Quantifying variability of emissions of greenhouse gas (CO_2 & CH_4) across selected soils and agricultural practices

By

Tebogo Matsimela Sebake

Submitted in fulfilment of the requirements for the degree of Master of Science in the Faculty of Science, Nelson Mandela University, Port Elizabeth.

Supervisor: Prof MJ de Wit

Co-supervisor: Prof RMB Auerbach

Co-supervisor: Dr E Kotze

December 2021

ABSTRACT

Quantifying variability of emissions of greenhouse gas (CO_2 & CH_4) across selected soils and agricultural practices

Increasing concentrations of greenhouse gases (GHG's) in the atmosphere are warming the planet, and agriculture is responsible for about 30% of these emissions. Soils act as a host for greenhouse gases, since both their storage and emission capacities are large, accounting for two-times the amount of carbon in the atmosphere and in plant and animal life. It sequesters large amounts of carbon, and because agricultural practices depend on soil for production, the practices influence the soil's ability to store the carbon effectively. Production soils emit greenhouse gas, predominantly carbon dioxide and methane, which are assessed for emissions in this study.

Climate change creates unpredictability in precipitation and temperature; farmers need to be flexible and adapt production methods to such environmental changes in order to continue producing sustainably. Global food production needs to grow drastically to meet the projected demands for rising population and diet shifts; studies have shown that feeding a more populated and a more affluent, equal, world will require roughly a doubling of agricultural production by 2050, which means more GHG emissions from the soil. To enable better control on these emissions, their links to agricultural practices need to be better quantified.

The study was done in two areas: (1) long-term comparative farming systems research trial with controlled vegetable plots, in the agricultural school of Nelson Mandela University, in George, Western Cape province and (2) long-term wheat research trial of the Free State University, in Bethlehem, Free State province. The objective in study area one is to assess and compare GHG emissions from conventional and organic systems. Temperature and soil moisture were measured during gas samples to establish the influence they have on gas emissions. The objective in study area two is to assess and compare GHG emissions from no-till, plough and stubble mulch. Stubble mulch refers to crop residue left in place on the land as a surface cover during fallow periods.

Two polypropylene canisters are placed in a sampled plot to trap gas emitted from the soil. Analyses of the trapped gases in the headspace gives concentrations of CO_2 and CH_4 that was emitted during the duration the canister was closed. The gas is analysed by a G2201-i Picarro gas analyser, presently the only such instrument in South Africa. The analyser's near-infrared Cavity Ring Down Spectroscopy technology is capable of simultaneous measurements of CO_2 and CH_4 down to parts per million.

In study area one, conventional plots (R2T6 & R1T6) emitted 65.089 ppm CO_2 and 61.159 ppm CO_2, and 0.0010ppm CH_4 and 0.0004ppm CH_4, respectively. Organic plots (R1T3 & R2T3) emitted 53.264 ppm CO_2 and 47.885ppm CO_2, and 0.0023 ppm CH_4 and 0.0019 ppm CH_4 respectively. Thus, conventional plots emitted 19.98% & 30.98% more CO_2 than organic plots; but organic plots emitted 81.97% & 155.5% more CH_4 than conventional plots. In study area two, ploughed soils emitted 38.727 ppm CO_2 and 0.015 ppm CH_4, no-tilled soils emitted 31.798ppm CO_2 and 0.011 ppm CH_4 and stubble mulched soils emitted 28.373 ppm CO_2 and 0.009 ppm CH_4. Thus, ploughed soils emitted 19.65% more CO_2 than no-tilled soils, no-tilled soils emitted 11.38% more CO_2 than stubble mulched soils and ploughed soils emitted 30.36% more CO_2 than stubble mulched soils. Ploughed soils emitted 30.77% more CH_4 than no-tilled soils, no-tilled soils emitted 20% more CH_4 than stubble mulched soils and ploughed soils emitted 50% more CH_4 than stubble mulched soils.

Moist soils result in decreased CO_2 emissions in conventional plots and increased CH_4 emissions in organic plots. Increasing temperature patterns are followed by a trend of increasing gas emissions. Reducing GHG emissions from agriculture and developing sustainable tillage practices can help mitigate climate change and increases the chances of stabilising GHG concentrations and temperature control within a required range.

Keywords: climate change, greenhouse gases, food production, sustainability

Declaration

I, Tebogo Sebake, student number 213296748, hereby declare that the work contained in this thesis, for Masters of Science: Geography, is my own work and that it has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

Signature: Date: 12/08/21

In accordance with Rule G5.11.4, I hereby declare that the above-mentioned treatise/dissertation/ thesis is my own work and that it has not previously been submitted for assessment to another university or for another qualification.

Acknowledgements

Foremost I would like to thank my supervisor Prof Maarten de Wit, co-supervisor Prof Raymond Auerbach, project leader of the Mandela trail who supervises a number of research studies within the experimental site and co-supervisor Dr Elmarie Kotze, for presenting me the unique opportunity to complete my Masters dissertation on such a unique relevant subject, their support, guidance and commitment is sincerely appreciated.

To Christien Thiart for assisting immensely with statistics.

To Palo Loke (Post Doc UFS) and Lentjie (ARC employee), dividing responsibilities amongst ourselves helped me immensely during data collection, stay blessed.

To the AEON family at large, you all have a special place in my heart; wish you all the best on your future endeavours.

To my friends; your constant support, the intellectually stimulating conversations we have engaged in and the daily motivations did not go unnoticed, it’s all sincerely appreciated. Special Thanks to Vovo, thanks for reminding me every chance you got why I started the project, stay winning Queen.

To Maarten de Wit; farewell our Father; you shall never be forgotten. You may rest assured knowing I have continued with PhD as we had planned.

Acronyms and abbreviations

AAAS	: American Association for the Advancement of Science
ARC	: Agricultural Research Council
ASRC	: Advanced Science Research Centre
CH_4	: Methane
CO_2	: Carbon Dioxide
CRDS	: Cavity Ring Down Spectroscopy
EEA	: European Environmental Agency
FAO	: Food and Agriculture Organisation
GHG	: Greenhouse gas
GMO	: Genetically Modified Organisms
GWP	: Global Warming Potential
HYV	: High-yielding variety
IFOAM	: International Federation of Organic Agriculture Movements
IPCC	: Intergovernmental Panel of Climate Change
IWMI	: International Water Management Institute
LAN	: Limestone Ammonium Nitrate
N_2O	: Nitrous oxide
NOAA	: National Oceanic and Atmospheric Administration
NPK	: Nitrogen Phosphorus and Potassium
Soil C	: Soil Carbon
SOM	: Soil Organic Matter
UN	: United Nations
UNFCCC	: United Nations Framework Convention on Climate Change
WMO	: World Meteorological Organisation
WWF	: World Wide Fund for nature

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Chapter 1

1. Introduction

Climate refers to the behaviour of the atmosphere over relatively long periods of time (National Geographic, 2019); and is one of the main determinants of modern agriculture, as it controls plant and animal health and growth, that are dependent on heat, water and light (Mungall and McLaren, 1991). Climate change will affect the basic needs of people across the world; food production, access to freshwater, health and the environment (Vale, 2016; UN, 2019)

There is a small amount (less than 1%) of important gases in the atmosphere that influence the climate, popularly called Greenhouse gases (GHG), identified by John Tyndall in 1859 (Archer and Rahmstorf, 2010). This GHG “family” absorbs energy from sunlight and converts it into heat, and radiates heat away as infrared lights. (Archer and Rahmstorf, 2010). Collectively they act as an insulating blanket around the planet (Mungall and McLaren, 1991). They absorb and return the outgoing heat to the Earth’s surface, trapping it within the lower atmosphere; these effects are natural and essential for life toflourish on earth (Archer and Rahmstorf, 2010).

Nitrogen (N_2) and oxygen (O_2) are the gases that make up most of the atmosphere; (78% nitrogen and 20% oxygen respectively)(Granger et al., 2008). These gases are transparent to infrared light, therefore, they are not GHG’s (Jancovici, 2007). Only those containing three or more atoms, or two dissimilar atoms, act as GHG’s (Archer and Rahmstorf, 2010).

Climate change refers to the increase or decrease in concentrations of GHG’s in the atmosphere, which results in global warming or cooling. According to climate models, anthropogenic activities since the industrial revolution are the main driver behind climate change (Volk, 2008). Activities like burning fossil fuels for energy, producing food through farming, industry and transport are predominantly responsible for emitting anthropogenic GHG in to the atmosphere (Vale, 2016).

The most likely victims of climate change, in the short run, are farmers who rely on climate-linked atmospheric processes like rainfall; people who live on oceanic islands, in very low lying coastal settlements, in ice-bound Arctic communities, and around forests that burn after unusual dry spells (Stern, 2007).

Almost every nation in 2015 adopted the Paris agreement[1]. The deal aims to keep global temperature increase below $2^{O}C$ in the 21st century, amongst other objectives. (IPCC, 2018). The deal instigated climate action, and highlighted civilization toughest challenge so far. World leaders representing 198 nations concluded in an agreement to combat climate change and adapt sustainably to its impacts (WWF, 2019). The UN Climate Change Conference, Congress of the Parties (COP 25), has taken place in Madrid, Spain from 2nd to 13th December 2019. Countries negotiated more determined ideas to curb global warming to 1.5°C in this century.

Agricultural practices are affected by climate change and they contribute to climate change too; Soils emit GHG's, predominantly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Stavi and Lal, 2013). CH_4 is produced during enteric fermentation in ruminants and is released through belches, it can also escape from organic waste in landfills, stored manure and agricultural production soils (Topp and Pattey, 1997).

Soils act as a host for GHG's, since both storage and emission capacities are large (Bhullar et al., 2013). Soils sequester large amounts of carbon, and because agricultural practices depend on soil for production, the practices influence soil's ability to store the carbon effectively (Kaddo, 2016). Large amounts of carbon are lost due to practices such as land clearing, tillage, desertification, deforestation and degradation (Stavi and Lal, 2013).

Agriculture, forestry and other land use sectors account for about 25% of anthropogenic GHG emissions (Peter et al., 2017). Global emissions by crop and livestock increased by 14% Between 2001 and 2011, (EEA, 2016). Developing countries were in the forefront of the increase as a result of increased food demand and chamging food consumption patterns. (Lal, 2009).

Drastic unpredictability is expected in agricultural production because vegetation depends on temperature and precipitation during the growing season (Mungall and

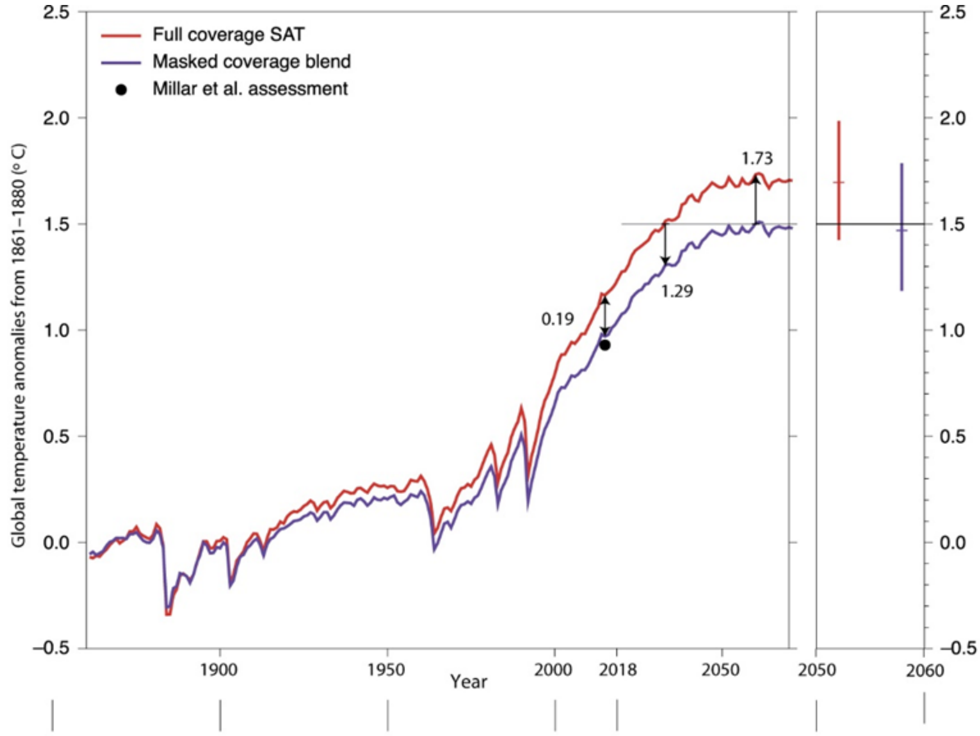
[1] The Paris Agreement brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. As such, it charts a new course in the global climate effort.

McLaren, 1991).Changing climate patterns will change distributions of plant diseases and pests, as well as other agricultural production determinants (Oreskes, 2005). Most agricultural production methods in South Africa are industrialised and rely on external synthetic inputs like fertilizer. Farmers both on commercial and subsistence level need to be flexible and adapt their production methods to environmental changes in order to continue producing successfully (Mashele, 2016).

Agriculture will most likely be negatively affected by climate change (Matthews et al., 2013), during a period which doubling in food production is required, as a result of increasing populations (Butler, 2015; Worldometers, 2019). It would be of utmost importance to reduce GHG emissions from the agricultural sector to mitigate climate change.

It's most likely that in the future, regions of optimum production of crops will shift, given climate change impacts. Certain regions like Africa are predicted to become drier and warmer, this means farmers will face altered seasons and weather patterns, erratic rainfalls, unpredictable floods and drought (Matthews et al., 2013). Already current drought conditions are proving to be challenging to farmers, with some contemplating to stop farming. This will have repercussions on the already volatile food production system, which on a national level is secure, but not so on a household level (Rojas-downing et al., 2017). These challenges have a direct impact on land productivity and an indirect impact on production resources like water and temperature (Matthews et al., 2013).

In 30 to 40 years from now, 3 billion more people will demand food security in a world at least 1.5 ^{O}C warmer than today. African agriculture must supply almost 30% of this. How is this going to be achieved when global demand for water is expected to outstrip supply by 40% within the next 20 years, and most people in Africa will be living in areas of high water stress (Figure 1.1) is simplified from AEON Report 6 in preparation (De Wit, 2019).



Population in billions - urban population in (%)

	1850	1900	1950	2000	2018	2050	2060	2100
WORLD	1.2	1.6	2.5(30%)	6.1	7.6(55%)	9.8 (66%)	10.2	11.2
AFRICA			0.2(14%)	0.3	1.2(41%)	2.5 (56%)	3.0	4.5
Projected rise in food demand:						70%	100%	

Figure 1.1: Global temperature model simulation in which estimate of current levels of anthropogenic warming following the start of the industrial revolution (1861 to 1880) is 0.93OC (From AEON Report 6, in preparation).The amount of warming remaining before Day Zero of 1.50C that must be curbed within 40 years from now, as recommended by the UN Paris Agreement, can be determined (From AEON Report 6 2019, in preparation). The model from which these future projections are calculated changes if pre-industrial baseline starting time was much earlier (for example 1400 to 1800; e.g Crutzen, 2002; Steffen et al., 2015, 2018); as do uncertainties about global temperature averages used to take these numbers into the future (IPCC, 2018) – shown by the red and blue limits, and calculated differences at specific times in black arrow; the double-headed arrow and accompanying value indicate difference between red and purple lines in 2015. The black dot shows the estimated anthropogenic warming (0.93°C in 2018; Millar et al., 2017). Population estimates (in billions) are from UN (2014, 2017); the demand compared with present day food is projected to increase 70 to 100% by the baseline decade, by which time freshwater demand will outstrip supply (Reyerson, 2015). If food production is increased using present agriculture practices, GHG emissions will surge (food production already contributes more than 30% anthropogenic greenhouse gases); and reducing water consumption will challenge food production. Moreover, global food production presently remains the most devastating enterprise for ecosystems. Unlike capital-intensive countries, where population is likely to decrease significantly over this century, this is not so clearly the case across Africa. Africa has a population of 1.2 billion predicted to increase to 2.5 billion by 2050.

United Nations (UN) reported one-third of the world's production land degraded (Lal, 2009). Globally, about a quarter of the total production land area has degraded. Soil carbon and nitrous oxide from fertilizer is released into the atmosphere when land is degraded (UN, 2019).

By 1798, British economists Thomas Multhus warned that unchecked population growth would outpace food production, and set the stage for widespread starvation. He "*observed that an increase in a nation's food production improved the well-being of the populace, but the improvement was temporary because it led to population growth, which in turn restored the original per capita production level*". Populations have a tendency of growing until the poor lower classes suffer hardship, and are more susceptibility to disease and famine (Agarwal, 2019).

Food, like air, it is a basic human need, additionally a healthy diet is a key component for human health and wellbeing. A globalised system has developed over time to enable food production and food delivery to meet our needs. Conventional and organic farming are different food production systems with different production processes. Conventional farming is a system with continual use of synthetic chemical fertilizer and often employs intensive tillage (Pitts, 2016). Organic farming, by contrast, is a system that avoids the use of synthetic fertilizer and strives for the sustainability of the environment and the ecosystem (Pitts, 2016).

Several studies that investigated how and why farmers choose between organic and conventional farming used a series of questionnaire (Fairweather, 1999; Darnhofer et al., 2005). Another study focused on why farmers still use pesticides and fertilizer given knowledge of their detrimental impacts on the environment and people (Wilson and Tisdell, 2001). Most farmer's state that they are highly driven by high crop yields, and simplified management for commercial farmers.

In America and Europe, there are running long-term research trials that have been established comparing organic and conventional farming systems. For example, in Pennsylvania, USA, Rodale Institute was founded in 1981, a long-term farming system trial established with the objective to compare three farming systems: legume based, manure based and agro-chemical input based farming (Mäder, 2006). Similarly in Therwil, Switzerland, DOK (D-biodynamic, O-organic, K-conventional) was founded in 1978 (Raupp et al., 2006; Mackintosh, 2011; Rodale Institute, 2011). Lastly, in

Denmark, Aarhus university founded ICROFS ( ) in 1996, with the objective to compare organic farming systems with green manure crops. (Mäder, 2006; Rodale Institute, 2011).

The above-mentioned research trials served as guidance in the establishment of the Mandela trials, in George campus of the Nelson Mandela University, Western Cape province, which is selected as study area one in this project (Figure 1.). Study area two is in Bethlehem, long-term wheat research trial of the University of Free State, Free State province, with three denoted tillage practices. The crop management practices to be compared for GHG emissions in study area one are organic versus conventional farming systems, and the tillage practices to be compared for GHG emissions in study area two are plough versus no-till versus stubble mulch.

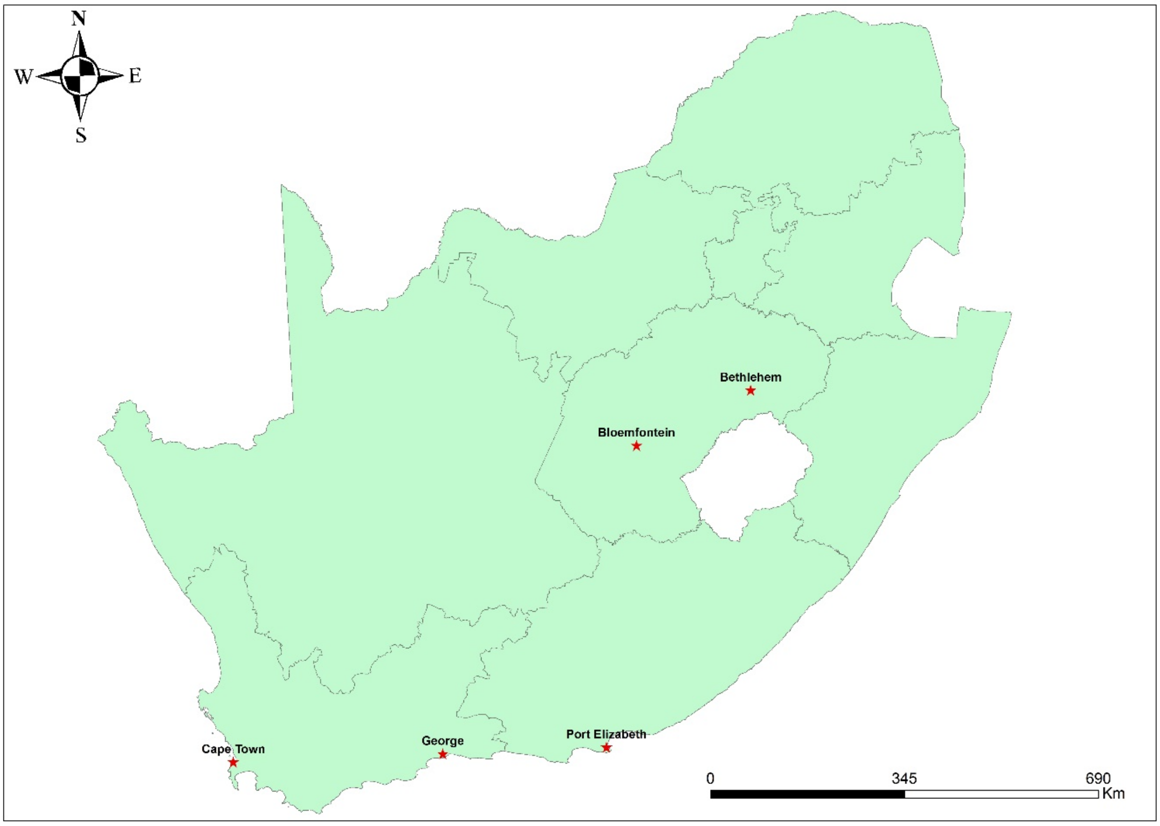


Figure 1.2: Map of South Africa showing location for study area one, in George, Western Cape and study area two, in Bethlehem, Free State.

The selected GHG's to be assessed for emissions in this study are CO_2 and CH_4. This study is focussed on measuring and quantifying emissions of the above-mentioned

GHG's from cultivated agricultural soils. The gases are analysed by a new infield mobile CO_2 and CH_4 quantification instrument (Picarro G2201-i) (Figure 1.3), currently the only such instrument in South Africa. The instrument is used to identify and quantify freely emitted CO_2 and CH_4 from the soil, which is trapped in a canister before analyses.

Figure 1.3: Picarro G2201-i gas analyser, presently the only such instrument in South Africa. The instrument is capable of identifying and quantifying CO_2 and CH_4 isotopes.

1.1 Objectives

The context of the study is arranged in a way that chapter one presents the introduction of the study, emphasizes on the importance of the study and provides the objectives.

The primary aim of this study in George was to assess which of the two production systems between conventional and organic production emit more GHG's in to the atmosphere. In Bethlehem, the aim is to assess GHG emissions trend from three different tillage systems, namely no-till, plough and stubble mulch.

The secondary aim of this study is to establish a relation between GHG emissions and soil moisture content.

The third aim of this study is to establish a relationship between GHG emissions and temperature. This will be obtained by:

- Trapping gas emitted from the soil during sampling and analysing it for CO_2 and CH_4 concentrations
- Collecting soil moisture content during gas sampling
- Recording ambient temperature during gas sampling

Chapter two presents the background of the study, including relevant factors affecting crop management practices and food production. Chapter three presents the study areas introduction and backgrounds of the research trials selected, as well as the research materials and methodology. Chapter four presents the results from both study areas. Chapter five presents the discussions of the results and discussion of the study at large. Chapter six concludes by presenting the summary and recommendations, which includes empirical findings and limitations of the study.

Chapter 2

2. Literature review

An estimated area of ca 18 million km^2 across the world covers cultivated farmlands, and grazing land for livestock occupy ca 30 million km^2 (Butler, 2015). Most of the arable land available is in the form of tropical forest, which is promoting biodiversity, and it would accelerate climate impacts if cut down to expand agriculture (Butler, 2015).

Cultivated farmland emits more GHG's than uncultivated land (Williams et al., 2018), the most significant effect is from mechanical cultivation of soils (Cho, 2018). By cultivating soil, the disturbance allows for greater oxidation by soil microorganisms with a consequent release of CO_2. Soils contain between 30-90ton of carbon/ hectare at 30cm depth. Cultivated soils can lose up to 3ton of soil carbon/ hectare/ year, depending on the number of factors, primarily soil type, preceding cropping, moisture content and intensity of the cultivation. (Young Carbon Farmers, 2019)

Scientific consensus has it that the recent concentrations of GHG's in the atmosphere are responsible for raising global average temperatures by 0.9^{O}C in the past hundred years (Thompson, 2016). The recent rise in atmospheric CO_2 increases on par with fossil fuel burning, population growth, increasing food demand and increasing soil degradation levels. Recently temperatures have near 1.5^{O}C above those of pre-industrial, a milestone the Paris agreement intends to avoid. It is very important to reduce the amount of GHG emissions in the next decades to mitigate the anticipated rise of 1.7 ^{O}C to 3 ^{O}C of warming within this century (Thompson, 2016; WWF, 2019).

Without GHG's, hypothetically, CO_2 levels drops to zero and the H_2O as a feedback response drops as well, calculations show that under such conditions the Earth's surface would be 33^{O}C cooler (Volk, 2008). Average surface temperature is now 15^{O}C; it is obvious that without GHG's earth would be a frozen ball in space (Archer and Rahmstorf, 2010). Natural levels of GHG's keep the planet from a natural ice age, but rising levels of GHG's threaten to destabilise the climate (Volk, 2008).

2.1 Climate change

The average of long-term weather conditions and behaviour is referred to as climate. It is significant to our livelihoods because it is a determinant of what food we can grow, where and how we can grow the food, where we can settle and indirectly controls the availability of water for irrigation and drinking (Davis, 2011).

Changes in climate is expected over a very long period of time (UN, 2019). These changes can occur both naturally, and/or influenced by anthropocene, like agriculture, which is the main focus of this study. (Crutzen, 2002). Since the industrial revolution, anthropogenic emissions of GHG has risen steadily, driving other changes of the climate system (Crutzen, 2002) .

Average global temperature in 2010 was 0.53^{O}C above the 1961-1990 average (Davis, 2011) . 2010 was also recorded as one of the warmest year, along with 1998 (IPCC, 2018). The World Meteorological Organisation (WMO) has recorded that we've experienced the warmest ten years on record in the past two decades(Davis, 2011).

Currently, global average temperature is 0.93^{O}C above industrial revolution average (De Wit, 2019). Temperature increase across the regions and across the globe is not uniform, as GHG emissions are not uniform too. Therefore changes across regions will be different (Davis, 2011).

2.2 Soil organic carbon

Carbon is responsible for life on earth. Its form of existence is as gas (CO_2) in the atmosphere, and can also be in the present as soil organic matter or plant biomass (Young Carbon Farmers, 2019). Soil organic carbon is responsible for nutrient availability in the soil as well as the health standard of the soil (Lal, 2014). Soils across the globe harbours twice the carbon in the atmosphere, ca 2500 billion tons of carbon in the soil, ca 800 billion tons of carbon in the atmosphere and ca 560 billion tons of carbon in animal and plant matter(Ecological Society, 2012).

Because of recent anthropogenic activities like overgrazing and cultivation, soil carbon levels have decreased by ca 50% from pre-agricultural levels in many regions (Lal, 2014). According to Lal (2014), the world's soils used for anthropogenic benefits have lost between 50-70% of their natural carbon stock, most oxidized to become CO_2 in the atmosphere.

The global available cropland has the potential to harbour an additional 1.85Gt/carbon/year (Cho, 2018). One study estimated soils may be able to sequester carbon for another 20-40 years, before becoming saturated (Cho, 2018). Soil is stored in the soil as soil organic matter. Decomposing life matter such as microbes, animal or plant tissue and other carbon compounds associated with soil minerals from soil organic matter (FAO, 2017; Cho, 2018).

The storage of carbon is known as carbon sequestration. For a long-term carbon can be stored in soils, oceans, vegetation, and geological formations (Brady and Weil, 2008). Temperature, rainfall, land-use management, and soil type influence soil organic carbon levels (Schwartz, 2014;.

2.3 Carbon dioxide (CO_2)

General scientific consensus has it that over the next century the biggest forcing agent on climate change will be CO_2, probably by more than 90% (Volk, 2008). This is the reason for the intense focus on carbon offsets, carbon tax and carbon cap (Volk, 2008).

CO_2 is one of the most significant earth's long-lived GHG. It has average atmospheric lifetime than other GHG, CH_4 or N_2O for example. This is because the gas isn't destroyed off in the atmosphere, but instead travels through living organisms, ocean and atmosphere. As opposed to CH_4 and N_2O, which die-off in the atmosphere after fourteen years and one hundred and twenty years respectively (Lindsey, 2019).

In sufficient amounts of oxygen, CH_4 burns to give off CO_2 and H_2O. When CH_4 burns in the air, it has a blue flame (Hütsch, 1998). When it undergoes combustion, it produces a great amount of heat, which makes it very useful as a fuel source; if it doesn't burn, CH_4 in the atmosphere oxidizes fairly rapidly, changing ultimately into CO_2 and H_2O, in about a decade (Cui et al., 2015).

About 85% of the world's CO_2 emissions comes from fossil fuels, and about 80% of those come from just two sources: coal (46%) in its various forms, including anthracite and lignite, and petroleum (33%) in its various forms, including oil, gasoline, and propane. However, coal produces the great majority of the world's steel and cement and 40% of its electricity (Global Carbon Project, 2016). The percentages vary from place to place, but the pattern remains. The latter observed increase in atmospheric

CO_2 shows an "on-par" growing relationship with burning fossil fuels. (Kaddo, 2016), and it is now well known that about 60% of all fossil fuels emissions are not cleaned by the ecosystem and are harboured by the atmosphere.

Overall rise of atmospheric CO_2 started in the 1850's at a pre-industrial value of 280 parts per million (ppm) (Volk, 2008). Today, CO2 levels in the atmosphere are higher than they've ever been in the past 800 000 years of climate variability (Lindsey, 2019) (Figure 2.1). National Oceanic and atmospheric administration (NOAA) collected data for analysis using air samples, they discovered CO_2 concentrations are now 409 ppm in 2019 (NOAA, 2019a).

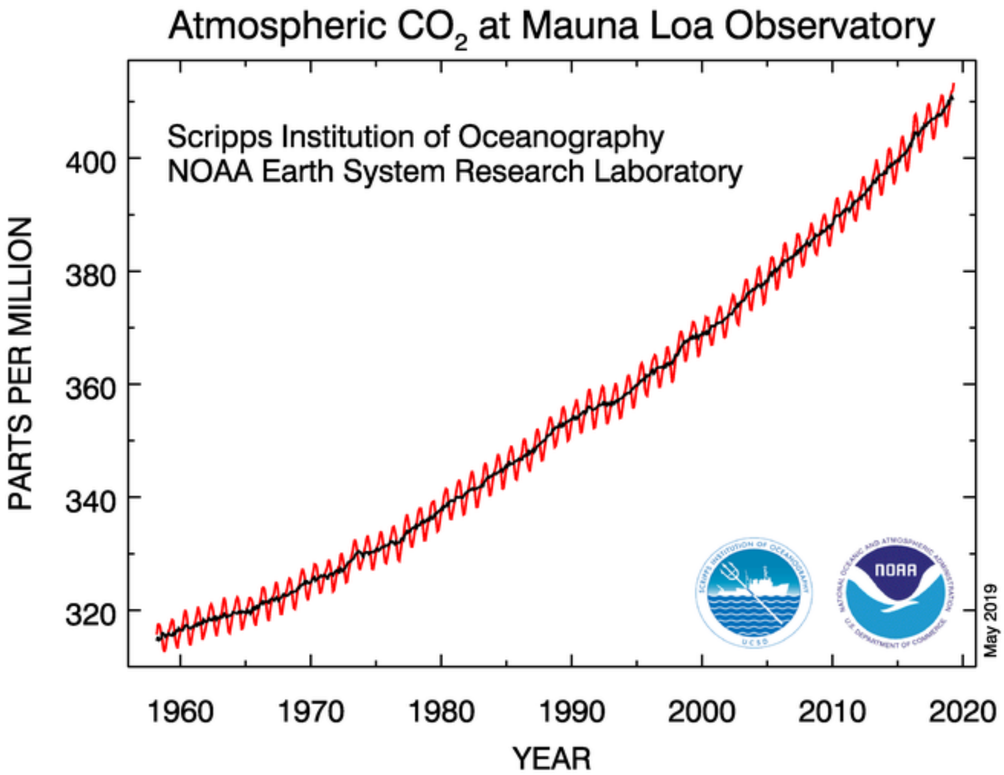


Figure 2.1: Changes in CO_2 concentrations in the atmosphere, from 1960 to 2020 (NOAA, 2019a)

Just as per cent means out of a hundred, ppm means out of a million, the most expedient unit for talking about the air's CO_2 concentration. This means that, hypothetically if you were to grab a handful of air (and remove the H_2O, which varies with humidity) only 409 of every million molecules of air would be molecules of CO_2. That would be 0.04% (Volk, 2008). If GHG emissions in the atmosphere are stabilized between 450-550 ppm, the risks of uncontrollable impacts will be reduced (Stern, 2007)

7.8 billion tons of CO_2 is equals to 1ppm of CO_2 (Mann, 2018). 409 ppm multiply by 7.8 billion equals to 3.1 trillion tons of CO_2. Doing the same type of maths, at a pre-industrial value 280 ppm- 280 ppm multiply by 7.8 billion tons equals 2.19 trillion tons of CO_2. Today's atmospheric concentration (409 ppm) subtract pre-industrial value (280 ppm) concludes Anthropocene has increased 0.91 trillion tons of CO_2 in the atmosphere in the past 200 years(Mann, 2018). The result of that has risen global temperatures by about 0.9^{O}C (Figure 2.2), with most of that warming since the 1970's (NOAA, 2019a).

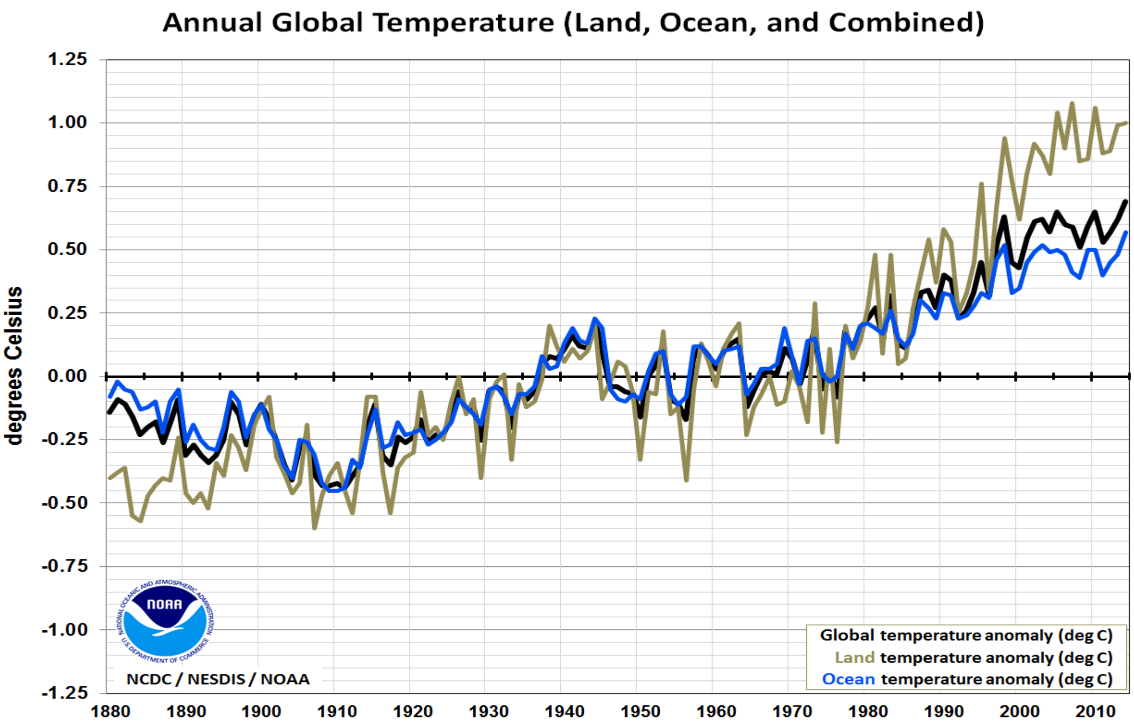


Figure 2.2: Presenting average temperature anomaly on land, ocean and global since the 20th century (NOAA, 2019a)

The view that a colourless, odourless, non-toxic gas that formed less than 1% of the atmosphere might threaten civilisation is bewildering (Mann, 2018). Anthropocene per year emits around 40 billion tons of CO_2 (Mann, 2018), that's way more CO_2 than plants and the ecosystem can soak up; about 40% (absorbed by plants, micro-organisms, and the ocean) leaving behind a very influential excess every year (Mann, 2018).

2.4 Methane (CH_4)

CH_4 is the second dominant widespread GHG emitted by Anthropocene after CO_2; accounts for around 14% of GHG emissions (Cui et al., 2015). It has about eighty times the effect on climate as an equivalent amount of CO_2, and it's global warming potential (GWP) is thirty four times more potent than CO_2(Lassen and Løvendahl, 2016). A typical CH_4 molecule will only remain in the atmosphere for ten to twenty years. CO_2 molecules, by contrast, will keep floating for centuries, even millennia (Cui et al., 2015). The gas is nontoxic when inhaled, but it can cause suffocation by reducing the concentration of oxygen (Wang et al., 2010).

Geological and biological processes occurring over time form CH_4under the seafloor and below ground (Lassen and Løvendahl, 2016). CH_4 concentration have been increasing fast, since pre-industrial period. This is observed by experiments done from ice cores, which suggests that the concentration of CH_4 currently increases by 0.8% per year (Pearman and Fraser, 1988; Lelieveld et al., 1993; NOAA, 2019b). From the year 1750, concentrations of CH_4in the atmosphere increased by 150%, this resulted in increased radiative forcing estimated at around 20% (NOAA, 2019b).

Half of the globe, north from the equator harbours at least 25% permafrost. Permafrost refers to the frozen ground for a period, mostly over two years (Nisbet et al., 2016; Radford, 2019). They harbour detritus, organic matter by decomposing organisms and other microbes over thousands of years. It's come to our attention that arctic soils are now thawing at a faster rate than previously anticipated, further threatening to emit large quantities of CH_4 (Radford, 2019).

According to NOAA (2019b), about 10 000 years ago natural atmospheric CH_4 concentration was about 700 ppb. Since industrial revolution, CH_4 has risen to about 1866 ppb (Figure 2.3) in 2019 as human activities added to natural sources.

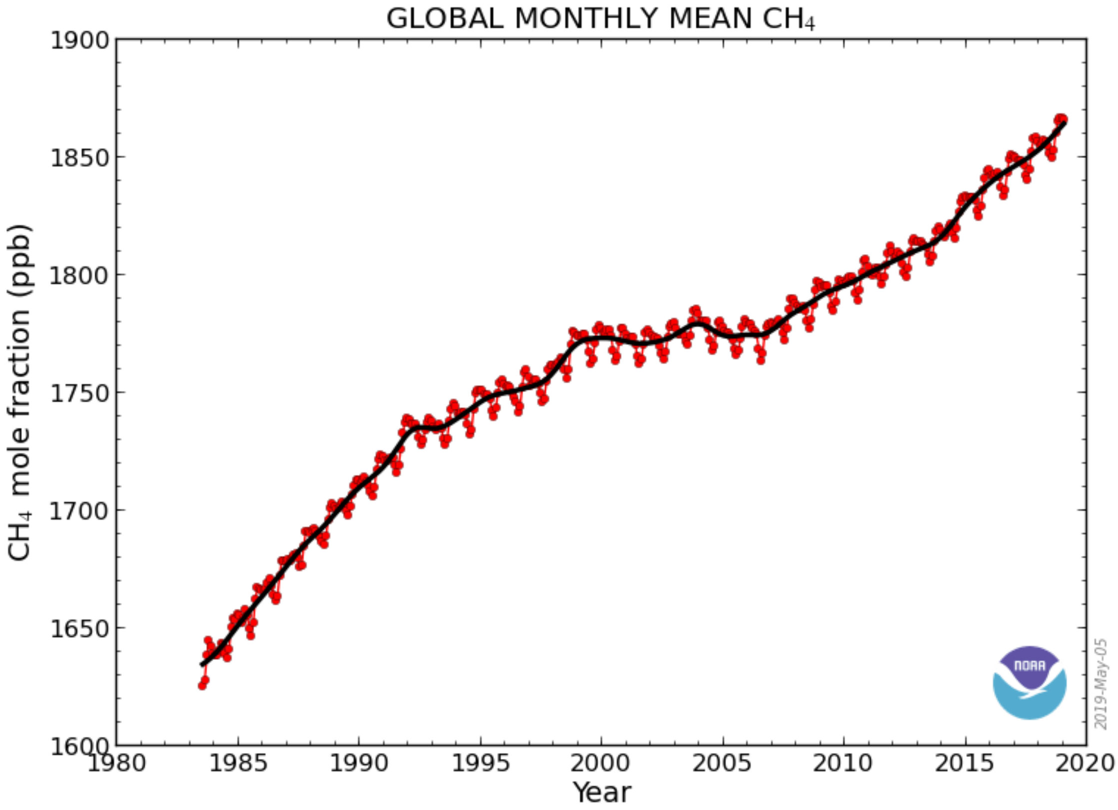


Figure 2.3: Changing CH_4 concentrations in the atmosphere from 1980 to present (NOAA, 2019b)

is formed by methanogenesis, respiration performed only by *Archaea* (Conrad, 2007); most of it is biogenic and originates from volcanoes. Agriculture emits CH_4 through digestion in ruminants, organic matter decomposition and wetlands(Lelieveld et al., 1993; Lassen and Løvendahl, 2016).

Methanogens are microorganisms that produce CH_4, they occupy landfills and soils and are present in fermentation in ruminants (NOAA, 2019b; Conrad, 2007). By contrast, Methanotrophs are organisms that are able to obtain energy by oxidizing CH_4, and they are aerobic (Conrad, 2007).

2.5 Soil

Soil is as important as gas is to supporting life and the sustenance of humanity (Brady and Weil, 2008). It plays a critical role in the ecosystem services of water, air and life. It is also responsible for gas regulation, meaning it adsorbs and emits important gases (Lal, 2014).

Soil harbours all terrestrial life including bacteria, arthropods, fungi, plants, animals and decaying organic matter at various stages of decomposing. soil stores and provides nutrients and water to plants when required, and hosts the greatest biodiversity through soil microorganisms(Brady and Weil, 2008; Bünemann et al., 2018; Hemmer, 2019) .

Soil is a natural occurring material formed by geological processes and composed of five constituents; namely, water, gas, living organisms, soil organic matter and minerals. Soil types are categorised into three classes, sand, silt and clay. Sand particles are 0.05mm- 2.0mm in diameter, silt particles are between 0.002mm-0.05mm in diameter and clay particles are less than 0.002mm in diameter (Needelman, 2013) .

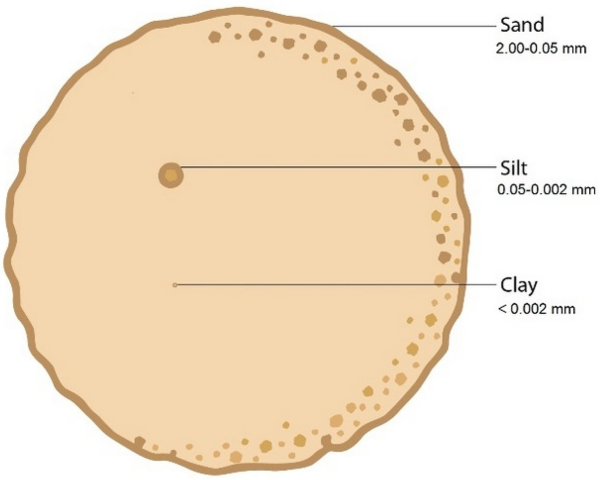


Figure 2.4: Different soil particles presented in size (Needelman, 2013)

Sand has larger soil particles enabling nutrient leaching and water drainage too rapidly. It's got a very low ability of keeping nutrients in the soil. Silt is a sediment material with particle sizes in between clay and sand, it forms fertile deposit because it is easily transported or eroded during floods, and its relative size particles permit compaction. Lastly, clay prohibits water and nutrient movement because of the fine particles that stick together (Brady and Weil, 2008; Bünemann et al., 2018).

Through geologic soil formation processes, different soil layers are formed, called soil horizons (Figure 2.5). These horizons are dependent on each other as they interact, yet they are different in responsibilities, colour and age. The diversity in soil horizons is vast (Lal, 2009).

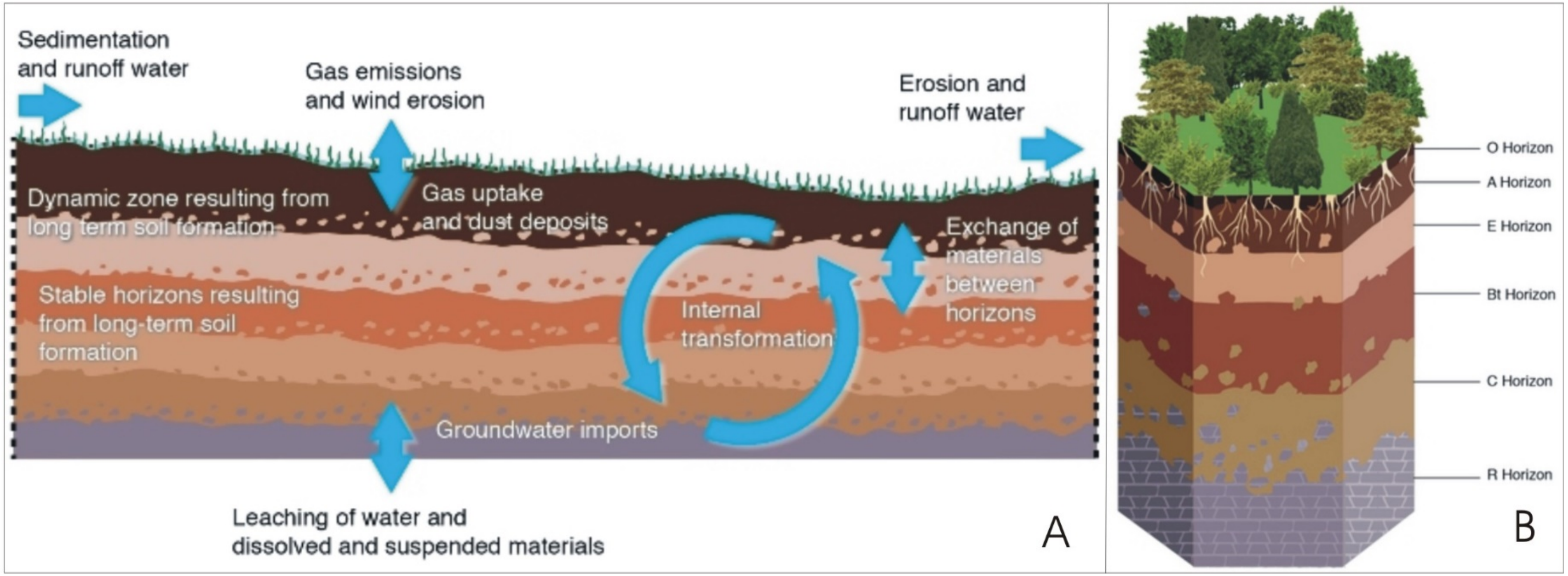


Figure 2.5: (A) Summary of soil layers with soil profile, functions and origins. (B) Soil layers and their names; O - Rich in organic matter; A – Build-up of organic matter; E – Eluviation of organic matter; B – Illuviation of organic matter; C – No soil formation and soil structure development; R – Unweathered bedrock (Lal, 2009).

Soils are primary foundation to the ecological system, and soil fertility is the soils ability to act in the living system (Bünemann et al., 2018). The two major soil fertility constraints in the semi-arid areas of Sub-Saharan Africa are: low nutrient content and acidification due to continuous cultivation and fertilisation (Mashele, 2016).

Recent studies based on noble gas geochronology concludes that on average, Southern African soils are currently being lost 30-100 times faster than they are being replaced (Decker et al., 2011). Erosion is primary culprit with regards to soil degradation. Each year around 24 billion tons of global topsoil runs-off, main blame placed upon ploughing(Coombs, 2007). In arid areas, soil degradation is accelerated by salinization and desertification(Amezketa, 2006)

Organic soil contains carbon-based material like decaying plants, microorganisms, colloidal humus and worms; and its rich in nutrients and minerals. Non-organic soil on the contrary, contains neutral pH and is free from contaminants because it has no organic matter and nutrients (Hemmer, 2019). Organic soils have an enhanced ability to sequester atmospheric carbon and store it securely. This is because soil organic matter is increased. The colloidal humus increases the surface area of the soil, allowing more nutrients to be adsorbed and more carbon to be stored (Lal, 2008; Ponzio et al., 2013; Hemmer, 2019).

2.6 Food production

The process of converting raw materials into ready-made products human can consume or store for consumption (Walter, 2018; Mckenzie, 2007). The process comprises of scientific approaches like agriculture; cultivation of crops and raising of domesticated animals, generally called farming. For the past 13 000 years, farming has been sporadically practiced, around 7 000 years ago it became widely established in the Middle East and that was foundation for growth in civilisations (Goldblatt, 2019)

As human populations grew throughout history, there has always been a pressing need to grow agricultural production to be on par with demand, simultaneously dealing with droughts, floods, resource degradation and other factors that episodically shaped food supplies (Environmental Science, 2019). Innovations that shaped food production and brought advancement include irrigation and ploughing, introduced 6000BCE and 3000BCE respectively (Mckenzie, 2007; Liebenberg et al., 2013).

Food production emits GHG through various processes, like processing, transport and packaging, in addition to the initial emitted by soil, livestock and select crops (EEA, 2016; Walter, 2018). Some unsuitable agricultural practices such as intense tillage and over fertilization accelerate GHG emissions and soil erosion (Lal, 2009).

Farmers have always ploughed manure and compost into their soil to promote plant growth (Niglia, 2019). The main reason these biological fertilizer helped the crops was because they replenish a key nutrient, nitrogen (Xin et al., 2014). In the early twentieth century, synthetic fertilizer was introduced and commercialised; chemicals enabling feeding inorganic nitrogen directly to the crops. They drastically changed the nature of food production, increasing crop yields massively and creating dependence from industrial agriculture (Xin et al., 2014; Mckenzie, 2007; Environmental Science, 2019), even though it was already being criticized by scientist like William Vogt for example (Duffy, 1989).

From all innovations in farming, there’s possibly none more influential than synthetic fertilizers. However, this method of recharging the soil had drawbacks, farmers have injected so much nitrogen into their fields that soil and ground water nitrogen levels have risen worldwide (Xin et al., 2014). Today, more than half of all the crops consumed by humankind depend on nitrogen derived from synthetic fertilizer, meaning more than 3 billion people’s worth of food can be cultivated from the same land (Ramaila, Mahlangu and Toit, 2011; Long et al., 2006).

Prerequisite resources to food production throughout history include fertile soil and freshwater. Only since the 20th century did fossil fuels become so widely used in addition to mechanised tractors and machinery (Mckenzie, 2007; Environmental Science, 2019). Most global energy use in commercial food production is distributed amongst powering irrigation systems, transport and manufacturing pesticides and synthetic nitrogen fertilizer(Xin et al., 2014).

Global food production needs to grow drastically, on par with shifting diets and increasing demand of food (Long et al., 2006). Studies have shown that by 2050, the world would need to have doubled the rate of food production(Long et al., 2006; Zezza and Tasciotti, 2010; Stavi and Lal, 2013; Chakona and Shackleton, 2019). Other studies studying the top four global crops – maize, rice, wheat, and soybean –

suggests they are actually yielding less than expected to improve to meet the anticipated demand. (Ray et al., 2013; Mann, 2018).

Increasing the food supply has led to a concomitant increase in human numbers; one study has estimated that fertilizer since the 1960's was responsible for the prevailing diets of nearly 45 percent of the world's population (Borlaug, 2000). This is equivalent to feeding about 3.25 billion people.

Human population has shown a trend of growing geometrically (1-2-4-8-16-32), where else food supply has shown a trend of growing arithmetically (1-2-3-4-5-6). Malthusian catastrophe suggests that human populations will reproduce beyond their means of subsistence unless they are held back by practices that control reproduction rates, before populations inevitably grow too large to feed ((Agarwal, 2019; Butler, 2015).

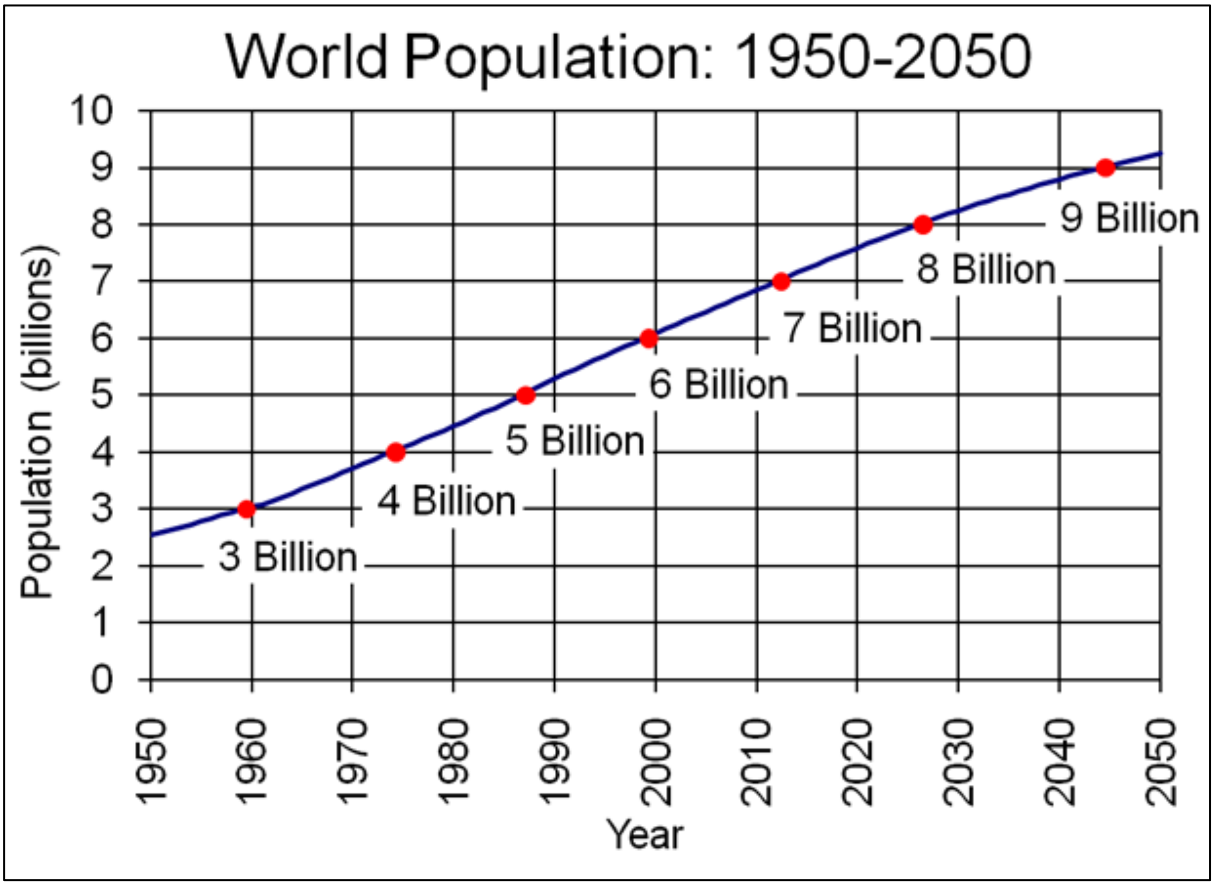


Figure 2.6: World population change from 1950 to 2050, predicted by (Theis, 2010)

2.6.1 Conventional farming

"It took about 10 000 years to expand food production to the current level of about 5 billion tons per year. We cannot turn back the clock on agriculture and only use methods that were developed to feed much smaller populations". - Norman Barloug - 2000

From the late 1950's to 1960's a revolution occurred that dramatically changed agricultural production; this revolution is known as the Green Revolution (Folger, 2009). A period were production in global agriculture increased dramatically because of new technologies and the development of high yielding varieties (HYV), new improved seeds. This was the birth of conventional production; "better farming through chemistry" (Ronald and Adamchak, 2019); synthetic fertilizer simplified nutrient supply and resulted in rapidly increased yield. Herbicides and pesticides control weeds, deter and kill insects and pests, and control disease, which also resulted in higher productivity (Folger, 2009). Increased mechanisation also meant that fewer people were needed to prepare the land (Borlaug, 2000).

Norman Borlaug is the scientist behind the research in the 1960's that led to the "Green Revolution" the combination of HYV and agronomy techniques that changed food production forever and raised crop yield around the world, saving millions of people from starvation and hunger (Mann, 2018).

The results of the Green Revolution have indeed been impressive in many areas, especially in Asia. In many regions, HYVs doubled or tripled food production (per hectare per season) in 20-30 years, outpacing population growth (Folger, 2009). History records no increase in food production that even remotely compares in scale, speed, spread and duration with that of the Green revolution (Mann, 2018).

The Green revolution simplified food production and increased yields without increasing the area of farming space. This resulted in cheaper food because production cost was reduced (Herder et al., 2010; Frankema, 2014). It further saved the environment from more deforestation because in 40 years (from 1960-2000) population increased by 100% to 6 billion, food production increased by 150% in the same period, but only 10% of natural land was converted to farmland (Borlaug, 2000)

By the late 1960's, the Green Revolution was already being criticized as culturally, environmentally, and socially destructive (Mann, 2018). Small-scale farmers had dramatic negative implications; to achieve high yields, careful management methods and relatively high and regular applications of fertilizer, pesticides and water were required (Herder et al., 2010). Farmers without access to these inputs did not and still do not benefit from the new seeds. In most Africa countries, for instance, these inputs are both scarce and subject to year-to-year fluctuations (Ray et al., 2013).

The introduction of HYVs put pressure on the traditional farming system, sustainability of the farming system, use of fallow periods, traditional multi-cropping patterns, and traditional systems of maintaining soil fertility have disappeared in many areas (Walter, 2018; Goldblatt, 2019). The HYVs replaced many traditional and locally grown varieties of crops leading to a loss of valuable natural genetic variation (Mckenzie, 2007; Mahlangu and Toit, 2011).

Conventional production employs intensive tillage which makes soil susceptible to erosion. This is damaging in various ways since top soil is more prone and richest in organic matter (Tal, 2018). Potentially transporting excess nutrients and pesticides to water streams (Edwards, 2015). A study from (FAO, 2011) suggests that around 30% of the global production land has degraded (Gibbs and Salmon, 2015; Edwards, 2015).

Applications of synthetic chemicals to soils often exceed soils capacity to filter and remediate, when soils contain more nutrients, they become a source of nutrient pollution to water bodies, leading to eutrophication; lack of oxygen. Excess application of chemicals reduces ecosystem services, degrades soils and has a harmful human health effects (Brady and Weil, 2008; Needelman, 2013; Bünemann et al., 2018).

Between 1960 and 2000 global synthetic fertilizer use rose by about eight hundred percent. About half of that production was devoted to just three crops; wheat, rice and maize. About 40% of synthetic chemicals applied sine the 1960's was not assimilated by plants as objected, instead runs off into in to water streams and is emitted as N_2O (Figure 2.7) (Edwards, 2015; Ronald and Adamchak, 2019; Xin et al., 2014).

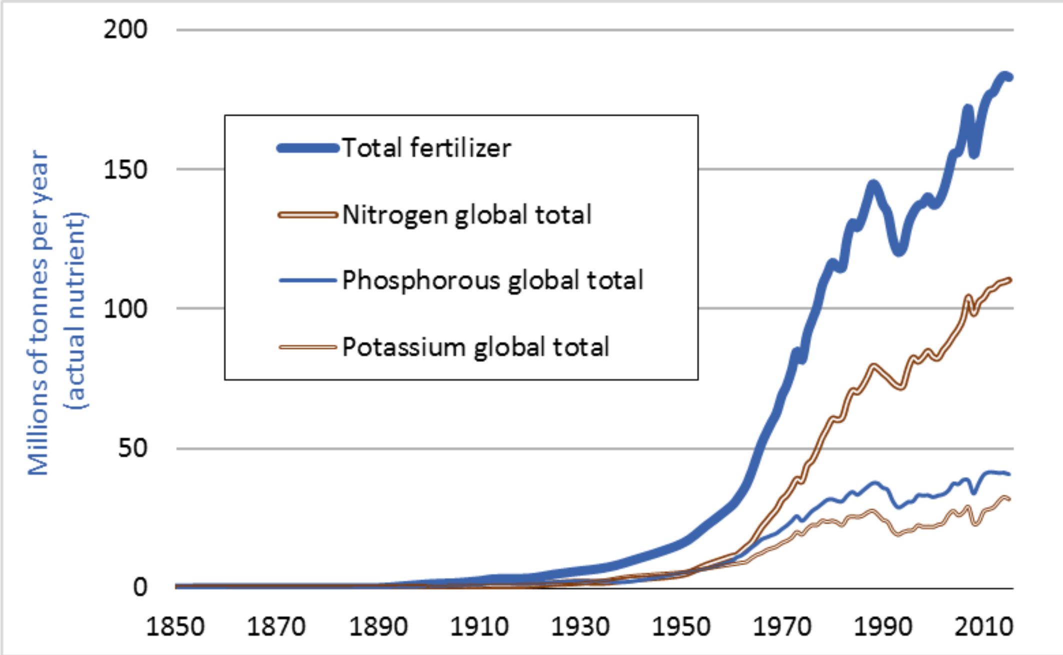


Figure 2.7: Changes in global fertilizer use from Pre-industrial 1850 to 2010 (Edwards, 2015)

Pests are able to develop resistance from pesticides over time, farmers apply more and different chemicals when this occurs and worsens potential environmental damage (Folger, 2009; Tal, 2018). One study estimated that pesticides residues are found five times more in conventional food that in organic food (Ronald and Adamchak, 2019; Edwards, 2015)

Big food production technology corporations, like Monsanto, push their agenda and business objective that genetically modified organism (GMO) seeds will significantly reduce the use of synthetic chemicals in farming. Since the introduction of GMO's in 1996, there has been an increase in chronic problems like allergies, digestive problems, autism and a few more(Zhang, Wohlhueter and Zhang, 2016; Ronald and Adamchak, 2019).

Current conventional methods may not be able to withstand challenges anticipated with climate change, and this may further exacerbate food insecurity, malnutrition and increase soil degradation as more regular crop failures occur. In addition, the increasing application and cost of fertilizers and other chemicals, and the difficulty of reaching remote farmers make high-external input farming a difficult practice for example in Africa (Mashele and Auerbach, 2016; Auerbach, 2019).

2.6.2 Organic farming

”The slow poisoning of the life of the soil by artificial manure is one of the greatest calamities which has befallen agriculture and mankind”- Sir Albert Howard- 1931

Organic farming is based on ecology and prohibits the use of synthetic chemicals; described by (Ronald and Adamchak, 2019) as “better farming through biology”. It aims to produce optimum quantities of high quality food whilst sustaining healthy soils, ecosystems and people by using processes that are natural and productive (IFOAM, 2009).

Farming organically uses natural biological technology, instead of artificial chemical technology, results in agrobiodiversity supporting farms, promoting biological symbiotic functions and supporting many interactions of the ecosystem (Ronald and Adamchak, 2019).

Unlike conventional farming and its technology, organic farmers rely on skills like crop rotation and mulch to maintain soil fertility and productivity, improve soil conditions, increase organic matter and promote soil microbiology (Auerbach, 2013; Ronald and Adamchak, 2019)

One of the primary aims of organic farming is to improve and sustain soil health, through methods that enhance the biological, physical and chemical properties of the soil (Watson et al., 2002). Various studies shown that by keeping the soil covered using cover crops and mulching, the biomass and diversity of soil microorganisms is much more prominent in organically farmed soils (Shepherd et al., 2002; Mashele, 2016). This is due to increased organic matter content, through the addition of and decomposition of plant residues from cover crops.

Compost is a good source of nitrogen, phosphorus and potassium (N.P.K) in organic farming. Compost is used to increase soil available nutrients; it is formed from decomposed organic material (Ingham, 2000). It can improve the physical and chemical properties of soils and water retention (Mashele, 2016). It is similar in composition to soil organic matter in that good compost consists of colloidal humus. Also contains macronutrients required by plants in a stabilised form, releasing them slowly to the plant roots, not all at ones on application (Ingham, 2000; Brady and Weil, 2008; Mashele, 2016).

Since organic farms use natural nitrogen from cover crops, instead of the commercially chemical based source, they use less energy to generate fertilizer (Badau et al., 2016; FAO, 2017a). Cover crops have a symbiotic relationship with soil bacteria that enables the crops to absorb atmospheric nitrogen and make it readily available for plants (Auerbach et al., 2013; Mashele, 2016; Auerbach, 2019).

A number of long-term studies have shown that crop yields from organic farming systems are usually about 20% less compared to conventional farming systems (Borlaug, 2000; Dube and Fanadzo, 2013; Oertel et al., 2016; Mäder, 2006; Mashele and Auerbach, 2016; Rodale Institute, 2011). Nevertheless Rodale research suggests that once local research has been carried out into optimising organic systems, yields can get close to that of conventional farming (Rodale Institute, 2011).

The low cost of farming organically can improve people living in poverty's livelihood by growing their own healthier food on a subsistent level, with less or no purchased external inputs (Mashele, 2016). They optimise use of locally available natural biological resources and indigenous technical knowledge (Auerbach et al., 2013). It presents a less expensive way of farming as it requires minimal external synthetic inputs, and benefits the environment by using biological resources and causing less pollution and contamination problems (Mashele and Auerbach, 2016).

Studies (from e.g Rodale Institute, 2011) have shown that organic farming produces better in during drastic climate variables, such as droughts, extreme rainfall and floods. This comes as a result of practices that improve water use efficiency and increase soil organic matter content (FAO, 2017a)

Organic farming is still closely related to its adoption challenges, which include weed control difficulties, nutrient deficiencies and uncertainties as a result of slower growth rate, less control of pests and diseases, reduced crop yields and intensive manual labour (Shepherd et al., 2002; Watson et al., 2002; Badau et al., 2016).

The high labour intensity of organic farming is viewed as a disadvantage by some, but also society's advantage as a solution to unemployment (especially across Africa) (Hammer and Anslow, 2008). Organic farming offers 32% more jobs than conventional farms, and even attracts the younger generation that as they pay more attention to healthier food (Hammer and Anslow, 2008; FAO, 2017a).

Agricultural practices are considered successful if they increase the natural resource base, are financially viable, yield sufficient produce, add to the well-being of living organisms and creates no externality costs (Reganold et al., 2011). It has been shown that organic farming in Africa is far more cost effective than high external input systems as a developmental tool for improving food security (Auerbach et al., 2013).

2.7 Food security

A food secure world is when people have access to enough healthy food, to reach their nutritional requirements at all times. The food should be affordable, nutritious and must be produced using sustainable methods that properly steward natural resources (Ziervogel and Frayne, 2011). Food security is not just producing large enough quantities to support the population; it takes into consideration social, economic and environmental factors that affect food production and consumers (DAFF, 2014).

Food insecurity brings about hunger, malnutrition and death (DAFF, 2014). It is importance to have abundance of food to feed the population, but also more important to have food products that contain the nutrients needed for the efficient functioning of human beings (Lal, 2020). The growing population and uncertainties of climate conditions require the adoption of resilient systems that will ensure food security (Reganold et al., 2011). About 900 million people annually went hungry from 2011-2013 (Rojas-Downing et al., 2017).

Given he anticipated population growth and dietary habits, global food production should double in the next 30 years to stay on par with demand. Producing more food often requires more energy/input, for example more chemical based fertilizer or more production land, which in turn emits more GHG contributing to climate change. (Hammer and Anslow, 2008; DAFF, 2014; Lal, 2020).

2.8 Water (H_20)

Water is a transparent, tasteless, odourless, chemical substance, which comprises of no organic nutrients and no calories. It is vital in supporting all forms of life(FAO, 2017c). Seventy percent of the earth’s surface is covered by water, visibly in oceans and seas and can be found underground, referred to as groundwater (IWMI, 2008). Anthropocene’s most important use for water, but drinking, is irrigation for agriculture, which is key in meeting food security. Livestock feed and crop production all depend on availability of fresh water. Even though most of the earth is covered by water, only 2.5% of global available water is fresh water, the rest is salty (Molden, 2007).

A century ago, it was common knowledge to assume water is an infinite resource. In a reality of 2 billion people, they basically needed less water that we do today (FAO, 2017c). Today, approximately 70% of earth's freshwater is used by agriculture, and there is increasing competition from biofuel crops, urbanisation and growing industries (Santos et al., 2002; Lathuilli et al., 2018; Sentlinger, 2019).

A study to establish if the world has enough water to produce for the anticipated populations was conducted by the International Water Management Institute (IWMI), they discovered that around 1.2 billion people are experiencing "physical scarcity" and 1.6 billion people are experiencing "economic water scarcity" as a result of insufficient investments or capacity and authority to meet demand (IWMI, 2008).

Various studies reported the plausibility of feeding more people in the future, though this requires a change of approach in food production because todays food production methods and environmental responses would accelerate "Malthus catastrophe" (Santos et al., 2002; Lathuilli et al., 2018; Sentlinger, 2019). Global water crisis can be avoided by farmers transitioning to methods using less water and producing more sustainably.

2.9 Biodiversity

Biodiversity is an indicator of the ecology of the environment. Various studies suggest that more diverse ecosystems are resilient to variability and change, and support a diverse population of species and ecosystem services (Steffen et al., 2011).

Widespread biodiversity loss as a result of deforestation and conventional production is not sustainable and beneficial as it affects the regulation services of the ecosystem. Given the population of our species, global challenges such as biodiversity loss and climate change needs to be addressed urgently.

2.9.1 Agrobiodiversity

Agrobiodiversity is an indicator of ecology within and amongst agricultural environments. Diverse environments offer advantageous traits like adaptability and tolerance, which can be very beneficial during changing climates. Wheat, rice and maize produce about 80% of global crop food, these three crops are selected from roughly 10 000 diverse edible sources. Our dependence on only three crops is awakening and not sustainable(Brookfield and Stocking, 1999; Bhattarai, Beilin and Ford, 2015; Karl and Haan, 2017)

Chapter 3

3. Study areas

This chapter provides the location and description of the two study areas. The study areas are firstly introduced, then their layout and objectives are provided. Secondly, soil background and treatments of the study areas are provided. Lastly, the instruments used in both study areas are discussed, and the research methodology is provided. The locations for the two study areas are illustrated on the map in (Figure 3.1).

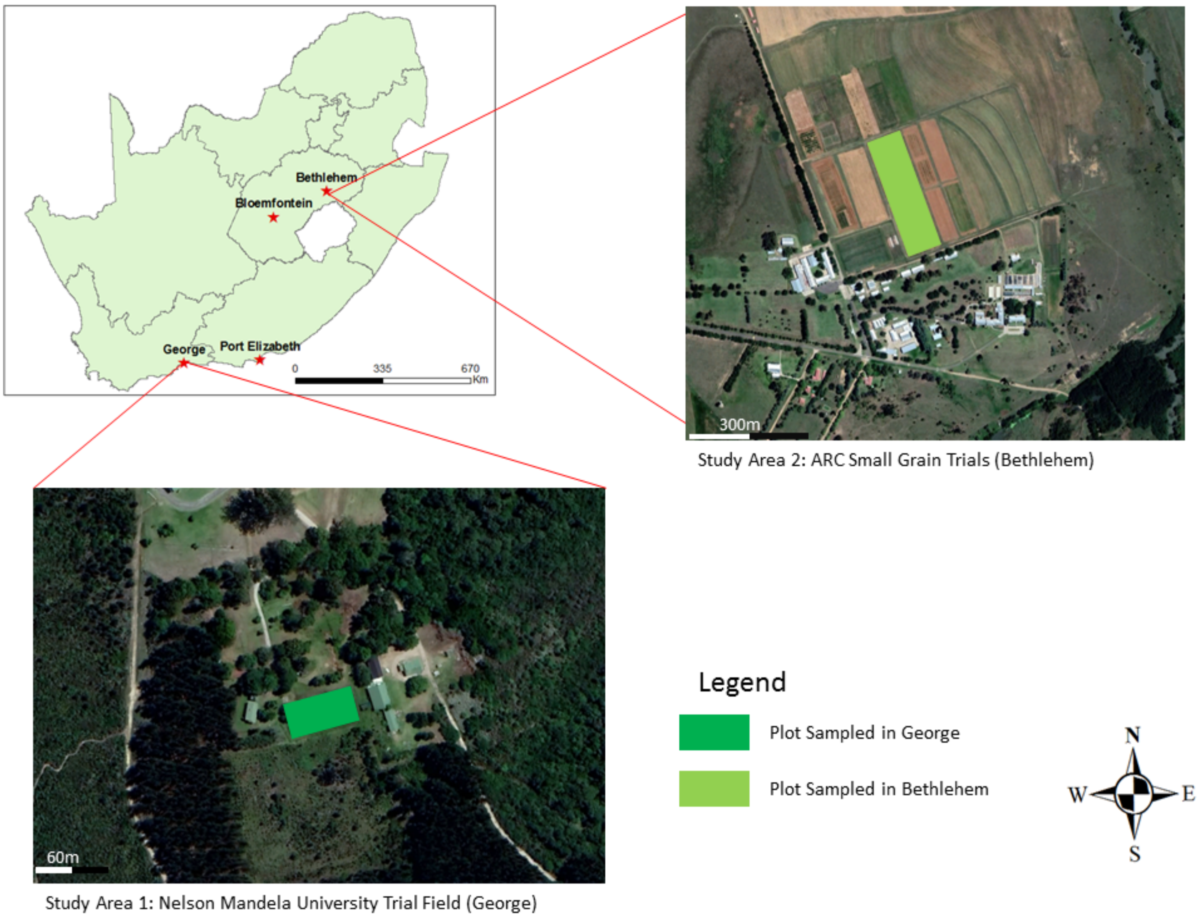


Figure 3.1 South African Map showing the location for study area 1 in George, Western Cape province (WC), and study area 2 in Bethlehem, Free State province (FS).

3.1 Introduction

3.1.1 George (Western Cape)

In 2014 comparative farming research trials were set up (Mandela Trials) at the George Campus of Nelson Mandela University (study area 1). The campus is situated to the northeast of George between Cape Town and Port Elizabeth (Figure 3.1). The comparative research site is situated to the South eastern part of the campus (22^0 32' 6. 546" E; 33^0 57' 49.289" S), and it has a 2.4 metre high electric fence around it, for safety from theft, baboons and bush pigs (Auerbach and Mashele, 2016). The research trials were set up to examine the effect of farming production systems on soil fertility and productivity, soil organic matter, water profiles, yield components, water use efficiency, disease and pest control, and food quality in conventional and organic farming systems.

The average annual precipitation in this area is around 863 mm, with an all year rainfall pattern. The climate is temperate, with daily average temperatures ranging from 7^{o}C in winter to 28^{o}C in summer (World Weather and Climate Information, 2019b). The site is under natural watering conditions (rainfed). Due to the size of the experimental area and the design of the plots, tillage was uniform for all the treatments. A mechanical tiller was used to turn over the soil.

The soil is sandy loam in texture, acidic and greyish in colour. The soil has an underlying resistant clay layer, which causes top soil to become waterlogged during wet periods. The soils had been undisturbed for about 20 years prior to the establishment of the research site, and was dominated by kikuyu grass (*Pennisetum clandestinum*) (Mashele and Auerbach, 2016)

The trial field is separated into forty plots, consisting of two farming systems (conventional and organic) and monocrop control treatment (non-fertilised). The field employs two crop rotations, mono-crop and rotation amongst cowpea, sweet potato and cabbage. The biometric layout is a randomised block (divided amongst conventional and organic production systems) with four replications of similar treatments including two control plots in every replication to improve degree of freedom for statistical analysis. Treatments were randomly allocated to each plot, keeping the organic and conventional treatments as a block, and ensuring that the control treatments were well spread out over the site (Auerbach and Mashele, 2016). See the layout of the plots illustrated in (Figure 3.2)

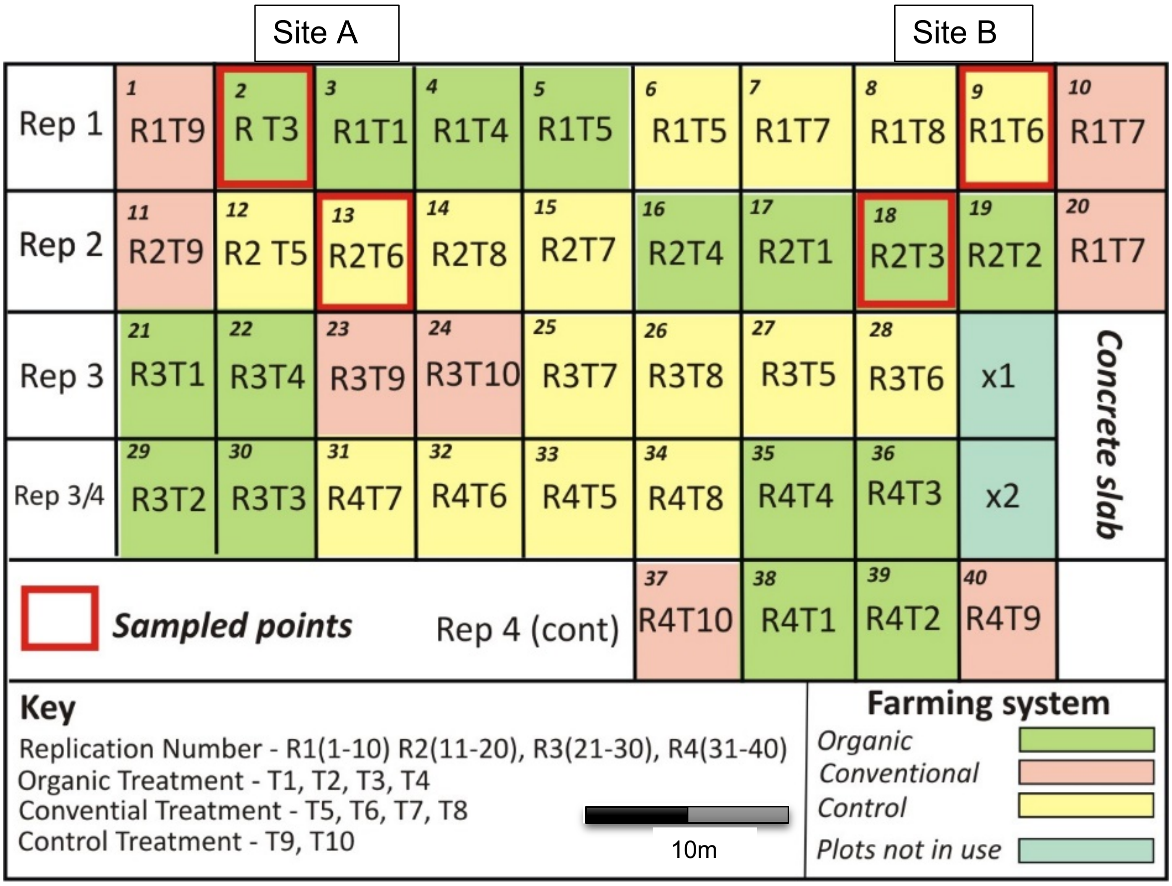


Figure 3.2: Randomised layout of the experimental site, comprising of four organic plots, four conventional and two control plots, per each replication, with four replications, adding up to forty plots in total. The blue plots (X1 and X2) next to the concrete slab, are not used for experiments in this trial site, because soil tests revealed they have high phosphorus levels. Highlighted in red squires are the four plots used for sampling in this project, two organic plots (R1 T3 and R2 T3) and two conventional plots (R1 T6 and R2 T6). R refers to replication and the number refers to the treatment, as illustrated on the key in (Figure 3.2) above. For replication purposes the sampled plots are divided into two sites, two plots in site A, organic and conventional, and two plots in site B, organic and conventional. The field covers a total area of 1500m2, each plot covers an area of 5m X 6m = 30 square meters. There is 1m space allocated in between the replications to inhibit contamination amongst the differences in treatment.

These selected rotated organic and conventional plots represent the most common production management practice used by farmers locally. The aim in this study area is to compare CO_2 and CH_4 emitted from conventional rotated soils and organic rotated soils. The objective is to derive reliable indications of gas emissions (if any) across selected plots, and help draw up a reliable budget. This aims to provide details for land use management, and reducing gas emissions from the agricultural sector in relation to climate change. Temperature and soil moisture were collected during sampling of emissions to establish the relationship between these variables and soil emissions.

3.1.2 Bethlehem (Free State)

In 1979, a research trial site was set up at the ARC (Agricultural Research Council)-Small Grain Institute in Bethlehem, Free State, South Africa (28^0 13’ S and 28^0 18’) (study area 2). The soil was previously conventionally tilled for around 20 years prior to acquisition by ARC (Loke et al., 2012). Other management details prior to 1979 are unknown.

This research trial was set up to examine crop productivity and soil fertility from various wheat production management practices (Loke et al., 2012). The average annual precipitation is around 743 mm, 82% of the rain falling in summer (October to March), with average daily temperatures range of 7ºC - 21ºC in summer (World Weather and Climate Information, 2019a).

The soil is classified under the Avalon form and Mafikeng family in the South African soil classification system; which covers 17% of the land type (Loke et al., 2012). According to Land Type Survey Staff, the trial is situated in the land type Ca6n, laid on a catena from margalitic soils from Beaufort mudstone, sandstone, shale and dolerite sills. Soil texture of the profile shows a transition from sandy loam to clayey loam at 45 cm depth (Loke et al., 2018).

This site is a monoculture wheat trial (*Triticum aestivum* L.) grown annually without any cover crop or rotation built in.

To restore soil water in this trial, since there is no irrigation, it is put on a five months fallow period during summer. Wheat was substituted with oats (Avena *sativa* L.) when signs of the soil-borne disease (*Gaeumannomyces graminis* var. tritici “Take-all” disease) occured in some plots. This was done in 1980, 1989, 1990, 2004, 2010, during which harvests were not recorded (Loke et al., 2012).

The trial layout is a randomised complete block design with three blocks (I, II and III), with block (I) being the highest and block (III) being the lowest. Each block comprises 36 plots with different treatments: three methods of tillage (no-tillage, ploughing and stubble mulch) plus two methods of straw disposal (burned and unburned) + two methods of weed control (chemical and mechanical) plus three levels of nitrogen fertilization (20, 30, and 40 kg N ha-1 until 2003, thereafter 20, 40 and 60 kg N ha-1 were used). In each block, three tillage methods were selected to be tested for CO_2 and CH_4 emissions in this study, plot number 14, 16 and 18. The layout of the experimental trial is illustrated in (Figure 3.3)

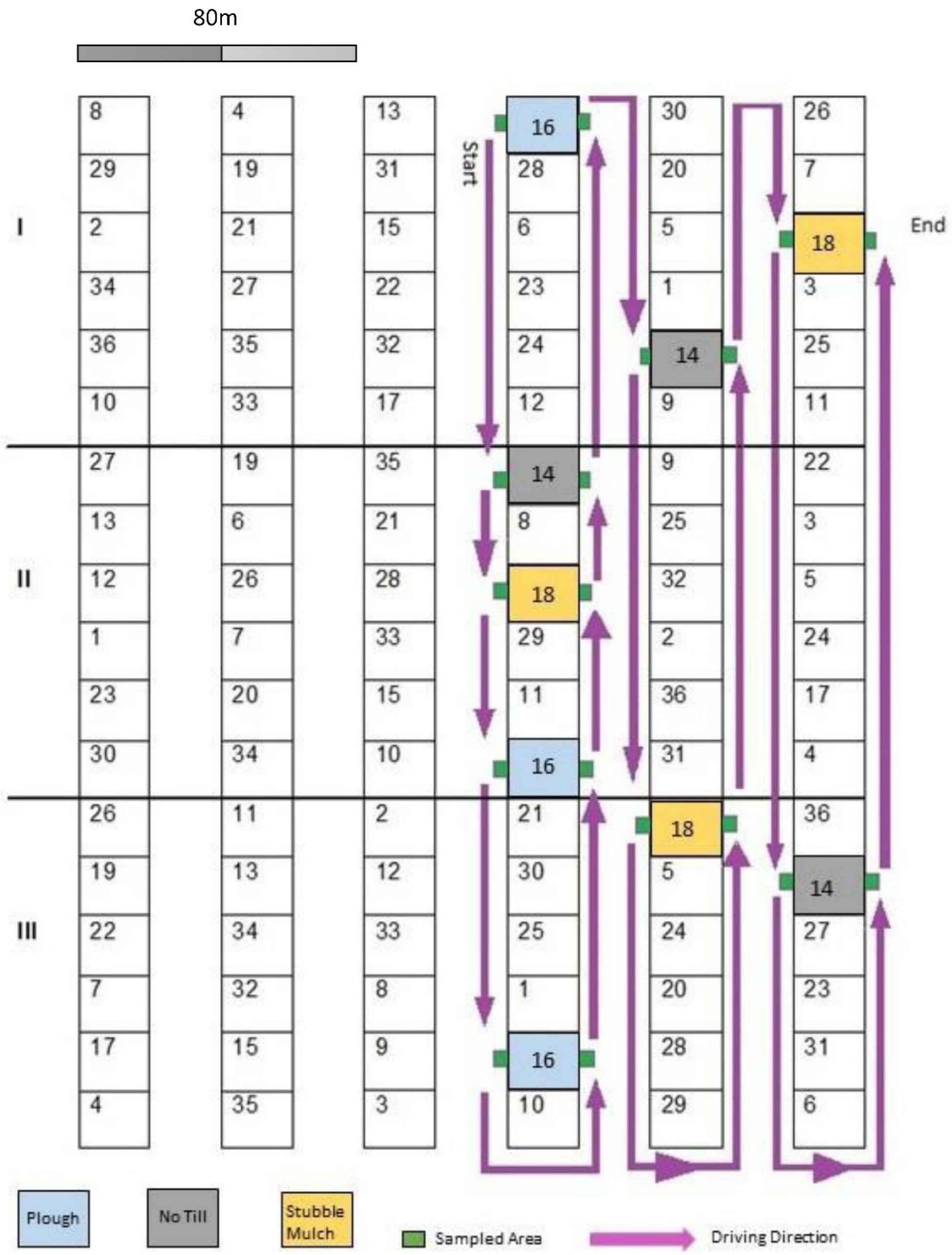


Figure 3.3: Randomised layout of the experimental site (study area two). Highlighted in grey, blue and yellow are the three sampled plots in each block. Plot 14 illustrates no-till, plot 16 illustrates plough and plot 18 illustrates stubble mulch. The purple

arrows illustrates the driving direction and the order in which samples were collected. Each plot covers an area of 30m X 6m = 180 square meters. There is a 10m border in between the rows. The total area of the experimental site is 24 840 square meters including the driveways and the total area for the plots is 19 440 square meters (Loke et al., 2012).

These selected plots (14, 16 and 18 in each block) represent the most common production management practice used by farmers locally, in South Africa. The aim in this study area is to compare CO_2 and CH_4 emitted from wheat monoculture crop management practices. The objective is to derive reliable indications of gas emissions from three tillage systems which are assessed for emissions, namely no-till, plough and stubble mulch, with the intention to minimise emissions from tillage practices and help draw up a reliable budget for land use management linked to relation with climate change.

Randomised complete block designs are the standard experimental design in agricultural experiments. The method accounts for variations in the field, randomisation converts systematic errors into independent random errors (Mashele, 2016). The blocking reduces experimental error by reducing the effect of known sources of variation in a particular field. It also increases the accuracy of the experiment, and reduces the possibility of systematic error (Cochran and Cox, 1957).

3.2 Soil Background

3.2.1 George soil background

Initial soil analysis in 2014 revealed considerable soil variation between the plots, therefore, before the comparative trial could commence, it was essential to quantify this variation by planting an indicator crop to investigate whether this variation in soil fertility parameters translated into variation in crop yield across the plots. The high variability in soil phosphorus, sulphur and pH in particular was not correlated significantly with any known factors, and appeared to be random (Auerbach and Mashele, 2016).

Caliente mustard (*Brassica juncea*), was planted on prepared soil on Friday 21st March 2014, as an baseline crop, and was lightly raked in. 1kg of seeds was planted on the gross plot area of 1500m^2.

This variety was chosen because of its abilities to suppress weeds, disease and pests as a result of high levels of glucosinolates. This variety improves soil quality, yields higher biomass under optimal soil nutrients conditions and encourages aggregated formation through extensive roots(Auerbach and Mashele, 2016).

The same crop, caliente mustard (*Brassica juncea*) was used for this study, planted over the entire field on 16th May 2018. It was obtained from Hygrotech, and broadcast at the rate of 2kg on the entire field. The site was sub-optimal with respect to pH, available phosphate and exchangeable aluminium, because of this, and the fact that nitrogen was not supplied, low yields were expected.

Yield was higher in replication 1, and dropped significantly in replication 2, 3 and 4. It was clear that plants were running out of both phosphorus and nitrogen, given that the unimproved soil is very low in both, and high aluminium levels, giving high exchangeable acidity and high acid saturation levels exacerbated the phosphorus deficiencies. For this reason, the entire field was treated with 1t/ha of dolomitic lime on the 26th August 2014, and was washed in by 12mm rain the following week. There was little change in soil acidity or available phosphorus, and a second dressing of 1t/ha of dolomitic lime was applied to all plots in August 2015, resulting in more significant, but still lacking effects. A third dressing of 1t/ha of dolomitic lime was applied to all plots in August 2016, to reduce the acidity.

Compost and fertilizer application (organic and conventional plots respectively) were calculated to bring soil phosphorus up to 30 mg/kg using the initial soil analysis results, however there was little change in soil phosphorus or pH by the end of the 2014/5 summer cropping season. Given the acidity in the trial site, and the low level of magnesium relative to calcium, the application of 1 t/ha of dolomitic lime reduced the acidity considerably, although exchangeable Al levels were not determined.

Application of 1t/ha of dolomitic lime equates to 3kg per plot in this field, lime was applied to both conventional and organic plots. In all organic plots, 15 kg/plot of compost was applied. In conventional plots, 2:3:4 of nitrogen, phosphorus and potassium (NPK) was applied to all plots; 200 kg/ha on monocrop cabbage, which equates to 0.6 kg/plot and 100 kg/ha on rotated fields, which equates to 0.3 kg/plot. Limestone ammonium nitrate (LAN) was added to all conventional plots; 0.3 kg/plot on monocrop cabbage and 0.15 kg/plot on rotated plots.

In organic farming it is customary to use mulch, to retain soil moisture and to supress weeds that might compete with the desired crop. A thick layer of mulch kept the weeds to a minimum in the organic plots, thus allowing crops to grow with very little competition, increasing chances of the crop thriving.

Organic farming often takes a few years to develop soil biology (2-4 years, depending on skill of the practitioners), to a level where yields stabilize at comparatively high levels compared to conventional farming. This study area has been chosen because soil biology has developed in the field, increasing the value of data to be collected. While the conventional systems will enjoy the benefit of chemical fertilizer and pesticides, the organic system will have to adapt to the pressures of pests and diseases, using natural and organic pest and disease management strategies.

During this study's sampling, yield wasn't very different from the one obtained in 2014, in the sense that it was higher in replication 1 and dropped significantly in rep 2, 3 and 4. It was clear that plants are running out of both phosphorus and nitrogen, given that no form of fertilizer or compost were applied for the indicator crop, therefore, low yield levels during sampling were expected. The pest and disease control strategies were used only in *brassicas* planted in the experimental cropping seasons and not in the baseline and indicator study crop.

3.2.2 Bethlehem soil background

Soil sampling was conducted in the perennial grass 40 years ago, and selected samples were analysed for some soil fertility indicators. Soil samples were then collected in 1990, 1999, 2010 and 2016 to study the response of soil fertility indicators to wheat production management practices applied in this long-term trial (Loke et al, 2012).

Weeding, either chemical or mechanical is done ones a year, generally after the summer. Chemical weeding entails spraying herbicides at recommended rates and mechanical weeding employs a cultivator, depending on soil water level (Loke et al., 2018).

All plots are slightly disturbed by a mechanised combined seeder-fertiliser drill that sows seeds with premixed fertilizer. A fertilizer ration of 3:2:0 NPK (25%), 0.75% zinc (Zn) and limestone ammonium nitrate (LAN) (28N) was applied at rates of 36 and

71kg/ha to supplement nitrogen levels to 30-40 kg ha–1 (Loke, Kotze and Du Preez, 2012).

The stubble mulch treatments are cut at 100–150 mm using a v-blade and ripped 300mm deep, as well as ploughed treatments. The no-tilled plots were not ploughed. Stubble in no-tilled plots was neither burned nor cut; no-tilled treatments were slightly disturbed only during planting(Loke et al., 2018).

The selected treatments represent the most common wheat production management practice used by farmers in this region. These treatments plot included the three tillage practices (no-tillage, stubble mulch and mouldboard plough).

3.3 Instruments

3.3.1 Picarro gas analyser

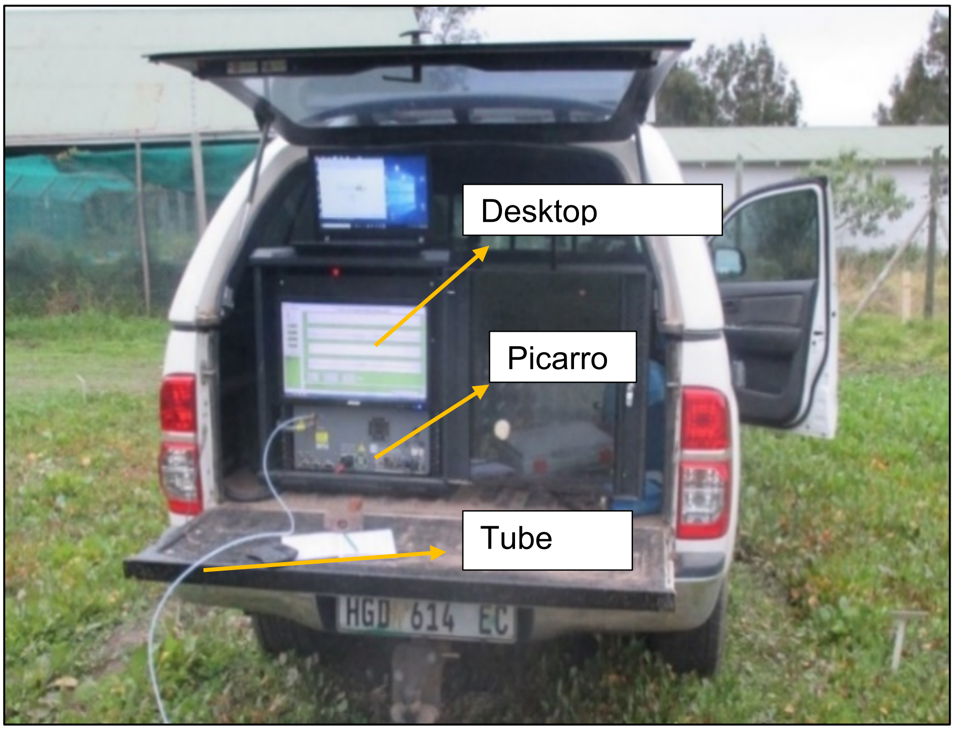


Figure 3.4: The Picarro G2201-i CRDS setup mounted into the back of a 4WD vehicle.

CO_2 and CH_4 analysis were done in field, using the field deployable Picarro G2201-i cavity ring-down spectroscopy (CRDS) (Figure 3.4) (Appendix 5). Its small and robust enabling easy transport to the field, and achieve optimal results from limited-time field campaigns. The instrument is cased and mounted into the rear of a 4WD bakkie. Two deep cycle batteries are connected to the analyser, charged via a solar panel on bakkie roof. Instrument is able to operate for over 20 hours without user interaction when fully charged. Currently the only field-deployable analyser for simultaneous high-precision measurements of CO_2 and CH_4 (Picarro, 2019).

The development of these CRDS have enabled high-precision, high resolution measurements of concentrations of gas in the field and stable isotope ratios (Campbell and Stroebel, 2018). When in use, samples are continuously suctioned through a 1.5m tube into the instrument by an externa vacuum pump. To promote stabilisation of pressure and temperature, the instrument is run for a few hours prior to sampling, though stabilization is usually observed after an hour.

Calibration was performed by multipoint Scott™ Stable Isotope Calibration Standards, a standard reference gas of a known concentration was used to ensure accuracy and consistency of CO_2 and CH_4 concentrations and isotopic ratios.

Picarro's near-infrared (CRDS) technology is capable simultaneous measurements of CO_2, CH_4 and H_2O down to PPM, with fewer calibration events than other spectral instruments (Maher et al., 2014; Picarro, 2019). The response time from the instrument was corrected for the 70-75 second lag time from the time the gas sample is introduced at the tube inlet and the time the gas sample is analysed in the cavity.

The instruments capability of identifying and detecting active CH_4 plumes was tested in a baseline study, by Richard Campbell, completed in the city of Port Elizabeth, where significant CH_4 plumes where identified at a landfill site, wastewater treatment site and in an industrial area. He also discovered that results from the mobile instrument across the Karoo can also detect CH_4 emissions along farms linked to specific agricultural practices, and which needs to be quantified when attempting to define an agricultural GHG emissions baseline (AEON, 2018; Picarro, 2019).

3.3.2 Gas canister

Study area one: Gas canister.- George

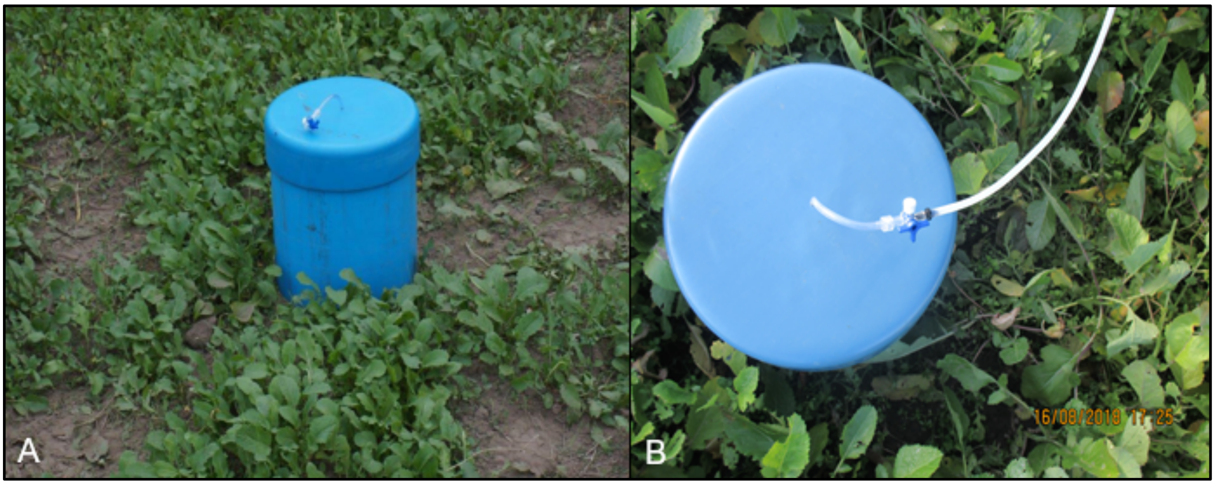


Figure 3.5: (A) Static Canister used to trap gas emitted from the soil in the airtight headspace during sampling. (B) Canister attached to Picarro tube, suctioning trapped emitted gas for analysis by Picarro.

Static chambers similar to those in (Figure 3.5) above have been widely used for gas sampling. The trial canister is made of polypropylene, it's quite robust and very easy to carry; comprises of two parts, the chamber and the lid; the lid comprises of a sampling port with a valve on it, allowing to open and close (B), it's airtight while on the canister. The chamber's dimensions are 12cm radius, 30cm height, open on both ends to allow for fitting the lid and the base being open to the field. Canister is hammered 7cm into the soil for gas sampling. The canister traps gas emitted from the soil in the headspace so the Picarro can analyse the emissions. The canister was designed and build by Bubba's in May 2018, (Appendix 8) invoice.

Study area two: gas canister. - Bethlehem

Figure 3.6: Static chamber used to trap emitted gas from the soil in Bethlehem. The canisters are different from the one used in study area one and they belong to the University of Free State (UFS).

Similar work with the instrument

Rowlings (2012) from Queensland University of Technology, Australia, used a similar type of canister to measure N_2O emissions from his trial field (Figure 3.6). Prior to the designing and building of the canister, the initial idea was to trap the emitted gas into a static tank-like structure, with installed irrigation pipes on the inside to allow for sampling long periods of time without interference (Appendix 6). Given the cost of building the tank-like structure (Appendix 7), and the objective of the study, the small robust polypropylene canisters were ideal, brought an effective process and reasonable costs (Appendix 8).

3.1.4.3 Theta probe

Figure 3.7: Theta probe placed next to canister before sampling to measure soil moisture content in percentage, 0% being very dry and 100% being very moist; this is too establishes the correlation between soil moisture and emissions. It measures only the top 6cm of the soil.

The HH2 Moisture Meter is a useful data capturing unit for use with Delta-T soil moisture sensors (Figure 3.7). The device is a compact, robust, hand-held unit, designed to be used infield. It provides immediate display on the LCD of water content in percentage, zero being very dry and hundred being very wet, and stores up to 1500 time-stamped readings, which can be displayed on the LCD or can be stored to memory for later download to a computer (DFM Technology; 2018Delta-T, 2019).

3.4 Methodology

3.4.1 Study area one- George

3.4.1.1 Experimental setup

Four canisters were emplaced in a trial field in George: two canisters in an organic field, and two canisters in a conventional field (Figure 3.8). The fields have a history of different production treatments, and this experiment measures the residual effects of the two systems (rotated conventional and rotated organic), by trapping emitted CO_2 and CH_4, as the objective of the study is to assess selected GHG emissions from these two agricultural production methods.

Figure 3.8: Two gas canisters placed in a conventional plot and two placed in an organic plot during sampling.

The open base of the canister was hammered (7cm) into the ground with the remaining 23cm above ground (headspace), this was done to all four canisters in both selected fields. The second canister in each field is for data replication purposes.

This experimental design was employed because the vehicle in which the Picarro is mounted to had to be close enough to the canisters for sampling every day. The canisters were placed in their respective fields two months after the crop was planted to ensure it had developed enough robust root systems. They are removed after sampling every day to ensure crops on the inside of the canister are exposed to the same natural environment as the crops on the outside of the canister and have access to rainfall too. Though they might be disturbances associated with placing the chamber or artificial flux of the gases, the practise is done in both field on all four canisters.

The canisters are not placed on the same area every sample; but are placed in the same field. This is to avoid disturbance of the growing crop and to ensure areas sampled are not depleted of gases from previous samples, as a result of the suction from the Picarro; thus allowing enough time to build back and not give inconclusive results.

3.4.1.2 Data collection

Prior to each experiment, soil moisture probe was placed around the canister early morning and three moisture results were collected. This is in relation to the second objective, to determine the correlation between soil moistures and CO_2 and CH_4 emissions from the selected production types.

Morning sample referred to as the zero sample (ambience) in this study refers to the gas sample collected in the early morning, after collecting soil moisture content, just following closing of the canister. This sample is then subtracted from the project sample collected in the afternoon. The difference between the two samples is the gas that was emitted during the duration that the canister was closed (Appendix 1). The other purpose of the zero sample is to suction out the ambient gas in the canisters headspace so emissions can be well sampled after the duration at which canister will be trapping the emitted gas.

After moisture content and zero sample were collected in the morning, the canisters are left undisturbed the whole day (Figure 3.9a). Atmospheric temperature is collected mid-day every day during sampling, this is in relation to objective three, to determine the correlation between gas emissions and temperature.

Figure 3.9: (A) Two gas canisters in a field during sampling. (B) Two gas canisters in the field during gas analyses, the Picarro is suctioning the gas trapped in the canister during emissions.

Later in the afternoon (before sunset) the second samples are collected, referred to as the project sample. These samples are collected in the order which follows the same one used for collecting zero sample (morning samples). The canisters are then removed from the field after this samples and stored safely for the following day.

The Picarro has a 75-80 seconds lag during analysing the data after the suction. For this reason, a stop watch is used after connecting it to the canister. For zero sample and project sample, results are only collected between 75-85 seconds, after the tube inlet is connected to the canister. (For example, if the sample is collected before, it is not a true reflection of the gas in the can, and if it is collected later, it includes gas forcefully suctioned from the top soil, not a true reflection of emissions).

3.4.1.3 Data analysis

Experimental data on GHG emissions from agriculture, particularly comparisons of crop management practices is scarce. The data collection method was designed in such a way that it could enable analysis to establish a trend of emissions between the compared variables.

For this study, I analysed the data collected from site A separately to that collected from site B. Comparison graphs are drawn with the intention to diagrammatically observe and quantify similarities or differences. The two variables, Soil moisture and temperature are also plotted with gas emissions to establish statistically significant correlations.

The soil moisture content figure used for analysis and drawing the graphs is an average of three samples collected in the morning around the canister. The gas concentration figure used for analysis and drawing the graphs is an average of the two canisters placed in one plot during sampling (Appendix 2).

3.4.2 Study are two- Bethlehem

3.4.2.1 Experimental setup

Just like in George, two canisters were placed in every sampled plot, but canisters used in Bethlehem are different to those used in study area 1 (George). The chamber comprises of two parts, the base that’s hammered into the soil (Figure 3.10), and the chamber with the lid is specially fitted to the base to make the chamber airtight, also attached to the roof of the lid is the tube (1metre long) and the valve that allows perfect fitting to the Picarro.

Figure 3.10: The base part of the canister that's hammered into the soil two days prior to sampling. The base is specially fitted to the chamber which is attached to the lid, and are airtight while attached.

The sampling strategy was the same as the one used in study area 1, in order to compare emissions of CO_2 and CH_4. The order in which gas samples were collected is illustrated in (Figure 3.3). Fortunately this study area has drive-ways planned well enough to reach all plots without causing a damage to the crops.

3.4.2.2 Data collection

This study used different data collection method to the one used in study area 1. Two days before sampling, 18 canister bases were placed in nine different fields, with three different treatments highlighted in (Figure 3.3). Two days later, the selected plots where sampled for CO_2 and CH_4 emissions. Just like in study area one, zero sample is collected, which is going to be subtracted to the project sample to observe similarities or differences amongst the three tillage practices. Each canister stayed closed for fifteen minutes during gas emissions sampling (Figure 3.11), that means project sample in all the nine sampled plots, was collected fifteen minutes after the zero sample is collected (Appendix 3). Sampling was done in one day and samples of atmospheric temperature and soil temperature were collected with the gas sample figures too.

Figure 3.11: Canister closed during fifteen minutes gas sampling. A stop watch is used to ensure exactly fifteen minutes in each plot. During the fifteen minutes, atmospheric temperature and soil temperature were collected too.

3.4.2.3 Data analysis

Analysis were done amongst the three different conventional treatments, for CO_2 and CH_4 emissions. It was not possible to include temperature and soil moisture due to insufficient observations of the variables since the data was all collected in one day, almost similar moisture and temperature conditions.

CO_2 and CH_4 comparison where not very different to those in study area one, in a sense that they are analysed diagrammatically from a graph plotting all three tillage systems together for CO_2 and CH_4 respectively. All the canisters are plotted on the graphs for analysis of this study, which is six canisters a block.

Chapter 4

4. Statistics analysis and results

Data collected was statistically analysed using two statistical approaches, pooled variance and paired t-test. These two statistical tests used for hypothesis testing decides whether we are going to accept the null hypothesis or reject it. The hypothesis test does not take decisions itself; rather it assists the researcher in decision making. Variance in emissions will only be calculated for study area one, statistical hypothesis test are not done for study area two since data is all collected in one day.

Paired t-test

Spurious variation in samples is reduced by pairing the samples on days, since conditions are closely similar (atmospheric temperature and soil moisture) on daily basis, but gas emissions. See appendix 9 for test calculations.

Conventional average– organic average = (difference used for CO_2)

Organic average – Conventional average = (difference used for CH_4)

Ho: $\mu d = 0$

H1: $\mu d > 0$

Hypothesis test used for both CO_2 and CH_4 emissions from conventional and organic soils.

Site A – CO_2

Conclusion: t-value = 1.774. Not enough evidence to reject Ho: no statistical difference between organic and conventional emissions. ($0.1 > P$ value > 0.05).

Site A – CH_4

Conclusions: t-value= 1.992. We reject Ho: there is a significant difference between organic and conventional CH4 emissions, organic > conventional. ($0.025 < P$ value < 0.05).

Site B – CO_2

Conclusion: t-value= 3.711. We reject Ho: there is a highly significant difference between conventional and organic emissions, conventional > organic. ($P<0.005$).

Site B – CH_4

Conclusion: t-value= 2.964. We reject Ho: there is a highly significant difference between organic and conventional emissions, organic > conventional. ($0.005 < P < 0.01$)

Pooled variance

A statistical way of estimating variance of several different populations when the mean of each population may be different, but one may assume that the variance of each population is the same. See Appendix 10 for calculations.

Conventional average– organic average (CO_2 hypothesis)

Organic average – Conventional average (CH_4 hypothesis)

Ho: $\mu d = 0$

H1: $\mu d > 0$

Hypothesis test used for both CO_2 and CH_4 emissions from conventional and organic soils. (One sided alternative)

Site A – CO_2

Conclusion: t value= 1.388. Not enough evidence to reject Ho: no statistical difference between organic and conventional emissions. ($0.1 > P$ value > 0.05).

Site A – CH_4

Conclusion: t value= 1.023. Not enough evidence to reject Ho: no statistical difference between organic and conventional emissions. ($0.1 > P$ value > 0.05).

Site B – CO_2

Conclusion: t-value= 2.457. We reject Ho: and conclude conventional > organic.

$2.457 > 2.441$ ($P=0.01$)

Site B – CH_4

Conclusion: t-value= 2.834. We reject Ho: there is a highly significant difference between organic and conventional emissions, organic > conventional. ($0.005 < P < 0.01$)

Results from both study areas are presented in comparable graphs. Firstly, CO_2 emissions from study area one, linked to both site A and site B are presented, followed by soil moisture content and temperature results. Secondly, CH_4 emissions in study area one are presented for site A and site B, following the same arrangement of soil moisture and temperature influences after the emissions respectively. The data is summarised on (Table 1) and its presented in figures from (Figure 4.1- 4.12.).

In study area two, the graphs compare three tillage practices and they are assessed for emissions of CO_2 and CH_4. In this study, as mentioned soil moisture and temperature are not included in the analysis. Therefore, data is presented in two graphs, the first presents CO_2 emissions and the second presents CH_4 emissions (Figure 4.13 and 4.14). The data is summarised on (Table 2).

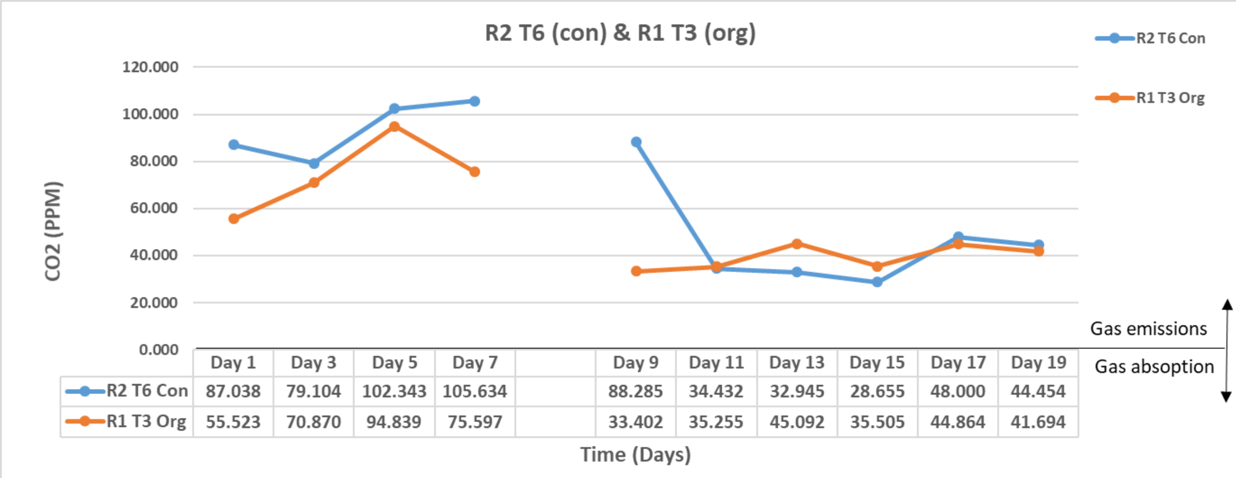
Due to the vehicle driving in the field over other plots for sampling, in study area one, it was advisable to not sample one plot over and over again, but to sample site A then Site B the following day so the soil would not be over-compacted and that the crops could revive from the pressure of the vehicle. For this reason, there is one spare day between all sampling of plots.

In study area one, data was collected for nineteen days in total. Between day seven and day eight, there was a two weeks gap without sampling. For this reason, data is presented on graphs showing a gap between day seven and day eight. During the gap time, the study area received heavy rainfall, which changed soil moisture conditions drastically and also stuck the car/instrument in the field.

4.1 George - Site A CO_2

4.1.1 CO_2 emissions

Figure 4.1 presents differences in CO_2 emissions from the conventional plot (R2 T6) and the organic plot (R1 T3). The observations suggest a conventional plot emits more CO_2 than organic plot over the ten sampled days. Though organic emitted slightly more day 6 and 8.



	Day 1	Day 3	Day 5	Day 7		Day 9	Day 11	Day 13	Day 15	Day 17	Day 19
R2 T6 Con	87.038	79.104	102.343	105.634		88.285	34.432	32.945	28.655	48.000	44.454
R1 T3 Org	55.523	70.870	94.839	75.597		33.402	35.255	45.092	35.505	44.864	41.694

Figure 4.1: Graph of variable CO_2 emissions from an organic plot (R1 T3) and a conventional plot (R2 T6) during the same time periods.

4.1.2 CO_2 emissions and soil moisture changes

Figure 4.2 presents CO_2 emissions plotted together with soil moisture content. It is very clear from the chart that when soil moisture content increased in general following heavy rainfall, CO_2 emissions decreased significantly, though on daily basis they follow a trend of increasing and decreasing together.

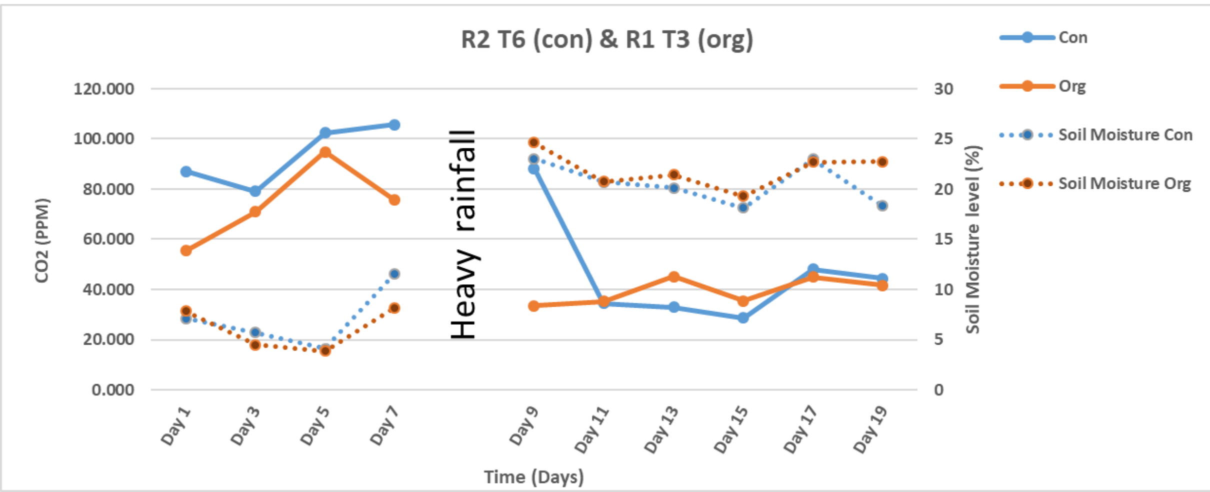


Figure 4.1: Graph of variable CO_2 emissions for two production types plotted with soil moisture to establish a relationship. Observations suggests both plots retain similar moisture patterns, though prior to rainfall, conventional soils retained slightly more moisture (Day 7). Organic soils retained slightly more moisture than conventional during moist soils, and clearly retaining more moisture on Day 12, suggesting organic soils retain slightly more moisture that conventional soils in moist soils.

4.1.3 CO_2 emissions with temperature changes

Figure 4.3 presents CO_2 emissions plotted together with temperature. Observations show that higher temperatures (19-26^{O}C) are received before the rainfall and slightly lower temperatures (15-21^{O}C) after the rainfall.

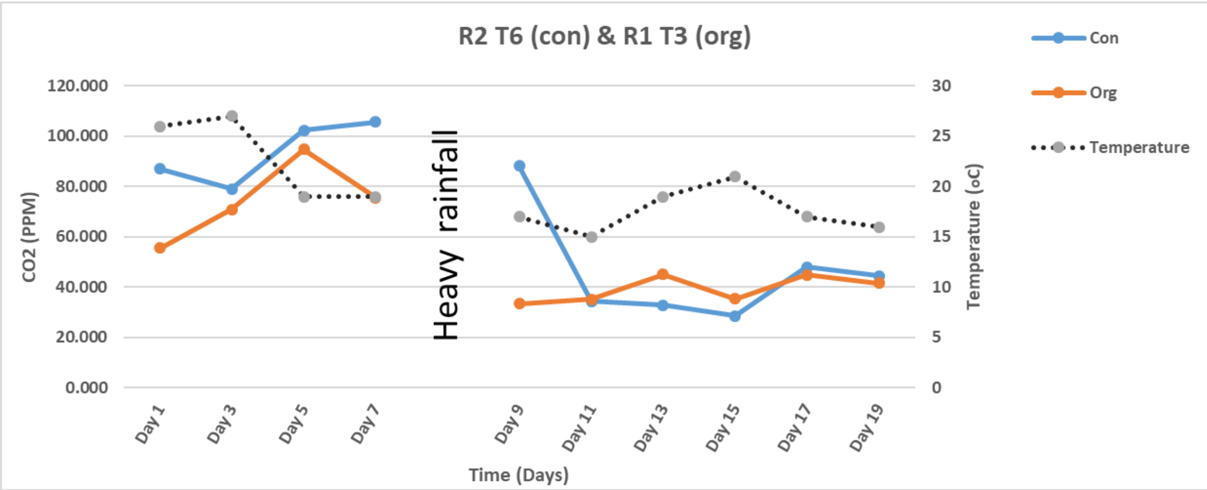
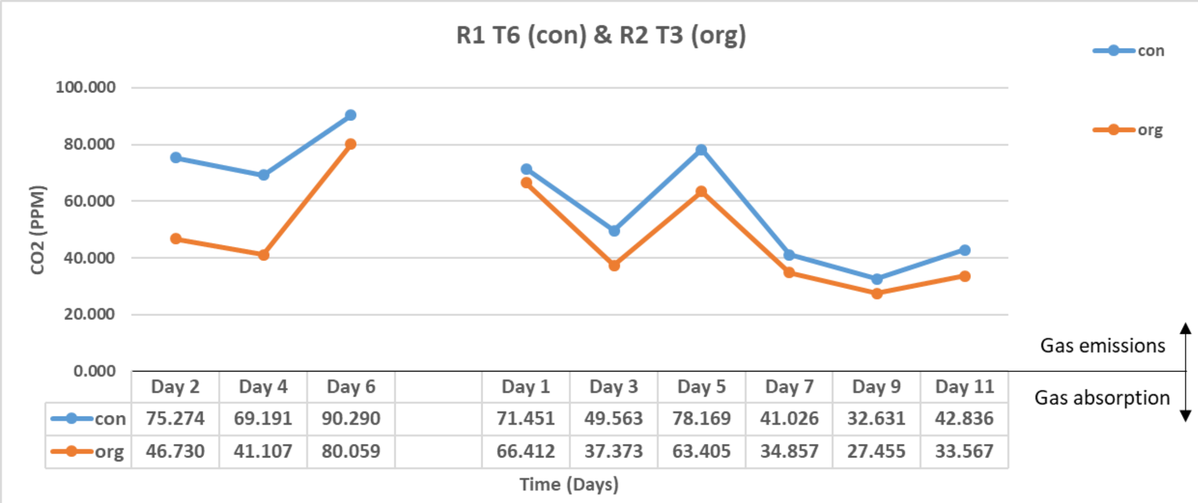


Figure 4.2: CO_2 emissions plotted with temperature. Observation show in dry soils before rainfall, CO_2 emissions increase with decreasing temperature. Trend after rainfall is not clear, though both organic and conventional CO_2 emissions increase during high temperatures, and drop with temperature during moist soils.

4.2 George - Site B CO_2

4.2.1 CO_2 emissions

Figure 4.4 presents differences in CO_2 emissions from the conventional plot (R1 T6) and the organic plot (R2 T3). The observations suggest a conventional plot emits more CO_2 than organic plot throughout the sampling duration of ten days. After the rainfall emissions followed a very similar trend with conventional soils consistently emitting slightly more CO_2 than organic soils.



	Day 2	Day 4	Day 6		Day 1	Day 3	Day 5	Day 7	Day 9	Day 11
con	75.274	69.191	90.290		71.451	49.563	78.169	41.026	32.631	42.836
org	46.730	41.107	80.059		66.412	37.373	63.405	34.857	27.455	33.567

Figure 4.3: Changes in CO_2 emissions from the organic plot (R2 T3) and the conventional plot (R1 T6) during same time periods over a sampling period of nineteen days.

4.2.2 CO_2 emissions with soil moisture content changes

Figure 4.5 presents CO_2 emissions plotted together with soil moisture content, observations are not very clear as to which production type retains more moisture in these plots. However, on daily basis they follow a trend of increasing and decreasing together, just like in site A.

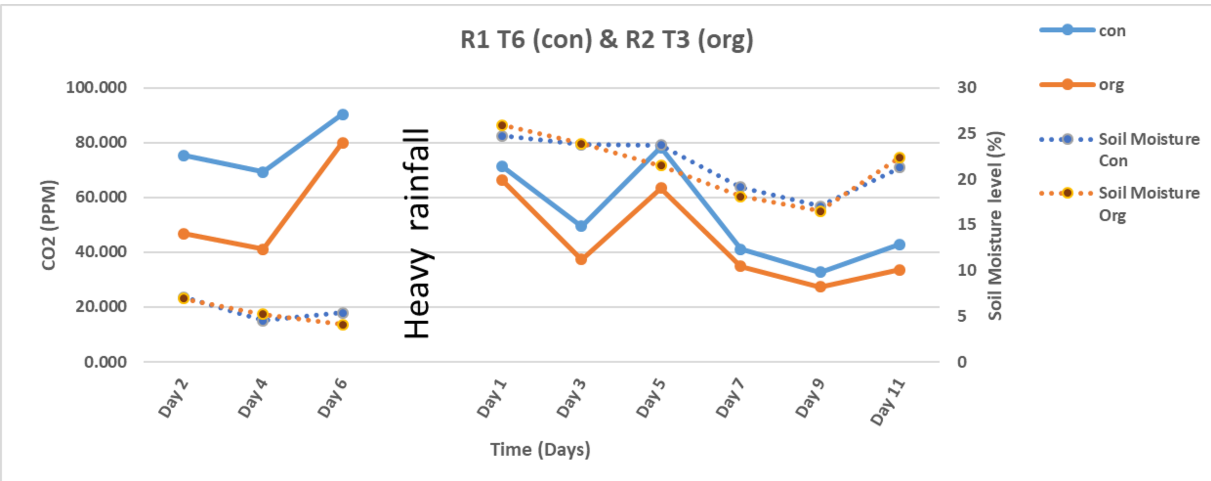


Figure 4.5: Graph of variable CO_2 emissions for two production types plotted with soil moisture to establish a relationship. Observations suggests both plots retain similar moisture patterns. Just like in Site A, observations clearly show that with increasing soil moisture content, following rainfall, CO_2 emission drop.

4.2.3 CO_2 emissions with temperature changes

Figure 4.6 presents CO_2 emissions plotted together with temperature. Observations show that temperatures are higher (18-30^{O}C) before the rainfall and slightly lower (13-21^{O}C) after the rainfall.

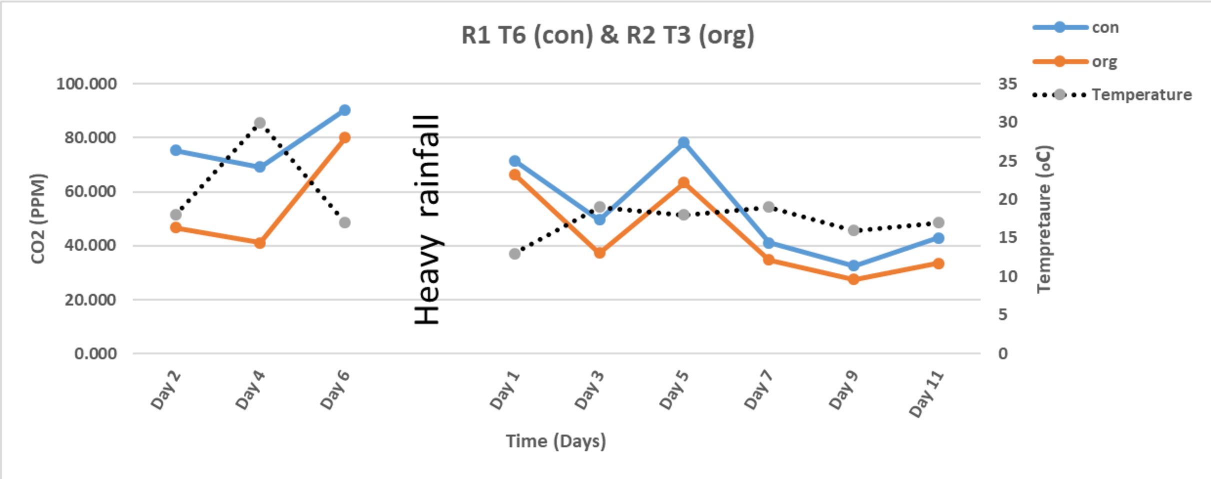


Figure 4.6: CO_2 emissions plotted with temperature. Observation show in dry soils before rainfall, CO_2 emissions increase with decreasing temperature. Trend after rainfall is not clear, though both organic and conventional CO_2 emissions increase slightly with decreasing temperatures, and decrease with increasing temperature.

4.3 George - site A CH_4

4.3.1 CH_4 emissions

Figure 4.7 presents significant differences in CH_4 emissions from a conventional plot (R2 T6) and an organic plot (R1 T3). The observations suggest that the organic plot emits significantly more CH_4 than conventional plot throughout the sampling duration, even when emissions from organic soils are at their lowest, they are still higher than those of conventional soils.

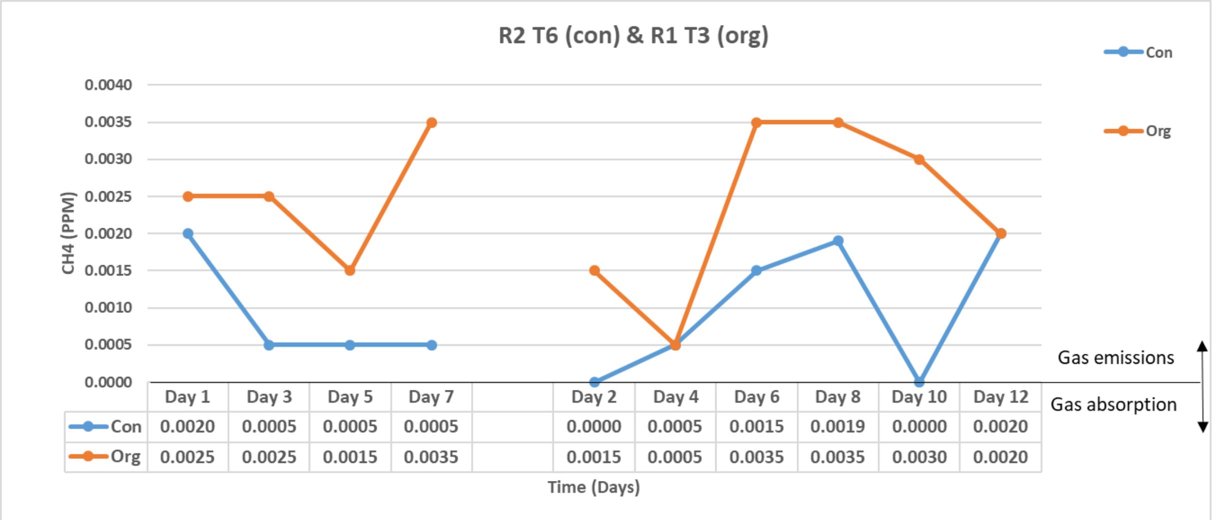


Figure 4.7: Changes in CH_4 emissions from an organic plot (R1 T3) and a conventional plot (R2 T6) during same time period, over a sampling period of nineteen days. On day 2 and 10 after the rainfall the conventional plots shows not to emit any CH_4. Note that organic plots emit more CH_4 but the concentration of the gas is very low.

4.3.2 CH_4 emissions and soil moisture changes

Figure 4.8 presents CH_4 emissions plotted together with soil moisture content, observations suggest organic plots retains slighlty more moisture than conventional plot when soils are well moist following rainfall. However, conventional plot seem to have retained slightly more moisture prior to rainfall.

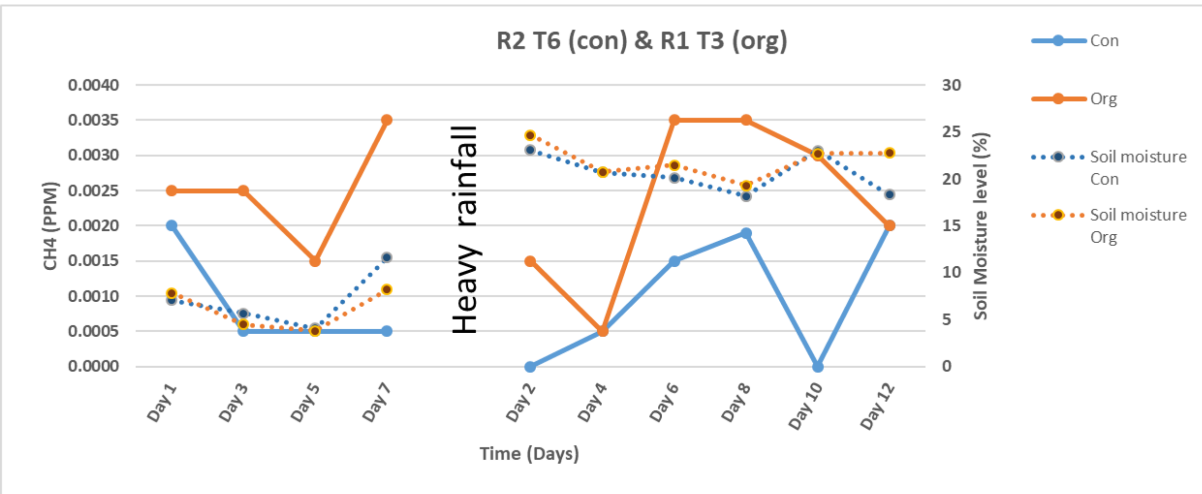


Figure 4.8: Graph of variable CH_4 emissions plotted with soil moisture content to establish the relationship. Observations suggests both plots retain similar moisture patterns. It is clear from the chart that when soil moisture content increased following heavy rainfall, CH_4 emissions from organic plot increase but not much in a conventional plot.

4.3.3 CH_4 emissions with temperature changes

Figure 4.9 presents CH_4 emissions plotted with temperature. Observations show that higher temperatures (19-26^{O}C) are received before the rainfall and slightly lower (15-21^{O}C) after the rainfall. CH_4 emissions from a conventional plot are very low during both moist and dry soils, though they follow a pattern of increasing and decreasing with temperature. Emissions from organic plots are highest (0.0035 ppm) during moist soils and still high during dry soils and high temperature.

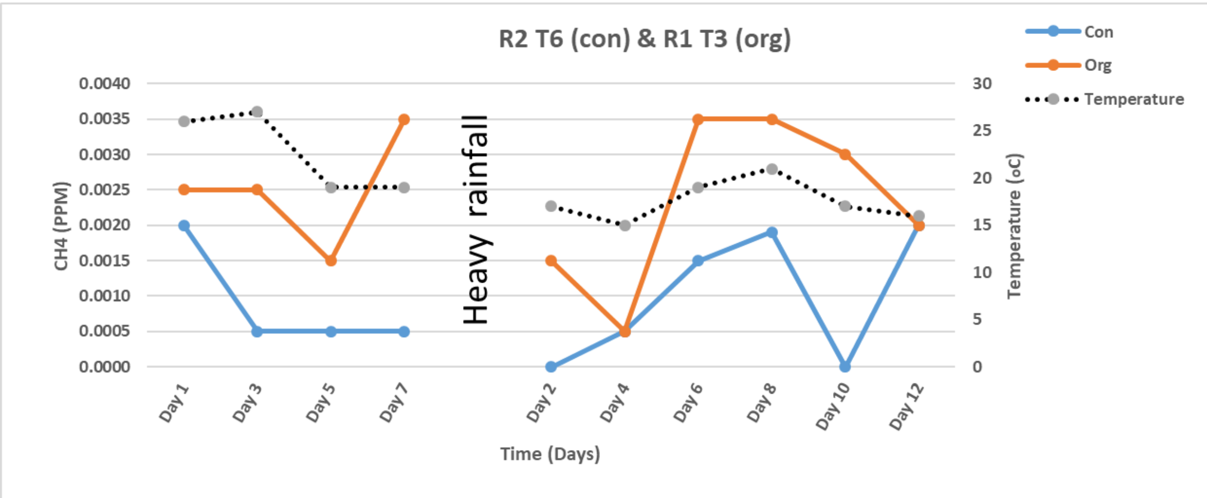
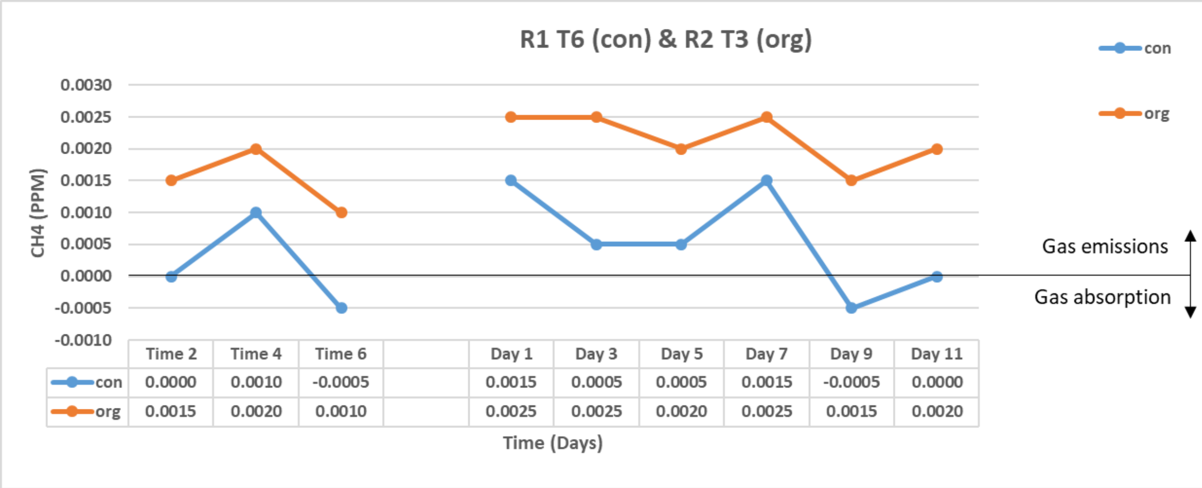


Figure 4.9: Graph of variable CH_4 emissions plotted with temperature to establish the relationship. Observations show that in dry soils prior to rainfall, emission drop with temperature. The same trend is followed in moist soils following rainfall, this suggests that temperature influences CH_4 emissions in both the organic plot and the conventional plot, since both the emissions follow a similar trend to the temperature.

4.4 George - Site B CH_4

4.4.1 CH_4 emissions and absorption

Figure 4.10 presents significant differences in CH_4 emissions from a conventional plot (R1 T6) and an organic plot (R2 T3). The observations suggest that the organic plot emits significantly more CH_4 than conventional plot throughout the sampling duration, and they follow a pattern of increasing and decreasing together.



	Time 2	Time 4	Time 6		Day 1	Day 3	Day 5	Day 7	Day 9	Day 11
con	0.0000	0.0010	-0.0005		0.0015	0.0005	0.0005	0.0015	-0.0005	0.0000
org	0.0015	0.0020	0.0010		0.0025	0.0025	0.0020	0.0025	0.0015	0.0020

Figure 4.10: Changes in CH_4 emissions from an organic plot (R2 T3) and a conventional plot (R1 T6) during same time period, over a sampling period of nineteen days. On day 6 before the rainfall and day 9 after the rainfall conventional soils show to be absorbing CH_4.

4.4.2 CH_4 emissions and soil moisture changes

Figure 4.11 presents CH_4 emissions plotted together with soil moisture content, observations are not very clear as to which production type retains more moisture in this plots.

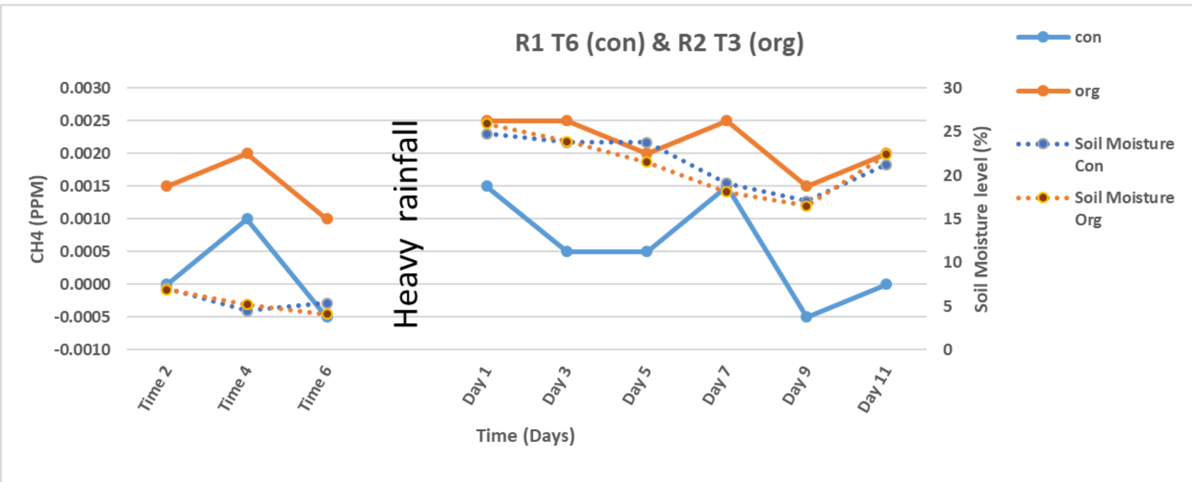


Figure 4.11: Graph of variable CH_4 emissions plotted with soil moisture content to establish the relationship. Observations suggests both plots retain similar moisture patterns. It is clear from the chart that when soil moisture content increased following heavy rainfall, CH_4 emissions from organic plot increase but not much in a conventional plot.

4.4.3 CH_4 emissions with temperature changes

Figure 4.12 presents CH_4 emissions plotted with temperature. Observations show that higher temperatures (18-30^{O}C) are received before the rainfall and slightly lower (13-19^{O}C) after the rainfall. Both conventional and organic emissions follow similar temperature patterns in dry soils; they comparably increase and decrease. After the rainfall, emissions from organic plots are at their highest and conventional emissions slightly increased than in dry soils, but still significantly lower than those of organic.

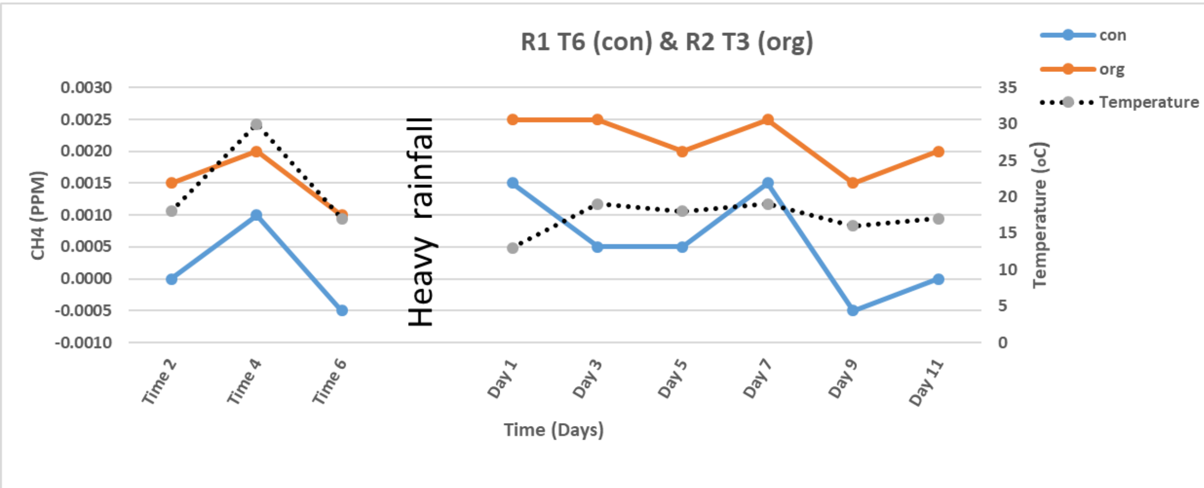


Figure 4.12: Graph of variable CH_4 emissions plotted with temperature to establish the relationship. Observations show that in dry soils prior to rainfall, emission increase and decrease with temperature. The same trend is not followed in moist soils following rainfall, the behaviour of emissions is not clear given the temperature patterns, though both emissions follow a similar trend.

4.5 Summary of George results

Table 4.1: Summary of George gas emissions results

	Site A		**Site B**	
	Conventional	**Organic**	**Conventional**	**Organic**
CO_2	64.887 ppm	53.264 ppm	66.424 ppm	47.885 ppm
CH_4	0.0018 ppm	0.0033 ppm	-0.0005 ppm	0.0024 ppm

4.6 Bethlehem CO_2

4.6.1 CO_2 emissions

Figure 4.13 presents significant differences in CO_2 emissions from monoculture plough, no-till and stubble mulch. The observations suggest ploughed plots emit more CO_2 than no-till and mulch, emitting the highest concentration of this sampling (50 ppm) and second highest (46 ppm) of CO_2, lowest being 29 ppm from plough. No-till plots emitted lower than plough, emitting the highest concentration of 40 ppm and second highest of 39 ppm, lowest being 12 ppm from no-till. Stubble mulch emitted the least amongst the three, emitting the highest concentration of 35 ppm and second highest of 30 ppm, lowest being 23 ppm.

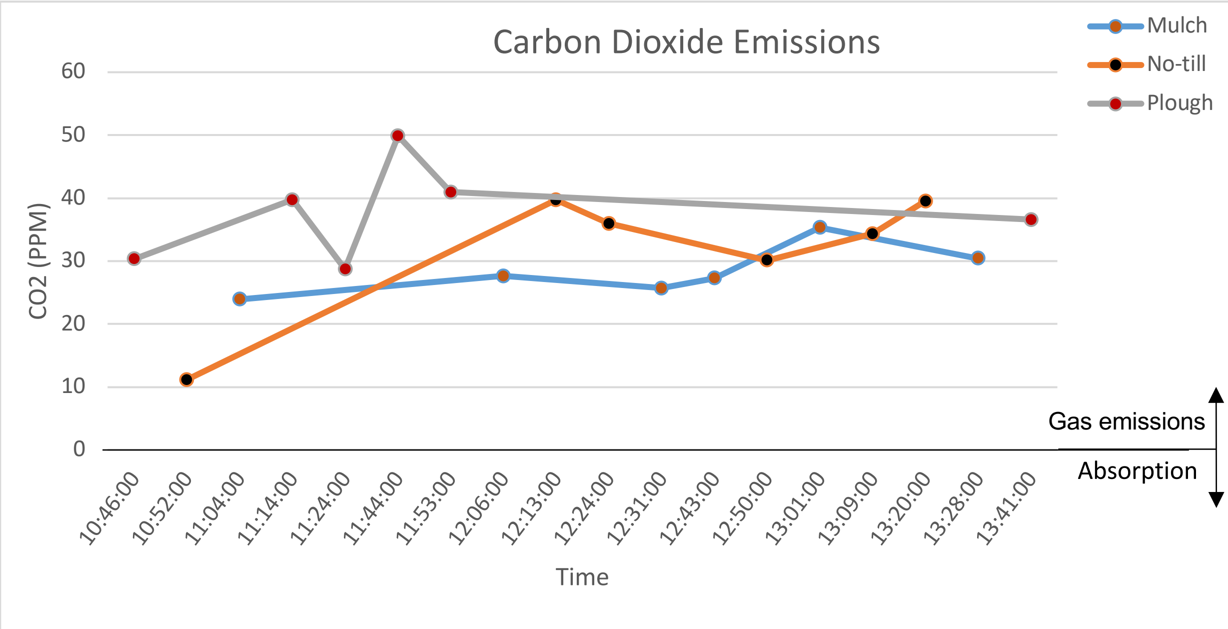


Figure 4.13: CO_2 emissions comparing three different treatments (mulch, no-till and plough) sampled for fifteen minutes.

4.7 Bethlehem CH_4

4.7.1 CH_4 emissions

Figure 4.14 presents significant differences in CH_4 emissions from monoculture plough, no-till and stubble mulch. The observations suggest ploughed plots emit more CH_4 than no-till and mulch, emitting the highest concentration of this sampling (0.022 ppm) and second highest (0.020 ppm) of CH_4, lowest being 0.009 ppm from plough. No-till plots emitted lower than plough, emitting the highest concentration of 0.020 ppm and second highest of 0.017 ppm, lowest being -0.004 ppm from no-till. Stubble mulch emitted the least amongst the three, emitting the highest concentration of 0.016 ppm and second highest of 0.012 ppm, lowest being -0.002 ppm.

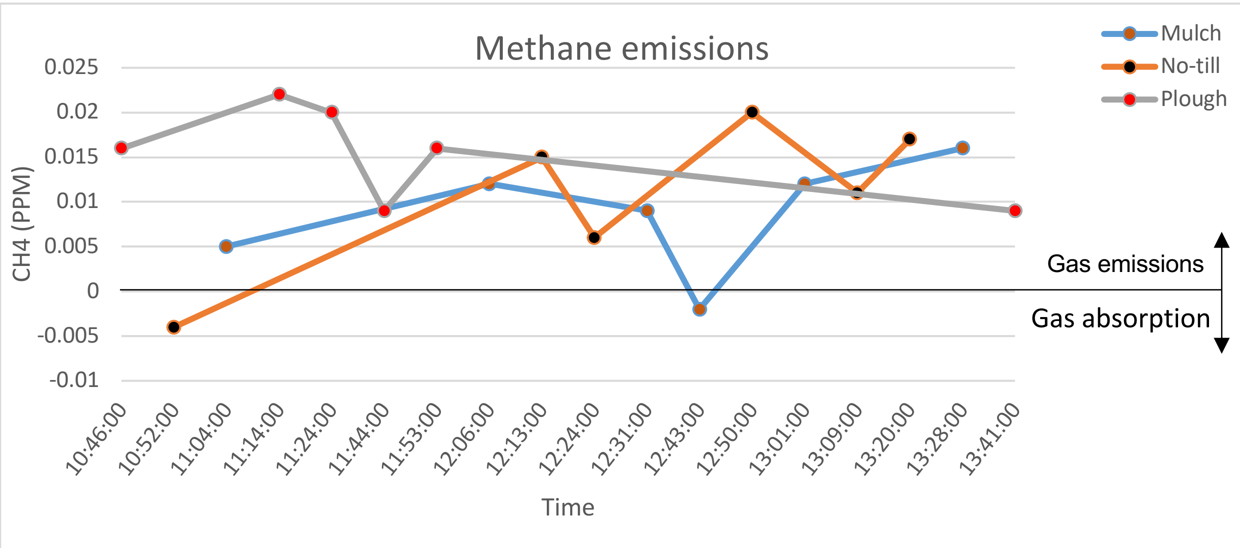


Figure 4.14: CH_4 emissions comparing three different treatments (mulch, no-till and plough) sampled for fifteen minutes.

4.8 Summary of Bethlehem results

Table 4.2: Bethlehem summarised gas emissions results

	Plough	**No-till**	**Stubble mulch**
CO_2	38.727ppm	31.798ppm	28.373ppm
CH_4	0.015ppm	0.011ppm	0.009ppm

Chapter 5

5. Discussion

The potential storage and emissions of carbon in soil is dependent on land use management and soil type (Oreskes, 2005). Below, CO_2 and CH_4 measured from respective study areas are interpreted and discussed separately.

5.1 George - site A CO_2

CO_2 is emitted from the soil surface, through soil respiration, a biological process which can occur in various ways (e.g faunal, root and microbial respiration) and one non-biological process (e.g chemical oxidization which could be noticeable at higher temperatures) (Lal, 2009).

5.1.1 Site A - CO_2 emission

Data suggests that the conventional plot (R2 T6) emitted 11.623 ppm more CO_2 than an organic plot (R1 T3) over ten samples, during sampling of nineteen days (Appendix 4). This equates to conventional plot (R2 T6) emitting near 20% (19.67%) more CO_2 than organic plot (R1 T3). Organic plot apparently emitted more CO_2 on days 6 and 8, this is not significant enough to make a change in the general trend of the emissions that suggests conventional plots emit more CO_2 than organic plots.

5.1.2 Site A - CO_2 emissions and soil moisture

Observations suggests a negative relationship between soil moisture content and CO_2 emission (Figure 4.2). It is clear from the first four samples, when soil moisture is at its lowest (ranging between 4.1% - 11.6% with an average of 7.13%) in a conventional plot, and (4.5% - 8.2% with an average of 6.1%) in an organic plot; CO_2 emissions are high, (ranging between 79.104 ppm - 105.634 ppm, with an average of 93.530 ppm) in a conventional plot compared to organic plot (ranging between 55.523 ppm - 94.839 ppm with an average of 74.20 ppm). Two weeks later, after significant rainfall, as soil moisture concentrations increased in both plots (ranging between 18.15% - 23.05%, with an average of 20.43%) in a conventional plot, and (ranging between 19.3% - 24.65%, with an average of 21.93%) in an organic field; CO_2 emissions dropped significantly (to a range of 28.655 ppm – 88.285 ppm, with an average of 46.129 ppm), in a conventional plot; and (a range of 33.402 ppm – 45.092 ppm, with an average 39.302 ppm), in an organic field.

Table 5.1: Soil moisture average (Av) and CO_2 emissions average (Av) prior to rainfall are obtained over four samples (from the 20th - 26th July 2018, see Appendix 1). Averages after the rainfall are obtained over six samples (from the 08th – 23rd August 2018).

Conventional plot - R2T6		**Organic plot – R1T3**	
Soil Moisture Av.	CO_2 emissions Av.	Soil moisture Av.	CO_2 emissions Av.
7.13%	93.530 ppm	6.1%	74.207
Rainfall			
20.43%	46.129 ppm	21.93%	39.302 ppm

The increase in soil moisture reveals a negative relationship between emissions from both conventional and organic systems, as they both drop in emissions as a result of increasing soil moisture content.

5.1.3 Site A - CO_2 emissions and temperature

Temperature is an influential factor affecting CO_2 emissions; this is confirmed in (Figure 4.3) during observations of dry soils and higher temperature concentrations of (19^{O}C-27^{O}C) high emissions are observed in both conventional and organic plot (ranging between 79.104 ppm – 105.634 ppm, with an average of 93.530 ppm), in a conventional plot and (ranging between 55.523 ppm - 94.839 ppm, with an average of 74.207 ppm) in an organic plot. Two weeks later during moist soils, and slightly lower temperature (15^{O}C-21^{O}C), lower emissions are observed, (ranging between 28.655 ppm – 88.285 ppm, with an average of 46.129 ppm) in a conventional plot and (ranging between 33.402 ppm – 45.092 ppm, with an average 39.302 ppm), in an organic field. Table 5.2

Table 5.2: Temperature average (Av) and CO_2 emissions average (Av) prior to rainfall are obtained over four samples (from the 20th - 26th July 2018, see Appendix 1). Averages after the rainfall are obtained over six samples (from the 08th – 23rd August 2018).

Conventional plot - R2T6		**Organic plot – R1T3**	
Temperature Av.	CO_2 emissions Av.	Temperature Av.	CO_2 emissions Av.
23^{O}C	93.530 ppm	23^{O}C	74.207 ppm
Rainfall			
18^{O}C	46.129 ppm	18^{O}C	39.302 ppm

Both organic and conventional emissions are higher during high temperatures, and drop significantly with temperature during moist soils. Temperature and CO_2 emissions reveal a positive relationship.

5.2 George - site B CO_2

5.2.1 Site B - CO_2 emissions

Data suggests that conventional plot (R1 T6) emitted 19.002 ppm more CO_2 than an organic plot (R2 T3) over nine samples, within a sampling duration of nineteen days (Appendix 1). Calculations equates to conventional plot (R1 T6) emitting 33% more CO_2 than organic plot (R2 T3) (Appendix 4). Conventional emissions over the sampling duration show a consistent trend of emitting more CO_2 than organic emissions.

5.2.2 Site B - CO_2 emissions and soil moisture

Observations suggests a negative relationship between soil moisture content and CO_2 emissions (Figure 4.5). It is clear from the first three samples, during dry soils, (ranging between 4.5% - 7.1%, with an average of 5.65%), in a conventional plot, and (ranging between 4.1% - 6.9%), with an average of 5.4% in an organic plot; CO_2 emissions are high, (ranging between 69.191 ppm – 90.290 ppm, with an average of 78.252 ppm), in a conventional plot and (ranging between 41.107 ppm – 80.059 ppm, with an average of 55.970 ppm) in an organic plot. Two weeks later during moist soils (ranging between 17.05% - 24.75, with an average of 21.62% in a conventional plot), and (ranging between 16.5% - 25.9%, with an average of 21.38%) in an organic plot; CO_2

emissions drop to a (range between 32.631 ppm – 78.169ppm, with an average of 52.613 ppm) in a conventional field and (a range between 27.455 ppm – 66.412 ppm, with an average of 43.844 ppm) in an organic plot (Table 5.3). Observations of the data reveals a daily positive relationship between conventional and organic CO_2 emissions and moisture content, as they increase and decrease together.

Table 5.3: soil moisture average (Av) and CO_2 emissions average (Av) prior to rainfall are obtained over three samples (from the 20^{th} - 26^{th} July 2018, see Appendix 1). Averages after the rainfall are obtained over six samples (from the 08^{th} – 23^{rd} August 2018, see Appendix 1).

Conventional plot – R1T6		**Organic plot – R2T3**	
Soil Moisture Av.	CO_2 emissions Av.	Soil moisture Av.	CO_2 emissions Av.
5.65%	78.252 ppm	5.4%	55.970 ppm
Rainfall			
21.62%	52.613 ppm	21.38%	43.844 ppm

The increase in soil moisture reveals a negative relationship between emissions from both conventional and organic systems, as they both drop in emissions as a result of increasing soil moisture content. Similar results are observed from site A.

5.2.3 Site B - CO_2 e missions and temperature

Temperature is an influential factor affecting CO_2 emissions; this is confirmed from (Figure 4.6) during observations of dry soils and higher temperature concentrations (ranging between 17^{O}C - 30^{O}C; high emissions are observed in both conventional and organic plots, (ranging between 69.191 ppm – 90.290 ppm, with an average of 78.252 ppm), in a conventional plot and (ranging between 41.107 ppm – 80.059 ppm, with an average of 55.970 ppm) in an organic plot. Two weeks later, during moist soils, and slightly lower temperatures, (ranging between 13^{O}C-19^{O}C; lower emissions are observed, (ranging between 32.631 ppm – 78.196 ppm, with an average of 52.613 ppm) in a conventional field and (ranging between 27.455 ppm – 66.412 ppm, with an average of 43.844 ppm) in an organic plot.

Table 5.4: Temperature average (Av) and CO_2 emissions average (Av) prior to rainfall are obtained over three samples (from the 20^{th} - 26^{th} July 2018, see Appendix 1). Averages after the rainfall are obtained over six samples (from the 08^{th} – 23^{rd} August 2018, see Appendix 1).

Conventional plot – R1T6		**Organic plot – R2T3**	
Temperature Av.	CO_2 emissions Av.	Temperature Av.	CO_2 emissions Av.
$22^{O}C$	78.252 ppm	$22^{O}C$	55.970
Rainfall			
$17^{O}C$	52.613 ppm	$17^{O}C$	43.844 ppm

Both organic and conventional emissions are higher during high temperatures and drop significantly with temperature during moist soils. A similar trend is confirmed from study area 1.

5.3 George CO_2 discussion

Modern agriculture employs conventional practices like tillage and application of synthetic chemicals; which in responds, contaminates the atmosphere and degrades soil health and capacity to store organic matter (Adviento-Borbe et al., 2007). This is confirmed in the results from (Figure 4.1 and 4.4) that both suggest conventional production emits 20 - 31% more CO_2 respectively, than organic production, which is known to store soil organic matter more effectively.

Based on this knowledge, hypotheses were established that soils ability to store more carbon can be improved when is protected from microbial activity, which leads to more emissions. To store more carbon, soils needs higher concentrations of organic matter and formation of soil aggregates caused by tiny soil particles clinging together (Cho, 2018). This results in less emissions, as observed from (Figure 4.1 and 4.4) which shows organic soil emitted less CO_2 than conventional soils.

Soil moisture and temperature affect microbial activity (Bell et al., 2009; Horak, Igaz and Kondrlova, 2014; Almagro et al., 2009). Strong relationships between soil moisture and temperature and soil CO_2 respiration rates have been identified (Dutta and Gokhale, 2017; Rey et al., 2017; Abdalla et al., 2016). Furthermore, they stated that, if soil moisture content is above 10%, there was a positive relationship between soil respiration and temperature (Almagro et al., 2009).

In one study, it was determined that soil water content prevented soil CO2 diffusion and inhibited microbial activity and root respiration (Curiel Yuste et al., 2003). This is confirmed from (Figure 4.2 and 4.5) where CO_2 emissions are at their highest during low moist soils and CO_2 emissions are at their lowest during very moist soils directly after rainfall. A similar study stated that soil respiration increased with an increase in soil temperature. However, when soil water content dropped below 10%, soil respiration decreased.

5.4 George - Site A CH_4

5.4.1 CH_4 emissions

Data suggests that organic plot (R1 T3) emitted 0.0015 ppm more CH_4 than conventional plot (R2 T6) over ten samples, within a sampling duration of nineteen days (Figure 4.6). This equates to organic plot (R1 T3) emitting 59% more CH_4 than a conventional plot (R2 T6) (Appendix 4). Organic plot shows a consistent trend of emitting more CH_4 than conventional plot. However, the concentration of these emissions are very small, for this reason four decimal places were used to analyse CH_4 emissions in George.

5.4.2 CH_4 emissions and soil moisture

Observations suggest CH_4 emissions from organic plot and CH_4 emissions from conventional plot behave differently to soil moisture (Figure 4.7). It is clear from the results that when soil moisture content is low, (ranging between 4.1% - 11.6%, with an average of 7.13%) in a conventional plot, and (ranging between 4.5% - 8.2%, with an average of 6.1%) in an organic plot; CH_4 emissions from a conventional plot (range between 0.002 ppm - 0.005 ppm, with an average of 0.0009 ppm) and CH_4 emissions from an organic plot (range between 0.005 ppm – 0.0035 ppm, with an average of 0.0023 ppm). Observation reveal organic plots consistently emit more CH_4 than conventional plots, and emissions are stimulated by high moisture content. Two weeks later, during moist soils following rainfall (ranging between 18.15% - 23.05%, with an average of 20.43%) in a conventional plot, and (ranging between 19.3% - 24.65%, with an average of 21.93%) in an organic field; CH_4 emissions from an organic field (range between 0.005 ppm – 0.0035 ppm, with an average of 0.0023 ppm) and CH_4

emissions from a conventional plot (range between 0-0.0015 ppm, with an average of 0.0016 ppm) Table 5.5.

Table 5.5: Soil moisture average (Av) and CH_4 emissions average (Av) prior to rainfall are obtained over four samples (from the 20^{th} - 26^{th} July 2018, see Appendix 1). Averages after the rainfall are obtained over six samples (from the 08^{th} – 23^{rd} August 2018).

Conventional plot - R2T6		**Organic plot – R1T3**	
Soil Moisture Av.	CH_4 emissions Av.	Soil moisture Av.	CH_4 emissions Av.
7.13%	0.0009 ppm	6.1%	0.0023ppm
Rainfall			
20.43%	0.0016 ppm	21.93%	0.0023 ppm

The increase in soil moisture does not influence CH_4 emissions from this organic plot. However, conventional plot CH_4 emissions increase as soil moisture content increased.

5.4.3 CH_4 emissions and temperature

Temperature is an influential factor affecting CH_4 emissions; this is confirmed in (Figure 4.9) during higher temperature concentrations (ranging between $19^{O}C$-$27^{O}C$), slightly lower CH_4 emissions are observed from a conventional plot (ranging between 0.0005 ppm - 0.002 ppm, with an average of 0.0009 ppm) and slightly higher CH_4 emissions are observed from an organic plot (ranging between 0.0005 ppm – 0.0035 ppm, with an average of 0.0023 ppm). Two weeks later, after significant decrease in temperature (ranging between $15^{O}C$ - $21^{O}C$), CH_4 emissions from conventional plot decreased to a (range between 0- 0.0025 ppm, with an average of 0.0016 ppm) and CH_4 emissions from an organic plot increased to a (range of 0.005 ppm – 0.0035 ppm, with an average of 0.0023 ppm) Table 5.6.

Table 5.6: Temperature average (Av) and CH_4 emissions average (Av) prior to rainfall are obtained over four samples (from the 20^{th} - 26^{th} July 2018, see Appendix 1). Averages after the rainfall are obtained over six samples (from the 08^{th} – 23^{rd} August 2018).

Conventional plot - R2T6		**Organic plot – R1T3**	
Temperature Av.	CH_4 emissions Av.	Temperature Av.	CH_4 emissions Av.
$23^{O}C$	0.0009 ppm	$23^{O}C$	0.0023 ppm
Rainfall			
$18^{O}C$	0.0016 ppm	$18^{O}C$	0.0023 ppm

Conventional plot CH_4 emissions are higher during high temperatures, and drop with temperature respectively. Organic plot CH_4 emissions increased with the decrease in temperature, though it was expected to decrease. This suggest that soil moisture might be more of an influential factor to this emissions outcome than temperature. Temperature and CO_2 emissions reveal a positive relationship on daily basis of increasing and decreasing together.

5.5 George - Site B CH_4

5.5.1 CH_4 emissions

Data suggests that organic plot (R2 T3) emitted 0.0029 ppm more CH_4 than conventional plot (R1 T6) over nine samples, within a sampling duration of nineteen days (Figure 4.10). This equates to organic plot (R2 T3) emitting 131% more CH_4 than conventional plot (R1 T6) (Appendix 4). Organic emissions over the sampling duration shows a trend of consistently emitting more CH_4 than conventional emissions. Similar trends are observed in site A.

5.5.2 CH_4 emissions and soil moisture

Observations suggest CH_4 emissions from organic plot and CH_4 emissions from conventional plot behave differently to soil moisture (Figure 4.11). It is very clear from the results that when soil moisture content is low, (ranging between 4.5% - 7.1%, with an average of 5.65%), in a conventional plot, and (ranging between 4.1% - 6.9%, with an average of 5.4%) in an organic plot; CH_4 emissions from a conventional plot (range -0.005 ppm – 0.001 ppm, with an average of 0.0005 ppm) and CH_4 emissions from an organic plot (range between 0.001 ppm – 0.002 ppm, with an average of 0.0015 ppm). Two weeks later, during moist soils following rainfall (ranging between 17.05% - 24.75, with an average of 21.62%) in a conventional plot, and (ranging between 16.5% - 25.9%, with an average of 21.38%) in an organic plot; CH_4 emissions from an organic plot (range between 0.0015 ppm - 0.0025 ppm, with an average of 0.0022 ppm) and CH_4 emissions from a conventional plot (range -0.005 – 0.0015, with an average of 0.0006   ) (Table 5.7). Observation of the data reveals organic plots consistently emit more CH_4 than conventional plots, and emissions are stimulated by high moisture content.

Table 5.7: soil moisture average (Av) and CO_2 emissions average (Av) prior to rainfall are obtained over three samples (from the 20th - 26th July 2018, see Appendix 1). Averages after the rainfall are obtained over six samples (from the 08th – 23rd August 2018).

Conventional plot – R1T6		**Organic plot – R2T3**	
Soil Moisture Av.	CH_4 emissions Av.	Soil moisture Av.	CH_4 emissions Av.
5.65%	0.0005 ppm	5.4%	0.0015 ppm
Rainfall			
21.62%	0.0006 ppm	21.38%	0.0022 ppm

The increase in soil moisture reveals a positive relationship between CH4 emissions from organic plot as emissions increase with soil moisture. Increasing soil moisture content shows to have increased CH4 emissions from both organic and conventional plot.

5.5.3 CH_4 emissions and temperature

Temperature is an influential factor affecting CH_4 emissions; this is confirmed (Figure 4.12) during higher temperature concentrations (ranging between 17^{O}C-30^{O}C), lower CH_4 emissions are observed from a conventional plot (ranging between -0.0005ppm - 0.001 ppm, with an average of 0.0005 ppm) and slightly higher CH_4 emissions are observed from an organic plot (ranging between 0.001 ppm – 0.002 ppm, with an average of 0.0015 ppm). Two weeks later, after decrease in temperature (ranging between 13^{O}C - 19^{O}C), CH_4 emissions from conventional plot slightly increased to a (range between -0.0005- 0.0015 ppm, with an average of 0.0006 ppm) and CH_4

emissions from an organic plot increased to a (range of 0.0015ppm – 0.0025 ppm, with an average of 0.0022 ppm).

Table 5.8: Temperature average (Av) and CO_2 emissions average (Av) prior to rainfall are obtained over three samples (from the 20th - 26th July 2018, see Appendix 1). Averages after the rainfall are obtained over six samples (from the 08th – 23rd August 2018).

Conventional plot – R1T6		**Organic plot – R2T3**	
Temperature Av.	CH_4 emissions Av.	Temperature Av.	CH_4 emissions Av.
22^{O}C	0.0005 ppm	22^{O}C	0.0015 ppm
Rainfall			
17^{O}C	0.0006 ppm	17^{O}C	0.0022 ppm

5.6 George CH_4 discussion

Soil management practices influence CH_4 fluxes. Several studies have shown that soils with higher organic matter content results in more CH_4 emissions, compared to conventional tilled soils, with high concentrations of nitrogen fertilizer, which inhibits CH_4 oxidation(Mosier et al., 1991; Hansen et al., 1993; Bronson and Mosier, 1994; Dunfield et al., 1995; Hutsch, 1996). This is confirmd in the results from (Figure 4.7 and 4.10) which suggests organic production emits 79% more CH_4 and 130% respectively, than conventional production, possibly because of high organic matter content in organic soils and prior applied nitrogen fertilizer on conventional soils.

Methanotrophs and methanogens are influenced by factors like pH, soil moisture and temperatures; they determine whether a particular soil acts as a source or sink of CH_4. Under waterlogged soil for example, the balance shifts from methanotrophs to methanogens and the soil becomes a CH_4 source (Lew and Gli, 2018). This is because water stimulates biological activity and CH_4 oxidation in very dry soils (Striegl et al., 1992; Hütsch, 1998; Bell et al., 2009; Lew and Gli, 2018).

Striegl et al. (1992) determined rates of CH_4 uptake by a desert soil increased by 250% in forty-eight hours following precipitation. Similar observations from (Figure 4.8 and 4.11) where CH_4 emissions from organic plots are higher during moist soils and slightly lower prior to rainfall. Moist soils are leading to reduced CH_4 gas absorption, emitting more into the atmosphere (Mosier et al., 1991; Dunfield et al., 1995; Alluvione, 2009).

Moist soils and high temperatures show a trend that could accelerate an increase in atmospheric CH_4 levels and intensify global warming (Hansen et al., 1993; Venterea et al., 2005; Ussiri et al., 2009;). A recent study from Advanced Science Research Centre (ASRC, 2018) suggests recent the soils ability to absorb CH_4 has been decreased by the effects of climate change.

In addition to soil moisture, temperature and chemical concentrations in the soil are very important factors in determining the soils ability to source or sink CH_4 (Lew and Gli, 2018). Conventional emissions are inhibited by the concentration of nitrogen in the soil (Figure 4.7 and 4.10) possibly from prior applications. Methanogenesis is reactive to temperature (Lew and Gli, 2018); Mosier et al., (1991) suggest that since CH4 oxidation is not reactive to temperature, lower temperatures will result in decreased emissions and higher temperatures will result in increased emissions.

Methanotrophs are insensitive to temperature fluctuations in the mesophilic range and CH_4 sinks soils has little diurnal variation (Mosier et al., 1991). Numerous studies suggests that an increase in temperature leads to increased microbial activity, which increases soil respiration(Mosier et al., 1991; Striegl et al., 1992; Ussiri et al., 2009; Alluvione, 2009). Similarly, from (Figure 4.9 and 4.12) we observe high CH_4 emissions from both conventional and organic during high temperature concentrations with low soil moisture levels, and a positive relationship between organic CH_4 emissions and temperature especially during moist soils.

5.7 Bethlehem CO_2 discussion

Stubble mulch emitted the least amongst the three compared tillage practices, ploughed plot emitted 7 ppm (6.929 ppm) more CO_2 than no-tilled plot, and no-till emitted 3ppm (3.425 ppm) more CO_2 than stubble mulch plot, thus plough emitted 10ppm (10.354 ppm) more CO_2 than stubble mulch (Appendix 3). Lower CO_2 emissions from no-till compared to plough were consistent with results from other studies (Al-kaisi and Yin, 2005; Reicosky and Archer, 2007; Alluvione, 2009).

Calculations show that plough emitted ca 20% (19.65%) more CO_2 than no-till, no-till emitted ca 11% (11.38%) more CO_2 than stubble mulch and plough emitted ca 30% (30.36%) more CO_2 than stubble mulch (Appendix 4). A similar study by (Abdalla et al., 2016) concluded plough emitted 27% more CO_2 than no-tillage in arid climates; while for pairs in humid climates, plough emitted 16% more CO_2 than no-tillage.

Reduced tillage leaves soil aggregates intact, conversely, tilled soils emit carbon into the atmosphere(Cho, 2018). Tilled soils increase contact between soil and crop residues, accelerates SOC oxidation to CO_2 emissions by increasing soil aeration, and exposing aggregate-protected SOM to microbial attack resulting in more decomposition and CO_2 emissions. (Reicosky and Archer, 2007) suggest CO_2 fluxes are less under no-till than ploughed soil. Similar findings are observed in this study (Figure 4.13), where plough emitted ca 20% (19.65%) more CO_2 than no-till.

Curtin et al., (2000) measured the CO_2 fluxes from a 13-year-old tillage treatment plot. They concluded the mean annual CO_2 fluxes were 20 to 25% less from no-till than plough. Lower CO_2 fluxes under no-till than under plough are attributed to natural soil formation and slower decomposition of crop residues placed on the surface of no-till soil, compared to residue incorporation under ploughed soil.

Mulch reduces soil erosion, regulates soil temperature and maintains soil moisture. It acts as a “blanket”, protecting soil surface from solar energy and wind (Bristow, 1988; Kar and Kumar, 2007). Since soil respiration increases with temperature, reduced emissions are observed under mulch soils, emitting ca 30% (30.36%) and ca 20% (19.65%) below plough and no-till respectfully.

Smith and Elliott (1990) indicated that the most important priority in world agriculture is to develop tillage systems and residue management strategies that will increase the quantity and quality of SOM, effectively control erosion and restore soil productivity to optimum levels, ultimately leading to increased soil health.

Cultivation increases microbial activity and soil aeration, which responds in increased emissions of CO_2 (Govaerts et al., 2009), a great potential to decreasing CO_2 emissions lie in the ability to manipulate cultivation practices CO_2 (Smith and Elliott, 1990; Al-kaisi and Yin, 2005; Adviento-Borbe et al., 2007; Reicosky and Archer, 2007; Abdalla et al., 2016; Bojarszczuk et al., 2017).

5.8 Bethlehem CH_4 discussion

CH_4 GWP is very high compared to other GHG, and CH_4 concentrations are relatively low compared to other emitted gas (Hutsch, 2001; Alluvione, 2009). This results in

CH4 being emitted in low quantities but the impacts are more detrimental than other gas (Jacinthe and Lal, 2005; Sanhueza and Donoso, 2006; Mosier et al., 2006;).

This study suggests stubble mulch emitted the least amongst the three compared tillage practices, ploughed plots emitted 0.004 ppm more CH_4 than no-tilled plots and no till emitted 0.002 ppm more CH_4 than stubble mulch plots, thus plough emitted 0.006 ppm more CH_4 than stubble mulch (Appendix 4). Calculations show that plough emitted 30.77% more CH_4 than no-till, no-till emitted 20% more CH_4 than stubble mulch and plough emitted 50% more CH_4 than stubble mulch (calculations appendix).

Chapter 6

6. Summary and recommendations

This study was conducted in two agricultural study areas. Study area one in George focussed on comparing emissions of CO_2 and CH_4 from a long-term comparative farming systems (organic vs conventional) research trial established in 2014. The second study area in Bethlehem focussed on comparing emissions of CO_2 and CH_4 from three tillage methods, namely plough, no-till and stubble mulch from a long-term wheat research trial established in 1979.

The sampling processes and analyses were conducted to test variation in CO_2 and CH_4 emissions from these different crop production systems and tillage practices in relation to climate change mitigation from soil respiration. The aim was to work in a systematic approach; (1)comparing gas emissions from above mentioned production systems, (2)collecting soil moisture content during gas sampling to observe response patterns/establish a relationship between the variables, if any, (3) recording ambient temperature during gas sampling to observe response patterns/establish a relationship between the variables, if any.

The results show that in study area one, conventional soil emit more CO_2 than organic soils, site A emitted 12 ppm more which is calculated to be 20% more CO_2 than organic. Site B emitted 19 ppm more which is calculated to be 33% more CO_2 than organic. Results further showed that organic soils emitted more CH_4 than conventional soils. Site A emitted 0.0015 ppm more which is calculated to be 59% more CH_4 than conventional. Site B emitted 0.0029 ppm more which is calculated to be 130% more CH_4 than conventional soils.

In study area two, plough emitted the most CO_2 and CH_4 than no-till and stubble mulch followed by no-till and mulch emitting the least. Plough emitted 40 ppm CO_2; no-till emitted 32 ppm CO_2 and stubble mulch emitted 28 ppm CO_2. This suggests plough emitted 20% more CO_2 than no-till, no-till emitted 11% more CO_2 than stubble mulch and plough emitted 30% more CO_2 than stubble mulch. Plough emitted 0.015 ppm CH_4, no-till emitted 0.011 ppm CH_4 and stubble mulch emitted 0.009 ppm CH_4. This suggests plough emitted 30.77% more CH4 than no-till, no-till emitted 20% more CH_4

than stubble mulch and plough emitted 50% more CH_4 than stubble mulch. The results of these experiments emphasize the need for long-term research to understand the ecological processes and emissions in agriculture.

6.1 Implications

Soil moisture and temperature affect microbial activity; therefore, they influence emissions of GHG's. Water stimulates biological activity and CH_4 oxidation in very dry soils. It is determined that soil water content prevented soil CO_2 diffusion and inhibited microbial activity and root respiration. An increase in soil temperature results in an increases in microorganism activities, disintegration and decay, which means carbon emissions volume increase as well.

6.1.1 Policy implications

Agricultural policies are usually implemented with a goal of achieving a specific outcome in the domestic agricultural markets. Evidence from several studies and this thesis, has used empirical findings to show that the current crop production system emits significant GHG's into the atmosphere. The theoretical argument for this justification suggest the need for policy review, which will require mitigation and sustainable practices to be adopted.

Fertile soil, availability of freshwater, a favourable climate, diverse plant and animal species and skills of farmers are primary factors to our food system. They're natural productive ecological standards are threatened are threatened by depletion of resources and anthropogenic disruptions. The sustainability of our food system lies in our ability to manipulate agricultural ecosystem.

Given current population trends, the more affluent anticipated populace demands two times more food than we produce today, yet resources to help meet this demand are depleting by the day. Food production is responsible for around 30% of anthropogenic climate change, and this figure will keep increasing with food demand if no mitigation or adaptation strategies are adopted. By reducing GHG emissions from agriculture, and developing sustainable tillage practices, we increase chances of stabilising GHG concentrations and temperature within a required range.

6.1.2 Climate change implications

Agricultural production has always been highly adaptable to changing conditions throughout civilizations; climate and weather are/have always been determinants of our food supply, challenges arise when we face extreme weather events, increase in temperature, water scarcity and exposure to disease.

Anticipated severe impacts brought about by climate change include higher temperatures, accelerating intense heat waves and widespread crop failure. Increased temperatures/droughts will make stable crops like wheat, rice and maize supplies less stable, leading to an increase in food prices and decrease in food security. Currently, there are about 800 billion people experiencing severe food insecurity, these people will be most affected by global warming.

Oceans sequester ca 30% of CO2 in the atmosphere pear year, this natural process has changed the oceans natural habitat. Sea levels are rising as a result of thermal expansions and melting glaciers, increasing risks of storms and erosion. Marine life is drastically affected by all this changes and the fact that oceans have become more acidic lately.

Anthropocene is responsible for the severity of climate impacts because they respond to the concentration of GHG in the atmosphere, and people are responsible for getting so much GHG in the atmosphere during the 20^{th} century. The extent at which each impact can be suffered is dependent on our collective actions and choices.

6.1.3 Food security implications

Agricultural crops are the most cited literature in relation to GMO's. Agricultures dependence on genetic engineering is increasing at a disturbing rate; genetic engineering improves food security, increases pest and disease resistance, improves and increases crop yields, less chemical production costs and enables crops to grow in habitats they naturally wouldn't.

Genetic engineering manipulates natural "gene settings" of an organism and transfers desired traits to another organism, though this genes occur naturally in one organism, the consequences of modifying biology are unknown. The organisms response may vary in factors like growth rate, metabolism or response and adaptability to habitat. The natural environment harbouring genetically engineered organisms is susceptible to the uncertainty from foreign gene expression; further increasing potential health risks to humans by introducing new allergens and possible exposure.

6.2 Limitations of the study

There are two major limitations to this study. Firstly, the inability to sample during rain because the Picarro analyser is not waterproof; secondly the inability to sample non-stop, as the suction of the Picarro forcefully suctions gas from the top soil after it has exhausted the gas trapped in the canister.

6.3 Recommendations

The potential control of soils response to GHG lies primarily in our ability to steward land use practices. Precise use of chemicals and water can help keep soil emissions to the minimum depending on the skill of the farmer (Mosier et al., 2006; Ussiri, Lal and Jarecki, 2009;Lew and Gli, 2018)

6.3.1 Recommendations for future research

- Day and night sampling- future studies should include both day and night sampling to increase data about respiration, methanogenesis and gas emissions during photoperiod.
- Growing season sampling- future studies with more resources may sample for emissions over the entire growing season to figure emissions patterns during crop growth stage, from sowing to ripening.
- Advocacy- Raising awareness about GHG emissions from agriculture and the role they play on the ecosystem, to influence and promote mitigation policy development
- Research and development- Evidence based data is very necessary for mitigation interventions and technology development to increase applicability as well as increasing supply of new relevant data
- Financial incentives- Economically efficient mechanisms for incentivizing the adoption of mitigation technologies and practices may be introduced. These can include pollution tax for the emitters and beneficiary pays for the low emitters and carbon credit markets

6.4 Conclusion

The purpose of this study was to assess GHG emissions from agricultural soil. The results show significant differences in emissions from different crop management practices and food production systems. This experiment emphasizes the need for long-term research to understand the ecological processes in agriculture more, so that we may transition to methods that emit less GHG's, store more carbon in the soil an help be part of the solution to climate change.

The largest terrestrial carbon is stored in the soil. Sustainable management of soils can play an important role in carbon sequestration; concurrently, when managed unsustainably, soils emit GHG into the atmosphere and further exacerbates climate change. To control increase of <2^{O}C global atmosphere, requires emission to be 25% below current level by 2050.

The results of this study reveals a consistent trend with other similar studies that the inevitable soil emissions have become very significant in modern crop management, considering population and cultivated area size. As previously mentioned, the global warming potential of a CH4 molecule is thirty four times more potent than a CO2 molecule, (see appendix 12, for the global warming potential for the above presented gas). Given the central importance of food in our lives, a reduction of GHG emissions from agriculture is required. Practices and technology that degrade the soils and contaminate the atmosphere should be inhibited to mitigate climate change by crop management and sustainable food production. Whereas practices and technology that possibly help lower GHG emissions in the atmosphere and sustain food production should be researched, developed, financially supported adopted.

The magnitude of the gap in emissions is influenced by anthropogenic objectives. To achieve 25% reduction in emissions, this study suggests we employ farming practices and systems that store and recycle organic matter and promote sustainability as opposed to emitting CO_2. In addition to the farming system or tillage type, it is important to overlook sustainable practices like good application of manure or fertilizer, good irrigation strategies, improved soil biodiversity as they mitigate anticipated threats of climate change and improves adaptability.

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Appendix 1: George (study area one) results

	Date	Plot	cannum	Start Time	End Time	Soil moisture	Zero CO2	Project CO2	Zero CH4	Project CH4	Duration	Emission CO2	Emissions CH4	Temperature	Type
Day 1	20/07/2018	R2 T6	1	10:09	17:00	7.3	395.202	489.711	1.799	1.8	6:51	94.509	0.001	26	Conventional
Day 1	20/07/2018	R2 T6	2	10:15	17:06	6.9	401.284	480.851	1.795	1.798	6:51	79.567	0.003	26	Conventional
Day 1	20/07/2018	R1 T3	1	10:28	17:20	8	410.043	480.496	1.799	1.808	6:52	70.453	0.009	26	Organic
Day 1	20/07/2018	R1 T3	2	10:34	17:27	7.7	424.099	464.691	1.798	1.809	6:53	40.592	0.011	26	Organic
Day 2	21/07/2018	R1 T6	1	10:15	16:15	7.2	395.202	491.241	1.789	1.789	6:00	96.039	0	18	Conventional
Day 2	21/07/2018	R1 T6	2	10:26	16:32	7	401.284	490.792	1.79	1.79	6:06	89.508	0	18	Conventional
Day 2	21/07/2018	R2 T3	1	10:39	16:40	6.8	425.043	462.091	1.797	1.799	6:01	37.048	0.002	18	Organic
Day 2	21/07/2018	R2 T3	2	10:45	16:46	7	424.099	480.511	1.798	1.799	6:01	56.412	0.001	18	Organic
Day 3	22/07/2018	R2 T6	1	10:43	17:11	5.9	399.042	478.146	1.795	1.796	6:28	79.104	0.001	27	Conventional
Day 3	22/07/2018	R2 T6	2	10:48	17:15	5.5	402.179	477.247	1.795	1.795	6:27	75.068	0	27	Conventional
Day 3	22/07/2018	R1 T3	1	10:59	17:30	6	412.919	481.297	1.794	1.797	6:31	68.378	0.003	27	Organic
Day 3	22/07/2018	R1 T3	2	11:06	17:38	6.1	417.712	491.073	1.796	1.798	6:32	73.361	0.002	27	Organic
Day 4	23/07/2018	R1 T6	1	10:19	18:02	4.6	404.655	473.846	1.793	1.793	7:43	69.191	0	30	Conventional
Day 4	23/07/2018	R1 T6	2	10:30	17:59	4.4	404.623	491.591	1.794	1.796	7:29	86.968	0.002	30	Conventional
Day 4	23/07/2018	R2 T3	1	10:00	17:52	5.1	401.163	454.421	1.789	1.798	7:52	53.258	0.009	30	Organic
Day 4	23/07/2018	R2 T3	2	10:07	17:47	5.3	400.258	429.214	1.79	1.799	7:40	28.956	0.009	30	Organic
Day 5	24/07/2018	R2 T6	1	10:13	16:25:00	3.9	391.257	491.047	1.783	1.783	6:12	99.790	0	19	Conventional
Day 5	24/07/2018	R2 T6	2	10:18	16:29	4.3	394.318	499.214	1.783	1.784	6:11	104.896	0.001	19	Conventional
Day 5	24/07/2018	R1 T3	1	10:38	16:38	3.5	393.796	489.811	1.784	1.783	6:00	96.015	-0.001	19	Organic
Day 5	24/07/2018	R1 T3	2	10:45	16:41	4.2	395.88	489.542	1.784	1.786	5:56	93.662	0.002	19	Organic
Day 6	25/07/2018	R1 T6	1	10:17	16:12	6.1	401.638	512.421	1.784	1.783	5:55	110.783	-0.001	17	Conventional
Day 6	25/07/2018	R1 T6	2	10:21	16:21	4.6	402.046	490.843	1.784	1.784	6:00	88.797	0	17	Conventional
Day 6	25/07/2018	R2 T3	1	10:31	16:31	4	399.529	468.147	1.787	1.789	6:00	68.618	0.002	17	Organic
Day 6	25/07/2018	R2 T3	2	10:35	16:36	4.2	397.061	488.56	1.786	1.786	6:01	91.499	0	17	Organic
Day 7	26/07/2018	R2 T6	1	9:34	16:20	11.2	387.644	480.878	1.77	1.772	6:46	93.234	0.002	19	Conventional
Day 7	26/07/2018	R2 T6	2	9:37	16:25	12	402.694	520.727	1.771	1.77	6:48	118.033	-0.001	19	Conventional
Day 7	26/07/2018	R1 T3	1	9:09	16:08	8.7	389.225	476.177	1.77	1.778	6:59	86.952	0.008	19	Organic
Day 7	26/07/2018	R1 T3	2	9:13	16:12	7.7	384.428	448.669	1.771	1.777	6:59	64.241	0.006	19	Organic
Day 8	2018/08/08	R1 T6	1	10:01	16:23	24.3	401.319	474.912	1.784	1.786	6:22	73.593	0.002	13	Conventinal
Date 8	2018/08/08	R1 T6	2	10:06	16:30	25.2	392.408	461.717	1.787	1.788	6:24	69.309	0.001	13	Conventinal
Date 8	2018/08/08	R2 T3	1	10:15	16:42	25	391.787	464.818	1.784	1.79	6:27	73.031	0.006	13	Organic
Date 8	2018/08/08	R2 T3	2	10:21	16:24	26.8	401.386	461.179	1.783	1.79	6:03	59.793	0.007	13	Organic
Day 9	2018/09/08	R2 T6	1	9:11	16:24	23.1	401.538	510.467	1.788	1.788	7:13	108.929	0	17	Conventional
Day 9	2018/09/08	R2 T6	2	9:19	16:24	23	396.561	464.201	1.787	1.787	7:05	67.640	0	17	Conventional
Day 9	2018/09/08	R1 T3	1	9:33	16:33	25.6	399.638	434.142	1.791	1.792	7:00	34.504	0.001	17	Organic
Day 9	2018/09/08	R1 T3	2	9:41	16:39	23.7	395.163	427.463	1.79	1.792	6:58	32.300	0.002	17	Organic
Day 10	2018/12/08	R1 T6	1	9:08	16:30	24.6	391.942	440.661	1.796	1.797	7:22	48.719	0.001	19	Conventional
Day 10	2018/12/08	R1 T6	2	9:16	16:40	23	394.241	444.648	1.797	1.797	7:24	50.407	0	19	Conventional
Day 10	2018/12/08	R2 T3	1	9:33	16:56	24.5	400.885	445.719	1.799	1.803	7:23	44.834	0.004	19	Organic
Day 10	2018/12/08	R2 T3	2	9:45	17:10	23.3	395.368	425.28	1.799	1.804	7:25	29.912	0.005	19	Organic
Day 11	13/08/2018	R2 T6	1	8:40	16:45	19.5	395.896	430.752	1.779	1.78	8:05	34.856	0.001	15	Conventional
Day 11	13/08/2018	R2 T6	2	8:47	16:50	21.9	397.922	431.93	1.78	1.78	8:03	34.008	0	15	Conventional
Day 11	13/08/2018	R1 T3	1	9:02	17:00	21	391.013	425.886	1.78	1.78	7:58	34.873	0	15	Organic
Day 11	13/08/2018	R1 T3	2	9:08	17:05	20.5	394.974	430.611	1.78	1.781	7:57	35.637	0.001	15	Organic
Day 12	14/08/2018	R1 T6	1	10:02	17:09	25.5	398.338	472.926	1.784	1.785	7:07	74.588	0.001	18	Conventional
Day 12	14/08/2018	R1 T6	2	10:10	17:20	22	408.785	513.534	1.786	1.786	7:10	104.749	0	18	Conventional
Day 12	14/08/2018	R2 T3	1	10:23	17:30	22.6	394.295	460.81	1.797	1.798	7:07	66.515	0.001	18	Organic
Day 12	14/08/2018	R2 T3	2	10:39	17:40	20.4	390.938	451.233	1.794	1.795	7:01	60.295	0.001	18	Organic
Day 13	16/08/2018	R2 T6	1	10:00	16:30	17.8	392.228	424.476	1.783	1.784	6:30	32.248	0.001	19	Conventional
Day 13	16/08/2018	R2 T6	2	10:05	16:37	22.4	393.907	427.549	1.784	1.786	6:32	33.642	0.002	19	Conventional
Day 13	16/08/2018	R1 T3	1	10:19	16:48	19.9	394.325	427.957	1.784	1.789	6:29	33.632	0.005	19	Organic
Day 13	16/08/20158	R1 T3	2	10:15	16:55	23	392.656	449.207	1.781	1.785	6:40	56.551	0.004	19	Organic
Day 14	17/08/2018	R1 T6	1	9:25	17:05	19	389.688	428.23	1.79	1.791	7:40	38.542	0.001	19	Conventional
Day 14	17/08/2018	R1 T6	2	9:29	17:10	19.2	393.34	436.85	1.79	1.792	7:41	43.510	0.002	19	Conventional
Day 14	17/08/2018	R2 T3	1	9:44	17:19	18.2	391.788	424.231	1.791	1.793	7:35	32.443	0.002	19	Organic
Day 14	17/08/2018	R2 T3	2	9:49	17:30	18	392.371	429.641	1.791	1.794	7:41	37.270	0.003	19	Organic
Day 15	18/08/2018	R2 T6	1	10:29	16:57	18.2	396.314	421.02	1.796	1.808	6:28	24.706	0.012	21	Conventional
Day 15	18/08/2018	R2 T6	2	10:34	17:03	18.1	396.177	428.781	1.797	1.805	6:29	32.604	0.008	21	Conventional
Day 15	18/08/2018	R1 T3	1	10:41	17:14	20.4	397.903	435.473	1.794	1.799	6:33	37.570	0.005	21	Organic
Day 15	18/08/2018	R1 T3	2	10:46	17:19	18.2	396.277	429.716	1.794	1.81	6:33	33.439	0.016	21	Organic
Day 16	19/08/2018	R1 T6	1	9:30	16:00	17	399.061	439.417	1.781	1.781	6:30	40.356	0	16	Conventional
Day 16	19/08/2018	R1 T6	2	9:36	16:09	17.1	397.421	422.327	1.783	1.782	6:33	24.906	-0.001	16	Conventional
Day 16	19/08/2018	R2 T3	1	9:50	16:21	17	391.419	419.476	1.788	1.789	6:31	28.057	0.001	16	Organic
Day 16	19/08/2018	R2 T3	2	9:57	16:30	16	396.427	423.279	1.788	1.79	6:33	26.852	0.002	16	Organic
Day 17	21/08/2018	R2 T6	1	8:39	16:48	22.6	397.066	442.364	1.782	1.782	8:09	45.298	0	17	Conventional
Day 17	21/08/2018	R2 T6	2	8:44	16:57	23.4	397.892	448.594	1.782	1.782	8:13	50.702	0	17	Conventional
Day 17	21/08/2018	R1 T3	1	8:58	16:13	21.4	393.436	447.372	1.786	1.79	7:15	53.936	0.004	17	Organic
Day 17	21/08/2018	R1 T3	2	9:06	16:23	24	389.206	424.998	1.786	1.791	7:17	35.792	0.005	17	Organic
Day 18	22/08/2018	R1 T6	1	8:53	16:15	21.7	394.85	438.396	1.784	1.784	7:22	43.546	0	17	Conventional
Day 18	22/08/2018	R1 T6	2	9:00	16:25	20.8	398.639	440.764	1.784	1.784	7:25	42.125	0	17	Conventional
Day 18	22/08/2018	R2 T3	1	9:19	16:40	23.4	394.064	428.685	1.784	1.785	7:21	34.621	0.001	17	Organic
Day 18	22/08/2018	R2 T3	2	9:26	16:48	21.4	395.992	428.505	1.785	1.786	7:22	32.513	0.001	17	Organic
Day 19	23/08/2018	R2 T6	1	9:05	16:00	18.4	397.713	440.082	1.785	1.787	6:55	42.369	0.002	16	Conventional
Day 19	23/08/2018	R2 T6	2	9:12	16:09	18.2	399.18	445.719	1.785	1.787	6:57	46.539	0.002	16	Conventional
Day 19	23/08/2018	R1 T3	1	9:30	16:25	23.6	396.056	441.55	1.785	1.787	6:55	45.494	0.002	16	Organic
Day 19	23/08/2018	R1 T3	2	9:38	16:35	21.9	396.832	434.725	1.786	1.787	6:57	37.893	0.001	16	Organic

Appendix 2: George summarised data

		R2 T6 Conventional plot										
		Can 1	Can 2	Ave		Can 1	Can 2	Ave		SM Con		Temp
Sample 1	Day 1	94.509	79.567	87.038		0.001	0.003	0.002		7.1		26
Sample 2	Day 3	79.104	75.068	77.086		0.001	0	0.0005		5.7		27
Sample 3	Day 5	99.79	104.896	102.343		0	0.001	0.0005		4.1		19
Sample 4	Day 7	93.234	118.033	105.6335		0.002	-0.001	0.0005		11.6		19
Sample 5	Day 9	108.929	67.64	88.2845		0	0	0		23.05		17
Sample 6	Day 11	34.856	34.008	34.432		0.001	0	0.0005		20.7		15
Sample 7	Day 13	32.248	33.642	32.945		0.001	0.002	0.0015		20.1		19
Sample 8	Day 15	24.706	32.604	28.655		0.012	0.008	0.01		18.15		21
Sample 9	Day 17	45.298	50.702	48		0	0	0		23		17
Sample 10	Day 19	42.369	46.539	44.454		0.002	0.002	0.002		18.3		16
	Average		CO2	64.887			CH4	0.0018		15.18		

		R1 T6 Conventional plot										
		Can 1	Can 2	Ave		Can1	Can 2	Ave		SM		Temp
Sample 1	Day 2	96.039	89.508	92.7735		0	0	0		7.1		18
Sample 2	Day 4	69.191	86.968	78.0795		0	0.002	0.001		4.5		30
Sample 3	Day 6	110.783	88.797	99.79		-0.001	0	-0.0005		5.35		17
Sample 4	Day 8	73.593	69.309	71.451		0.002	0.001	0.0015		24.75		13
Sample 5	Day 10	48.719	50.407	49.563		0.001	0	0.0005		23.8		19
Sample 6	Day 12	74.588	104.749	89.6685		0.001	0	0.0005		23.75		18
Sample 7	Day 14	38.542	43.51	41.026		0.001	0.002	0.0015		19.1		19
Sample 8	Day 16	40.356	24.906	32.631		0	-0.001	-0.0005		17.05		16
Sample 9	Day 18	43.546	42.125	42.8355		0	0	0		21.25		17
	Average		CO2	66.424			CH4	0.0004		16.29444		

		R1 T3 Organic										
		Can 1	Can 2	Ave		Can 1	Can 2	Ave		SM		Temp
Sample 1	Day 1	70.453	40.592	55.5225		0.009	0.011	0.01		7.85		26
Sample 2	Day 3	68.378	73.361	70.8695		0.003	0.002	0.0025		4.5		27
Sample 3	Day 5	96.015	93.662	94.8385		-0.001	0.002	0.0005		3.85		19
Sample 4	Day 7	86.952	64.241	75.5965		0.008	0.006	0.007		8.2		19
Sample 5	Day 9	34.504	32.3	33.402		0.001	0.002	0.0015		24.65		17
Sample 6	Day 11	34.873	35.637	35.255		0	0.001	0.0005		20.75		15
Sample 7	Day 13	33.632	56.551	45.0915		0.005	0.004	0.0045		21.45		19
Sample 8	Day 15	37.57	33.439	35.5045		0.005	0.016	0.0105		19.3		21
Sample 9	Day 17	53.936	35.792	44.864		0.004	0.005	0.0045		22.7		17
Sample 10	Day 19	45.494	37.893	41.6935		0.002	0.001	0.0015		22.75		16
	Average		CO2	53.264			CH4	0.0043		15.6		

		R2 T3 Organic										
		Can 1	Can 2	Ave		Can 1	Can 2	Ave		SM		Temp
Sample 1	Day 2	37.048	56.412	46.73		0.002	0.001	0.0015		6.9		18
Sample 2	Day 4	53.258	28.956	41.107		0.009	0.009	0.009		5.2		30
Sample 3	Day 6	68.618	91.499	80.0585		0.002	0	0.001		4.1		17
Sample 4	Day 8	73.031	59.793	66.412		0.006	0.007	0.0065		25.9		13
Sample 5	Day 10	44.834	29.912	37.373		0.004	0.005	0.0045		23.9		19
Sample 6	Day 12	66.515	60.295	63.405		0.001	0.001	0.001		21.5		18
Sample 7	Day 14	32.443	37.27	34.8565		0.002	0.003	0.0025		18.1		19
Sample 8	Day 16	28.057	26.852	27.4545		0.001	0.002	0.0015		16.5		16
Sample 9	Day 18	34.621	32.513	33.567		0.001	0.001	0.001		22.4		17
	Average		CO2	47.885			CH4	0.0032		16.05556		

Appendix 3: Bethlehem raw data

	ARC-Small Grain												
	14-Feb-19												
Block	Treatment	Plot	Sample	Air temp	Soil temp	Sampling Time		Zero sample CO2	Project sample CO2	Emitted CO2	Zero sample CH4	Project sample CH4	Emitted CH4
A	Mulch, chemical weed control, 40 kg N/ha	18	A	20.8	19.0	12:43		392.780	428.094	35.314	1.768	1.780	0.012
A	Mulch, chemical weed control, 40 kg N/ha	18	B	21.4	20.6	1:09		386.815	417.242	30.427	1.764	1.780	0.016
B	Mulch, chemical weed control, 40 kg N/ha	52	A	20.3	19.6	10:46		391.222	415.127	23.905	1.766	1.771	0.005
B	Mulch, chemical weed control, 40 kg N/ha	52	B	21.5	19.7	11:48		387.740	415.366	27.626	1.765	1.777	0.012
C	Mulch, chemical weed control, 40 kg N/ha	77	A	20.7	20.0	12:13		390.777	416.464	25.687	1.778	1.787	0.009
C	Mulch, chemical weed control, 40 kg N/ha	77	B	20.8	20.0	12:25		388.242	415.523	27.281	1.785	1.783	-0.002
	AVERAGE									**28.373**			**0.009**
A	No-till, chemical weed control, 40 kg N/ha	29	A	20.8	19.7	12:06		393.870	429.824	35.954	1.777	1.783	0.006
A	No-till, chemical weed control, 40 kg N/ha	29	B	21.2	20.5	12:32		388.636	418.757	30.121	1.767	1.787	0.020
B	No-till, chemical weed control, 40 kg N/ha	40	A	20.6	19.0	10:35		395.918	407.053	11.135	1.770	1.766	-0.004
B	No-till, chemical weed control, 40 kg N/ha	40	B	21.7	20.0	11:55		389.169	428.888	39.719	1.772	1.787	0.015
C	No-till, chemical weed control, 40 kg N/ha	79	A	21.0	20.1	12:51		391.433	425.753	34.320	1.766	1.777	0.011
C	No-till, chemical weed control, 40 kg N/ha	79	B	21.1	20.6	1:02		386.445	425.985	39.540	1.766	1.783	0.017
	AVERAGE									**31.798**			**0.011**
A	Plough, chemical weed control, 40 kg N/ha	4	A	19.6	19.3	10:29		389.772	420.087	30.315	1.766	1.782	0.016
A	Plough, chemical weed control, 40 kg N/ha	4	B	21.3	20.7	1:23		389.831	426.427	36.596	1.766	1.775	0.009
B	Plough, chemical weed control, 40 kg N/ha	69	A	21.2	19.6	10:57		395.981	441.862	45.881	1.765	1.787	0.022
B	Plough, chemical weed control, 40 kg N/ha	69	B	21.4	19.9	11:35		389.505	439.397	49.892	1.770	1.786	0.016
C	Plough, chemical weed control, 40 kg N/ha	100	A	21.2	19.7	11:06		389.094	430.046	40.952	1.762	1.782	0.020
C	Plough, chemical weed control, 40 kg N/ha	100	B	21.5	19.4	11:26		389.170	417.894	28.724	1.769	1.778	0.009
	AVERAGE									**38.727**			**0.015**

Appendix 4: George and Bethlehem data calculations

1. George percentage difference site A – CO_2

64.887ppm – Conventional CO_2 emissions

53.264ppm – Organic CO_2 emissions

*64.887ppm - 53.264ppm = 11.623ppm (conventional emitted 11.623ppm more CO_2 than organic)

$$\frac{64.887 - 53.264}{\left[\frac{64.887 + 53.264}{2}\right]} X\ 100 = 19.67\%$$

2. George percentage difference site B – CO_2

66.887ppm – Conventional CO_2 emissions

47.885ppm – Organic CO_2 emissions

*66.887ppm – 47.885ppm = 19.002ppm (conventional emitted 19.002ppm more CO_2 than organic)

$$\frac{66.887 - 47.885}{\left[\frac{66.887 - 47.885}{2}\right]} X\ 100 = 33\%$$

3. George percentage difference site A – CH_4

0.0033ppm – Organic CH_4 emissions

0.0018ppm – Conventional CH_4 emissions

*0.0033ppm - 0.0018ppm = 0.0015ppm (organic emitted 0.0015ppm more CH_4 than conventional)

$$\frac{0.0033 - 0.0018}{\left[\frac{0.0033 + 0.0018}{2}\right]} X\ 100 = 58.82\%$$

4. George percentage difference site B – CH_4

0.0024ppm – Organic CH_4 emissions

-0.0005ppm – Conventional CH_4 emissions

*0.0024ppm – (-0.0005)ppm = 0.0029ppm (organic emitted 0.0028ppm more CH_4 than conventional)

$$\frac{0.0024 - (0.0005)}{[\frac{0.0024 + (0.0005)}{2}]} X\,100 = 131\%$$

5. Bethlehem percentage difference – plough against no-till – CO_2

38.727ppm – Plough CO_2 emissions

31.798ppm - No-till CO_2 emissions

*38.727ppm – 31.798ppm = 6.929ppm (plough emitted 6.929ppm more CO_2 than no-till)

$$\frac{38.727 - 31.798}{[\frac{38.727 + 31.798}{2}]} X\,100 = 19.65\%$$

6. Bethlehem percentage difference – no-till against stubble mulch – CO_2

31.798ppm – No-till CO_2 emissions

28.373ppm – Stubble mulch CO_2 emissions

*31.798ppm - 28.373ppm = 3.425ppm (no-till emitted 3.425ppm more CO_2 than stubble mulch)

$$\frac{31.798 - 28.373}{[\frac{31.798 + 28.373}{2}]} X\,100 = 11.38\%$$

7. Bethlehem percentage difference – plough against stubble mulch – CO_2

38.272ppm – Plough CO_2 emissions

28.373ppm – Stubble mulch CO_2 emissions

*38.272ppm – 28.373ppm = 10.354ppm (plough emitted 10.354ppm more CO_2 than stubble mulch)

$$\frac{38.272 - 28.373}{\left[\frac{38.272 + 28.373}{2}\right]} X\ 100 = 30.86\%$$

8. Bethlehem percentage difference – plough against no-till – CH_4

0.015ppm – Plough CH_4 emissions

0.011ppm – No-till CH_4 emissions

*0.015ppm – 0.011ppm = 0.004ppm (plough emitted 0.004ppm more CH_4 than no-till)

$$\frac{0.015 - 0.011}{\left[\frac{0.015 + 0.011}{2}\right]} X\ 100 = 30.77\%$$

9. Bethlehem percentage difference – no-till against stubble mulch – CH_4

0.011ppm – No-till CH_4 emissions

0.009ppm – Stubble mulch CH_4 emissions

*0.011ppm – 0.009ppm = 0.002ppm (no-till emitted 0.002ppm more CH_4 than stubble mulch)

$$\frac{0.011 - 0.009}{\left[\frac{0.011 + 0.009}{2}\right]} X\ 100 = 20\%$$

10. Bethlehem percentage difference – plough against stubble mulch –CH_4

0.015ppm – Plough CH_4 emissions

0.009ppm – Stubble mulch CH_4 emissions

*0.015ppm – 0.009ppm = 0.006ppm (plough emitted 0.006ppm more CH_4 than stubble mulch)

$$\frac{0.015-0.009}{[\frac{0.015+0.009}{2}]} X\ 100 = 50\%$$

Appendix 5: Box 24 published in the AEON Report 2018.

BOX 24

LOCAL FARMING ALSO NEEDS TO ADAPT TO CLIMATE CHANGE

TEBOGO SEBAKE

Cultivated farmlands in the world occupy a land mass the size of South America, and ranch-land for livestock grazing occupies a land mass the size of Africa (Crist, 2015). This agricultural industry, which contributes about 30% of anthropogenic greenhouse gas (GHG) emissions, predominantly CO_2 and CH_4, therefore directly influences global climate changes. In addition, there is very little arable land left; most of it is in the form of tropical forests (mostly of which, if removed further to expand agriculture, would accelerate biodiversity loss and further complicate efforts to control climate change emissions (Butler, 2015). There is a need, therefore, for agricultural food production to increase in the next decades. It would be of utmost importance to minimize the GHG emissions from the agricultural sector as it needs to keep pace with the growing population, currently at 7.5 billion people, projected to be 8 billion by 2025 (Butler, 2015). However, the production increase and adaptability will be more challenging and more demanding than ever before, as the environment is now more vulnerable to climate change. Adaptability is limited by vast areas with scarce water resources and rain-fed agricultural production, which is responsible for more than 90% food production in Sub Saharan Africa (Fan and Brzeska, 2016) Adaptation and mitigation strategies should be implemented before possible uncontrollable thresholds are experienced (e.g. Steffen et al., 2018); and switching from intensive-emissions to low emission goods and services is a major challenge, but sustainable long-term goals can still achieve this at costs that are low in comparison to the risk of inaction (Stern, 2007). To test GHG emissions from different agricultural practices and crops, this project focuses on collecting emissions data from a long term comparative farming systems. For example, crop rotation has increased significantly in Southern Africa in the past 10 years due to fluctuating in grain prices. Research on long term crop rotation reveal a 10-15% increase in soybeans and corn, in addition to other advantages; but their release and/or storage of CO_2 and CH_4 remains unknown. The aim of this project is to compare CO_2 and CH_4 emitted from organic and conventional crop production, with the objective to help draw up a reliable budget for land use management linked to relation to climate change, food security and reducing gas emissions from the agricultural sector. In 2014 long-term comparative farming systems research trials were set up at the George Campus of Nelson Mandela University (the ▸

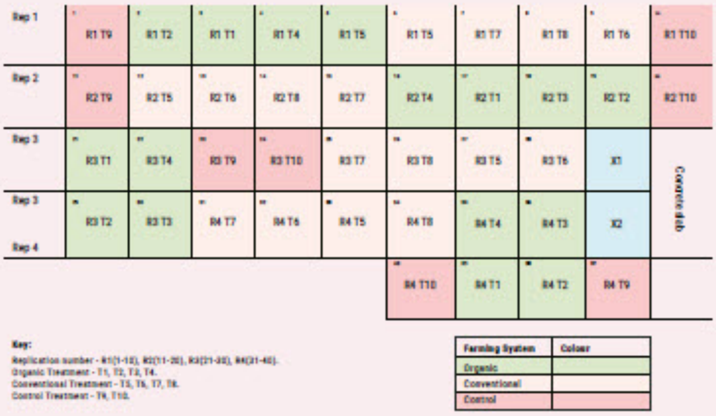


FIGURE B24.1.

Map of the crop-trial plot layout highlighting the long term comparative farming system. A crop-rotated conventional plot and a crop-rotated organic plot were sampled.

Mandela Trials; Auerbach, 2019). The research trials consist of two crop systems (organic and conventional) and two crop rotations (mono-crop and cabbage/ sweet potato/ cowpea rotation). The trial field is separated into forty plots (**Figure B24.1**), divided amongst organic production, conventional production and a monocrop control treatment (non-fertilised). The biometric design is a complete randomised block with farming systems as factors, split for monocrop and rotation, with four replications. All plots (5X6m, 30m^2) are rain fed.

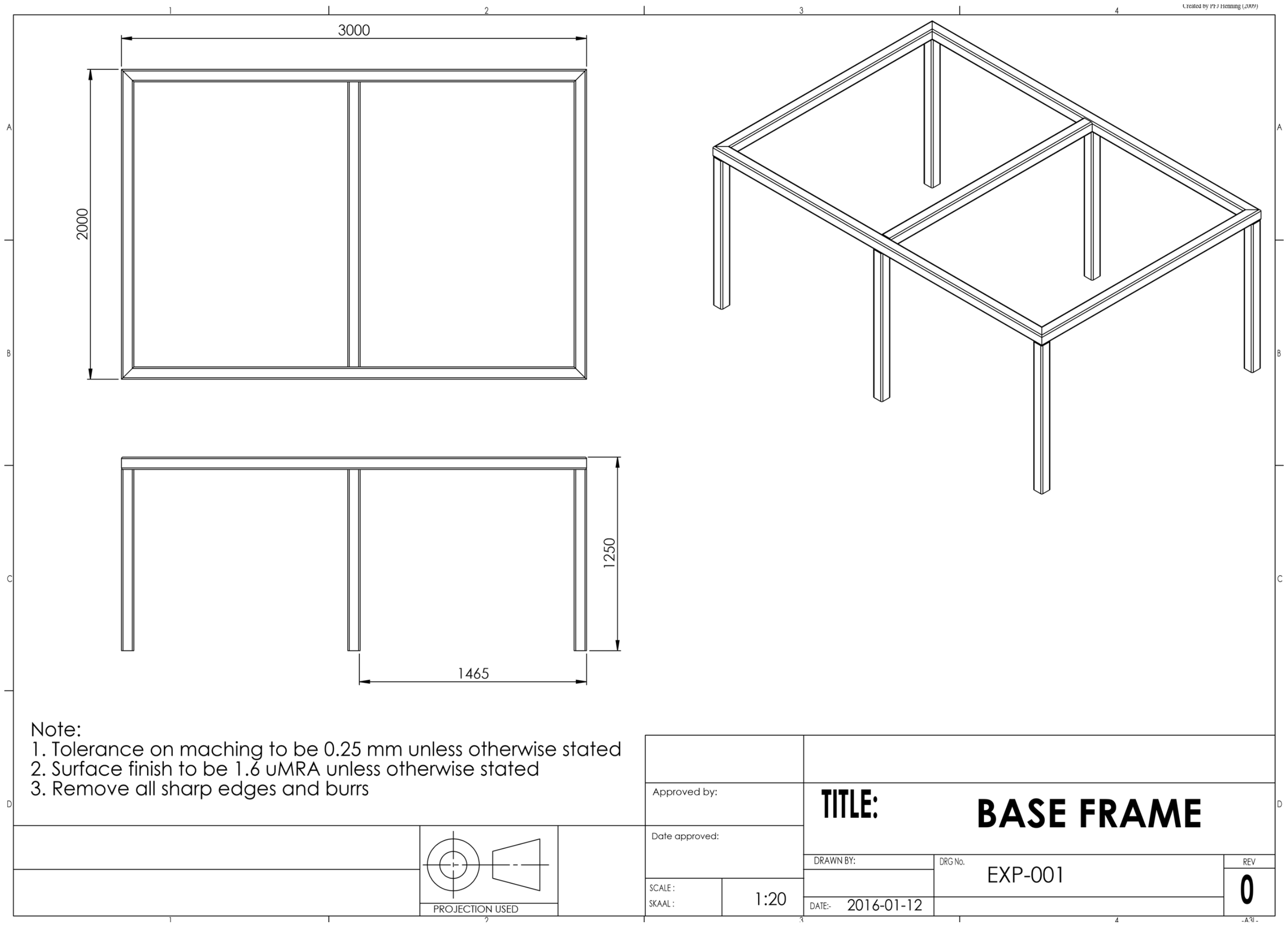
The instrument used to analyse the gas is a mobile Picarro (**Figure B24.2** and see **Box 13** for further detail). The analyser can simultaneously measure carbon isotopes from both CO_2 and CH_4. Gas emitted from selected crops (and their soils) are captured in a canister and then. The polypropylene canister, 50cm high and 50cm in diameter, has an open base that is placed/hammered 10cm into the ground. The remaining 40cm in the headspace traps gas emitted after the canister is secured.
An ambient (zero) sample is collected before closing the canister and two canisters are used per plot for replication, and are left in the field for a certain period. After a few hours, the gas in the canister is analysed again to differentiate between the two production types emissions. Soil moisture, soil emissions and temperature are collected daily during emissions. Results to date reveal distinct differences in gas emissions between conventional and organic crops, but the data is too slim yet for reliable analyses. Moreover, the analyses will continue further through testing crops in active farms across the Karoo. ■

FIGURE B24.2.

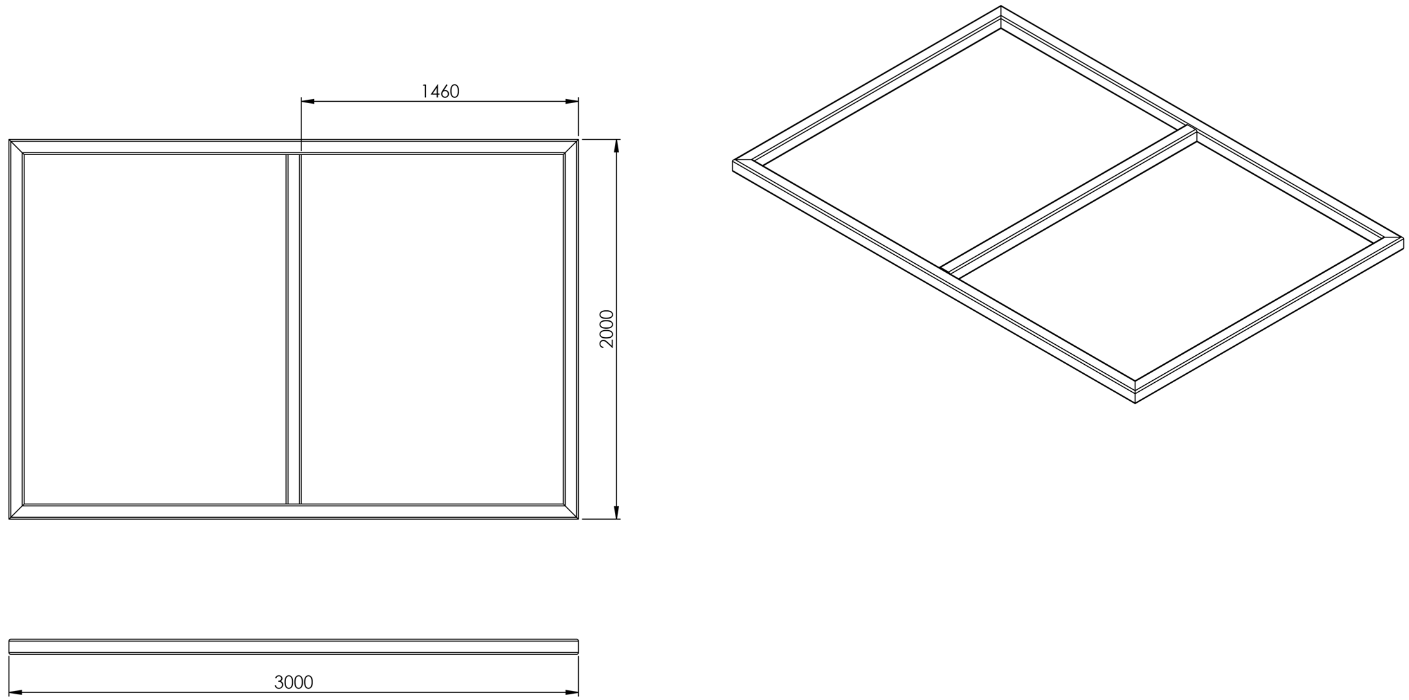
***Top:** Picarro in truck used to analyse CO_2 and CH_4 concentrations in gas canisters in the test crop-plots.*

***Bottom:** Special designed gas canister used to accumulate GHG in the headspace*

Appendix 6: Tank-like gas trapping structure



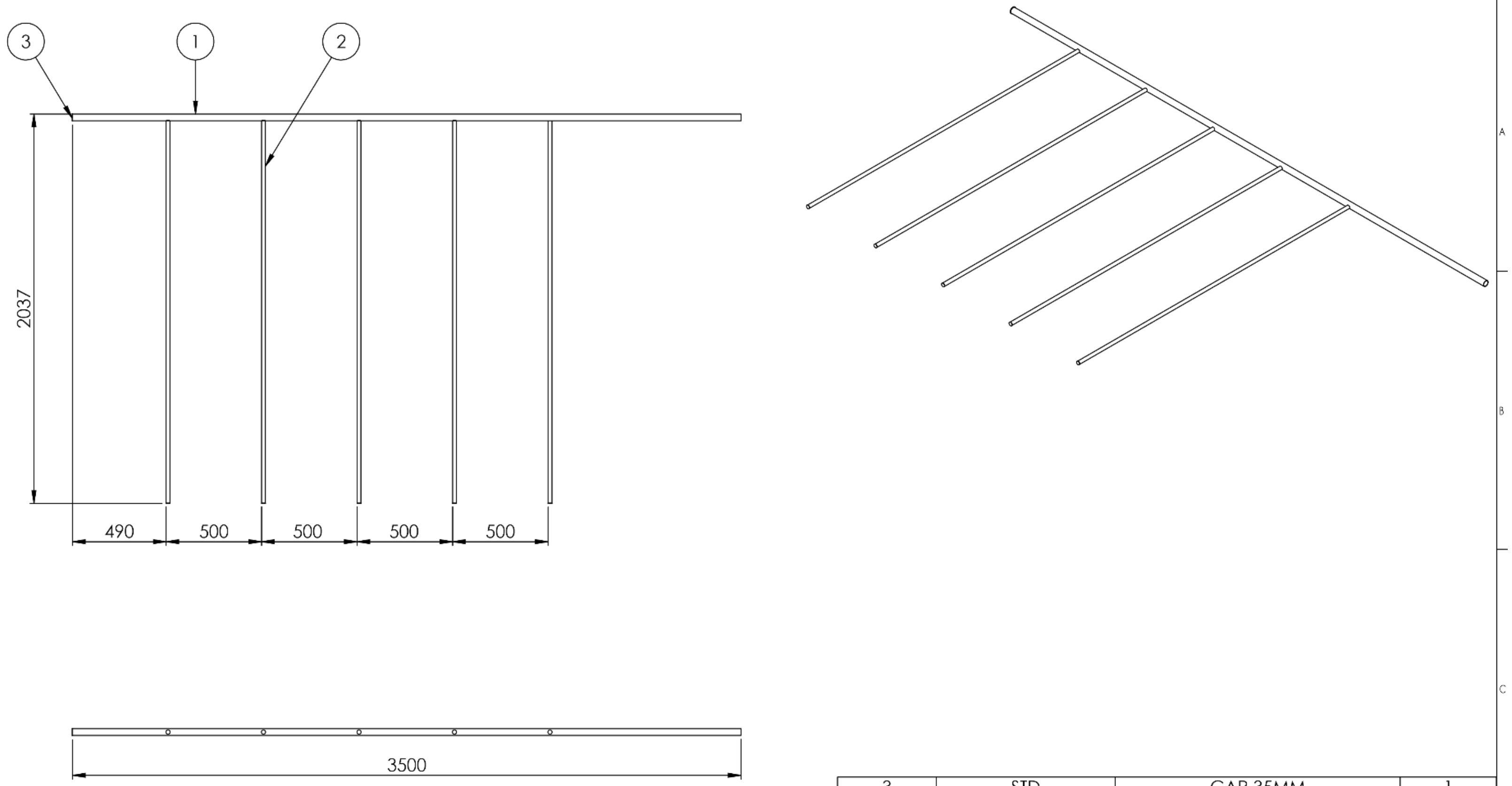
Created by PFJ Henning (2009)



Note:
1. Tolerance on maching to be 0.25 mm unless otherwise stated
2. Surface finish to be 1.6 uMRA unless otherwise stated
3. Remove all sharp edges and burrs

Approved by:	**TITLE:** **LID FRAME**
Date approved:	DRAWN BY:
SCALE : SKAAL : 1:20	DATE:- 2018-01-11
DRG No.	EXP-002
REV	**0**
PROJECTION USED	

A3



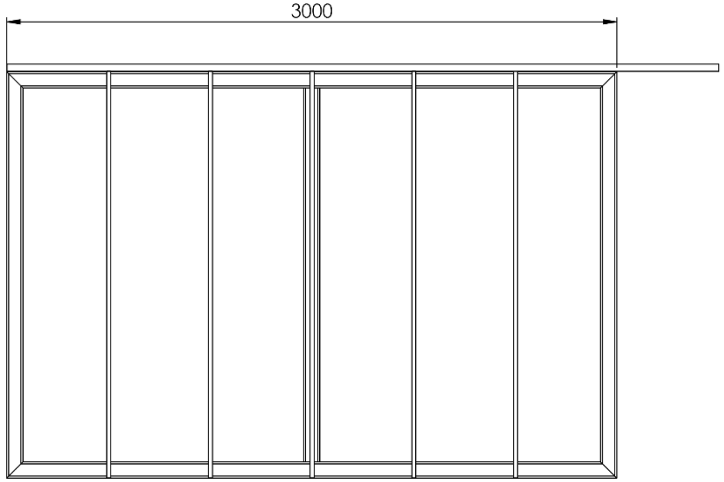
3	STD	CAP 35MM	1
2	EXP-ASM-01	DRIP PIPE ASSEMBLY	5
1	STD	MAIN IRRIGATION PIPE 35MM	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

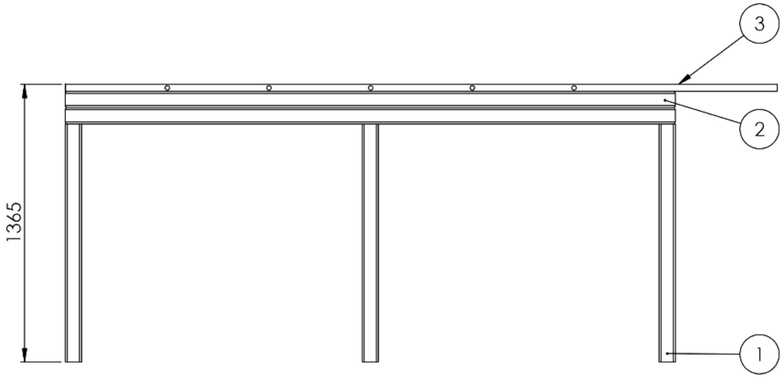
PROJECTION USED

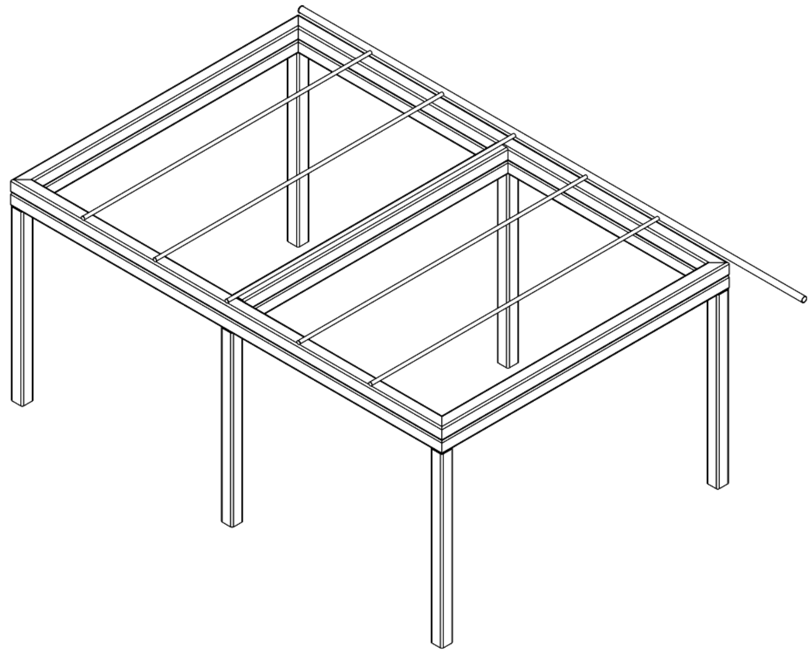
Approved by:	**TITLE:** **IRRIGATION NETWORK**
Date approved:	DRAWN BY:
SCALE : SKAAL : 1:50	DATE:- 2018-01-11
DRG No.	EXP-ASM-02
REV	0

-A3-

Created by PFJ Henning (2009)







3	EXP-ASM-02	IRRIGATION NETWORK	1
2	EXP-002	LID FRAME	1
1	EXP-001	BASE FRAME	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

Approved by:

Date approved:

TITLE: EXPERIMENTAL SET-UP

DRAWN BY:	DRG No. EXP-ASM-03	REV 0	
SCALE : SKAAL : 1:20	DATE:- 2018-01-12		

PROJECTION USED

-A3-

Appendix 7: Tank-like gas trapping structure quotation

QUOTE

Date: 1/11/2018
Invoice # 105

Coring Construction
30 Cuyler Crescent
Port Elizabeth
0843853545

To Tebogo Sebake

Qty	Description	Unit Price	Discount	Line Total
10	Marine Silicone	55.00		550.00
1	4mm Clear Polycarbonate Sheeting	2950.00		2950.00
2	3mm Clear Polycarbonate Sheeting	2210.00		4420.00
4	50mm holes cut in sheeting	100.00		400.00
1	2m x3m wooden support for plumbing	350.00		350.00
1	Drip irrigation system using 12mm polyprop piping and copper connections	848.50		848.50
	Labour for building 1 off 2m x 3m open tank	10000.00		10000.00
	Labour for building 1 off 1m x 1m water tank	2000.00		2000.00
		Total Discount		
			Subtotal	21581.50
			Sales Tax	1341.40
			Total	22922.90

Appendix 8: Gas canister invoice

INVOICE

Date: 5/21/2018
Invoice # 137

Bubba's
90 Karmin St
Port Elizabeth
0843853545

To

Tebogo Sebake

Qty	Description	Unit Price	Discount	Line Total
1	250mm UPVC Pipe	1 590.00		1 590.00
5	250mm End caps	1 065.00		1 065.00
5	3 way valves	60.00		60.00
1	Pvc adhesive	100.00		100.00
	Labour for cutting and beveling 5 off 30cm sections and installing 3 way valves	1 000.00		1 000.00
Total Discount				
Subtotal				
		Sales Tax	498.00	
			Total	3 815.00

Appendix 9: Paired t-test calculation

Site A CO_2

$$t = \frac{M\bar{d}}{S\sqrt{n}}$$

$$= t = \frac{11.623}{20.721\sqrt{10}}$$

t= **<u>1.774</u>**

Site A CH_4

$$t = \frac{M\bar{d}}{S\sqrt{n}}$$

$$= t = \frac{0.0015}{0.00238\sqrt{10}}$$

t= ***<u>1.9926</u>***

Site B CO_2

$$t = \frac{M\bar{d}}{S\sqrt{n}}$$

$$= t = \frac{18.539}{14.989\sqrt{9}}$$

t= **<u>3.711</u>**

Site B CH_4

$$t = \frac{M\bar{d}}{S\sqrt{n}}$$

$$= t = \frac{0.00289}{0.002924\sqrt{9}}$$

t= **<u>2.964</u>**

Appendix 10: Polled variance calculations

$$t = \frac{\bar{y}^1 - \bar{y}^2}{S_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

Where S_p = $S_p = \sqrt{\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{(n_1+n_2)-2}}$

Site A – CO_2

$$S_p = \sqrt{\frac{(20-1)30.582^2 + (20-1)21.621^2}{(20+20)-2}}$$

= <u>26.4830313</u>

$$t = \frac{64.887 - 53.264}{26.4830313\sqrt{\frac{1}{20}+\frac{1}{20}}}$$

t= **<u>1.388</u>**

Site B – CO_2

$$S_p = \sqrt{\frac{(18-1)25.774^2 + (18-1)18.97^2}{(18+18)-2}}$$

= <u>22.62773</u>

$$t = \frac{66.424 - 47.885}{22.62773\sqrt{\frac{1}{18}+\frac{1}{18}}}$$

t= **<u>2.457</u>**

Site A – CH_4

$$S_p = \sqrt{\frac{(20-1)0.0044^2 + (20-1)0.00486^2}{(20+20)-2}}$$

= <u>0.00463570</u>

$$t = \frac{0.0033 - 0.0018}{0.00463570\sqrt{\frac{1}{20} + \frac{1}{20}}}$$

t= **<u>1.023</u>**

Site B – CH_4

$$S_p = \sqrt{\frac{(18-1)0.00281^2 + (18-1)0.00327^2}{(18+18)-2}}$$

= <u>0.003304868</u>

$$t = \frac{66.424 - 47.885}{22.62773\sqrt{\frac{1}{18} + \frac{1}{18}}}$$

***t* = <u>2.834</u>**

Appendix 11: Summary of mean values and standard deviation

Pooled variance values

Gas	Site A				Site B			
	Conventional R2T6		Organic R1T3		Conventional R1T6		Organic R2T3	
	Average (ppm)	Standard deviation	Average (ppm)	Standard deviation	Average (ppm)	Standard deviation	Average (ppm)	Standard deviation
CO_2	64.887	30.5816	53.264	21.621	66.424	25.774	47.885	18.97
CH_4	0.0018	0.0044	0.0033	0.00486	-0.0005	0.00327	0.00238	0.00281

Paired t-test Values

Gas	Site A		Site B	
	Difference	Standard deviation	Difference	Standard deviation
CO_2	11.623	20.721	18.539	14.989
CH_4	0.0015	0.00238	0.00289	0.00292

Appendix 12- Global warming potential calculations

CH_4 has 34X more global warming potential than CO_2 (Cui et al., 2015; Lassen and Løvendahl, 2016).

George Site A.

Conventional emissions – 64.887 ppm CO_2

Organic emissions – 53.264 ppm CO_2

Difference = 11.623 ppm CO_2 (conventional – organic)

Conventional emissions – 0.0018 ppm CH_4

Organic emissions – 0.0033 ppm CH_4

Difference = 0.002 ppm CH_4 (organic – conventional)

0.002 ppm * 34 = 0.068 potency

$\frac{11.623}{0.068} =$ 170 (CO_2 has 170 times more global warming potential)

George Site B.

Conventional emissions – 66.424 ppm CO_2

Organic emissions – 47.885 ppm CO_2

Difference = 18.539 ppm CO_2 (conventional – organic)

Conventional emissions – (-0.0005) ppm CH_4

Organic emissions – 0.0024 ppm CH_4

Difference = 0.003 ppm CH_4 (organic – conventional)

0.003 ppm * 34 = 0.102 potency

$\frac{18.539}{0.102}$ = 181 (CO2 has 181 times more global warming potential)