
Erosion	Mobile app	Slakes: Aggregate Stability	Unitless scale	x	x
Erosion	Web-based Fieldprint Calculator	Soil Conservation Model	Kg/		x
SOC	Web-based Cool Farm Tool	Greenhouse Gas Assessment	Tonnes of CO2e/ha	x	x
SOC	Web-based Fieldprint Calculator	Soil Carbon Model	Unitless scale		x

6.5.2. Research Objective 2: What are the barriers to successful adoption of outcome-based measures?

The second research question emerged from the first and serves to uncover possible barriers to adoption of methodologies. The high levels of rented land in the United States were identified as a possible barrier to adoption of practices among farmers, as they would lack the incentives to adopt soil health practices, in the knowledge that improvements in soil condition can be slow and these they may not be around to see a return on investment, such as through higher yields. In such cases, a commercial solution to incentive adoption would be to pay farmers a financial incentive per tonne of product purchased. Unilever's "40 x 40" cover crop programme with Iowa soybean farmers is an example of this approach.

Another potential barrier to adoption is a lack of knowledge and awareness on the economic and environmental benefits of practices that would lead to positive outcomes for soil health. This was demonstrated again in the "40 x 40" programme, for which a vital farmer recruitment strategy came in the form of field days, to demonstrate the benefits of soil management practices in person and facilitate the exchange of learnings.

A third potential challenge to consider is whether to recognise one single methodology for implementation with users across the VSS, or to select these based on suitability to local conditions. The benefit of standardising use to a single methodology is comparably of the data, given that results would be derived from the same set of input data and calculated against the same formula. However, the methodology may require a certain level of capacity and skill among farmers to collect and report data, which may not be resolvable in some jurisdictions where farmer group are less equipped to meet these standards. Moreover, the recruitment of local partner organisation may be needed to successfully meet the project objectives.

Finally, a fourth possible barrier relates to potential trade-offs between scientific rigour and practical considerations. For example, collecting data in field and analysing this in a laboratory may generate more accurate results compared with a model that relies on less data and makes assumptions. However, the more rigorous methodology may be too costly or resource intensive to support.

6.5.3. Research objective 3: Under a management framework, how would such measures be captured and administered?

The final objective of this research was to consider the logical framework's role in capturing and administering a project that implements a methodology or methodologies. ISEAL Alliance's guidelines for the development of a M&E system, define a range of criteria needed to establish a credible framework against which outcomes and impacts of standards can be tracked and assessed. Designing a logical framework is one such criteria which helps the standard owner identify strategies to achieve the desired outcomes and impact. The logical framework depicts a linear pathway, with each strategy dependent on its predecessor to come to fruition. It therefore provides a central narrative to clearly describe what resources are required to initiate the project (inputs), what actions need to be taken and by who (activities), what the project produces (output), how the outcome is measured (methodology), what the project will achieve (outcome) and the desired impact the outcome will lead to. In addition, it recognises any assurance steps to verify the data. This framework is therefore considered advantageous in keeping true to the project specification and to monitor progress against these static indicators.

6.6. Limitations of the study

Several limitations and constraints were confronted during the research project, which if addressed, could have strengthened my findings and conclusions.

- Although the objective was to focus the research on evidence from the United States and China, all of information gathered from interviews and grey literature relates to the United States. The two participants interviewed with knowledge of VSS and sustainable agriculture in China were not aware of any tools developed for the local market that could be used to measure outcomes of soil management practices.
- The decision to conduct a systematic review was possibly a naive one, given that studies sourced from peer-reviewed literature were concerned with research trials, whose unsuitability could have been anticipated. Instead, the systematic review could have focused primarily on assessing grey literature, as well as a higher number of interviews. Nevertheless, this line of enquiry did provide an indication that the wider scientific community still regard traditional in-field and laboratory analysis methodologies as the gold standard.
- Insights from farmers using the recommended methodologies or otherwise could have been gathered if this group of participants had been included in the interview process. As farmers implementing the management practices would be the primary participant, their opinions would have been useful to gauge.
- The methodologies proposed may be unsuitable for smallholders, who may lack access to resources, like knowledge on management practices for adoption and data collection, as well as technology like smartphones to measure.

6.7. Recommendations

Considering the limitations as described above, a number of recommendations are proposed for future study:

- Due to the underrepresentation of evidence from China, a study with similar objectives should place a weighting on interview participants holding knowledge on China (e.g. 2 participants with knowledge on China for every 1 participants with knowledge on the United States).

- A systematic review should be designed to draw primarily on grey literature sources, to identify emerging approaches that may not yet have widespread recognition. Given the valuable knowledge gained from semi-structured interviews, this review should comprise a balance of written and verbal sources.
- A study of this nature would benefit from the inclusion of farmers as participants in semi-structured interviews, to gather their opinions, as they would be the ones required to adopt soil health practices, a likely source of data to assess outcomes of these, and would recognise barriers to adoption.
- The approaches identified by this research would require validation and a situational assessment to determine their suitability before adoption.
- Understanding barriers to adoption of practices is an area which requires deeper enquiry. The need for incentives to encourage adoption of practices by farmers was repeatedly mentioned by interviewees and so determining what the role of VSS or companies could be to facilitate the wider adoption of soil health practices, beyond supply chains at a landscape level, would be a useful topic for further investigation.
- Further research to understand how companies could support VSS in delivering wider market transformation, beyond purchasing certified material, would be beneficial to identifying potentially underutilised levers for change.

6.8. Concluding remarks

Voluntary Sustainability Standards are valuable tools to raise the performance of agricultural production to one that is less destructive on the health of soil and might even restore components of this in time. Yet, efforts must be taken to quantify what the effects of introduced management practices are if these tools are to demonstrate the effects they often claim to have. I believe I have identified a set of approaches that can be used by VSS to work towards achieving this objective. Given the limitations of this study though, it is recommended that further research be conducted, such as the engaging farmers to obtain their perspective on the suitability of approaches and barriers to adoption.

The importance of this research rests in the knowledge that environmental damage in the 21st century is happening at an accelerated pace, necessitating urgent action to protect soils from loss and to enhance their status to one of a precondition to current and future life. Under such circumstances, it is essential that supply chain actors like Unilever help set in motion a new evidence-based standard of performance, to rapidly address and curtail the impacts on soil health.

Chapter 7: References

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Appendix A: Boolean operators used to conduct the systematic review search

Search Script	Results	Boolean operator
soil AND "compost" AND "China"	20	TITLE-ABS-KEY (soil AND "compost" AND "China") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
soil AND "compost" AND "United States"	21	TITLE-ABS-KEY (soil AND "compost" AND "United States") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017
soil AND "cover crop" AND "China"	8	TITLE-ABS-KEY (soil AND "cover crop" AND "China") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
soil AND "cover crop" AND "United States"	47	TITLE-ABS-KEY (soil AND "crop rotation" AND "United States") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
soil AND "crop rotation" AND "China"	54	TITLE-ABS-KEY (soil AND "crop rotation" AND "China") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
soil AND "crop rotation" AND "United States"	47	TITLE-ABS-KEY (soil AND "crop rotation" AND "United States") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))

Soil AND "eddy covariance" AND "united states"	24	TITLE-ABS-KEY (soil AND "eddy covariance" AND "united states") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
Soil AND "eddy covariance" AND China	39	TITLE-ABS-KEY (soil AND eddy AND covariance AND china) AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
Soil AND "Inelastic neuron scattering" AND "united states"	0	TITLE-ABS-KEY (soil AND "Inelastic neuron scattering" AND "united states") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017
Soil AND "Inelastic neuron scattering" AND China	0	TITLE-ABS-KEY (soil AND "Inelastic neuron scattering" AND china) AND DOCTYPE (ar OR re) AND PUBYEAR > 2017
soil AND "monitor" AND China	22	TITLE-ABS-KEY (soil AND "monitor" AND "China") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
soil AND "monitor" AND United States	18	TITLE-ABS-KEY (soil AND "monitor" AND "United States") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
soil AND "tillage" AND "China"	132	TITLE-ABS-KEY (soil AND "tillage" AND "China") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
soil AND "tillage" AND "United States"	83	TITLE-ABS-KEY (soil AND "tillage" AND "United States") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))

soil AND compaction AND methodology AND "united states"	0	TITLE-ABS-KEY (soil AND compaction AND methodology AND "united states") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017
soil AND compaction AND methodology AND China	0	TITLE-ABS-KEY (soil AND compaction AND methodology AND china) AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
soil AND erosion AND methodology AND "united states"	24	TITLE-ABS-KEY (soil AND methodology AND "united states") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
Soil AND erosion AND methodology AND china	4	TITLE-ABS-KEY (soil AND erosion AND methodology AND china) AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
Soil AND LCA And "united states"	1	TITLE-ABS-KEY (soil AND lca AND "united states") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
Soil AND LCA And China	3	TITLE-ABS-KEY (soil AND lca AND china) AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
Soil AND LIBS AND "United States"	1	TITLE-ABS-KEY (soil AND libs AND "united states") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI"))
Soil AND LIBS AND China	1	TITLE-ABS-KEY (soil AND libs AND china) AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))

soil AND spectroscopy AND China	52	TITLE-ABS-KEY (soil AND spectroscopy AND china) AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))
soil AND spectroscopy AND United States	18	TITLE-ABS-KEY (soil AND spectroscopy AND "united states") AND DOCTYPE (ar OR re) AND PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "AGRI")) AND (LIMIT-TO (LANGUAGE , "English"))