Integrated Crop Management as a Sustainable Future for Global Agriculture

A report for:

NUFFIELD ZIMBABWE
FARMING SCHOLARS

By Philip Weller

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Scholar Contact Details

Philip Weller
P.O. Box BW 1779, Borrowdale
Harare
Phone: +263-772-302006
Email: plwtonsberg@gmail.com

NUFFIELD ZIMBABWE Contact Details

Nuffield Zimbabwe
Telephone: +263 772-296060
Email: nuffieldzimbabwe@gmail.com

EXECUTIVE SUMMARY

The world population is estimated to be 9.7 billion by 2050 and will require a 60 to 70% increase in food production. The majority of the world's population is going to increase in Africa (41%) and Asia (49%). These numbers are a stark warning that agriculture in the very near future will need to take into account the change in dietary requirements, the increase in competition for biomass from biofuels, and the increase in urbanisation, which will all apply pressure on current agricultural production. Of the 1,500 million hectares of arable land globally, around one-third has been threatened by erosion, seawater, and pollutants, degrading soil health and biological productivity.

Globally, agriculture takes a consumptive approach, where more resources are used than are replaced with each crop, resulting in a gradual degradation of the land. Productivity on these farms is not sustainable and thus diminishes over time with the land remaining productive only in the short term. The following are normally associated with these approaches to farming:

- Use of technology to increase yields and mask soil degradation;
- lack of emphasis on the soil microbiome;
- over-use of agricultural crop protection chemicals leading to resistance; and
- over-use of inorganic fertilisers leading to problems such as acidification.

Integrated Crop Management (ICM) is a pragmatic approach to agriculture that resolves these issues, whilst also offering a holistic approach to crop management, which involves the integration of the following:

- Site selection;
- soil health;
- regenerative agriculture;
- water management;
- crop rotation;
- crop nutrition;
- environment, energy, and waste management; and
- crop protection.

ICM embraces a philosophy of 'working with nature' as opposed to 'working against nature' and is the future of sustainable, profitable agriculture, offering an attainable way of preparing for the challenges of an increased population. This report serves to outline the premise of ICM and provides examples of its potential.

TABLE OF CONTENTS

TABLE OF FIGURES

FOREWORD

I had the privilege of completing my BSc. Agric. degree at the University of KwaZulu-Natal in Pietermaritzburg with majors in horticulture and chemistry. I then went on to a complete an MSc. Agric. majoring in horticulture, writing my thesis on the vapour heat treatment of 'Hass' and 'Fuerte' avocado fruit for extending storage life. I was fortunate to study under Professor Peter Allan (Horticulture), Professor Nigel Wolstenholme (Horticulture) and Professor Siegfried Drewes (Chemistry). The world-class Horticulture department had strong links with universities in California, Australia, and New Zealand, with a particular emphasis on subtropical horticulture, which is my passion.

I was privileged to grow up in a family where hard work, love and trying to be a better person were the order of the day. Growing up with a view to trying to make the world a better place as well as doing the best you can in one's current situation, and hopefully being able to pay the bills at the end of the day. With this background in mind Nuffield really appealed to me due to its good values and principles.

With a commercial agricultural background in intensive horticulture for export, my experience covers all stages of the business life cycle – growing, logistics and marketing of the product. Working within our family business, I am active in the biological control space of pest management by providing (mainly export horticultural projects) with biological control solutions that are zero chemical residue products. We work with our partners, Dudutech in Kenya, who have recently been acquired by Bioline Agrosciences.

Through my own growing experiences and through world travel, I have seen how devastating intensive horticulture can be to soil health, whilst increasing pest problems due to resistance. One tended to use the chemical 'treadmill' to try and fix problems as opposed to a more integrated approach. This, in turn, really affects one's viability. I personally disliked how toxic some of the commercial nematicides and fumigants were, which started my journey nearly a decade ago and lead me to Nuffield. I found my interest in biological control developing into a passion that will be the future of agriculture.

It seems to me 'where there is a will there is a way', especially with regard to holistic agricultural management. When I started my Nuffield journey it was only focusing on Integrated Pest Management, but after my Global Focus Programme I realised that my subject was too narrow, and that Integrated Crop Management was better suited to what I was trying to achieve.

My Nuffield journey started in Iowa after a 28-hour flight from Harare, Zimbabwe, for my Contemporary Scholars Conference (CSC) following which I went on the 'Chile' Global Focus Programme (GFP) as part of a group of eight. It was a diverse and fun group and we went to the following places on our travels: Washington, California, Argentina, Chile, Italy, and the United Kingdom. On my personal travels, I only went to South Africa and Kenya. Unfortunately, due to Covid-19 my intended travels to Australia, New Zealand and France were cancelled.

ACKNOWLEDGEMENTS

I would like to thank the following people and organisations most sincerely:

- Investors, namely Nuffield International, Dudutech, NuFarm and Driptech. Without your support this Nuffield journey would not have been possible;
- Rob Fisher and his Nuffield team: Doug Bruce, Helen Goodwin, Trevor Gifford, Janusz Negri, Maxwell Tauya and Ben Gilpin in Zimbabwe, who have made my Nuffield journey possible. Their commitment, support, and advice have been invaluable throughout the whole journey;
- Jim Geltch, the CEO of Nuffield International for all his support and advice, I found it invaluable, thanks Jim;
- Nicola Raymond for running our superb Global Focus Programme;
- Chontell Giannini for organising our air tickets for our Global Focus Programme;
- Jean Lonie and Ed Keys for looking after me so well at the CSC in Iowa – what a great start to Nuffield;
- ‘Chile’ Global Focus Group – Corrigan, Andrew, Jake, James, Jeroen, Kerri and Ollavo for an amazing GFP;
- all the farmers and business owners that let us into their lives so openly and honestly – I really enjoyed getting to know you all;
- Dad and Mum for all you have done for me in my life, you are both an inspiration to me. Sadly, my father died when I was 25 but he left me with a lot to look up to and strive to be. I miss you Dad. Thanks Mum, for all your help while I was away on Nuffield; and
- my family for their support throughout the Nuffield journey. David, Robert, and Pippa you have been stars. Bron, you have been fantastic, taking on the role of running the business and keeping the family all in check. You are a very special lady and I really appreciate all the support you have given me with regard to our Nuffield journey – I am lucky to have you as my wife.

ABBREVIATIONS

AI	Active Ingredient
CA	Conservation Agriculture
CIWM	The Chartered Institute of Waste Management
CSC	Contemporary Scholars Conference
CUSEA	Cultivating a healthy food system
DDT	Dichlorodiphenyltrichloroethane
FAO	The Food and Agricultural Organization
FMP	Water inflows to and outflows from a ‘farm’ as simulated by the farm process
GFP	Global Focus Programme
GSAs	Ground Water Agencies
GSPs	Ground Water Sustainability Plans
ICM	Integrated Crop Management
IoT	Internet of things
IPM	Integrated Pest Management
IRAC	The Insect Resistance Action Committee
LEAF	Linking Environment and Farming (LEAF)
PABRA	The Pan-African Bean Research Alliance
SDGs	Sustainable Development Goals
SGMA	The Sustainable Ground Water Management Act
SLM	Sustainable Land management
UC	University of California
USDA	United States Department of Agriculture
WHO	The World Health Organization

OBJECTIVES

The main objective of this report is to present a model for Integrated Crop Management (ICM), which will contribute to a sustainable future for global agriculture by maximising the resources available to farmers. The report will concentrate on the following:

- Introducing the global population dynamic, how we got there and where the population is going;
- highlight the global shortage of fertile land, and encourage farmers to maximise their land productivity;
- introduce the concept of Integrated Crop Management as a solution to holistic sustainable global agriculture;
- discuss each concept of Integrated Crop Management; and
- encourage all aspects of Zimbabwe agriculture and global agriculture to embrace a holistic farming approach by working with all elements of Integrated Crop Management and especially nature itself.

Chapter 1: Introduction

The Neolithic Revolution or First Agricultural Revolution is the period where many human cultures moved from hunting and gathering to one of permanent settlement and agriculture. This is thought to have happened 12,000 years ago and led to the possibility of larger populations (Jean-Pierre Bocquet-Appel, 2011). Population pressure may have increased competition for food, hence the need to cultivate food, which lead to a change in the way of life. Humans may have also become dependent on plants that they modified in initial domestic attempts, and they are believed to have selected plants as long as 23,000 years ago and started farming cereals 11,000 years ago. As early farmers improved their cultivation of crops, surplus harvest required storage, which led to a more stable food supply that in turn would increase populations (Blakemore, 2019).

Experimenting with domestic animals in agriculture dates back 12,000 years with evidence of sheep and goat herding in Iraq and Anatolia. Animals used as labour assisted intensive agriculture as well as providing a protein source through milk and meat (Blakemore, 2019).

The Neolithic Revolution led to a new period for modern societies, with civilizations comprising large populations who had improved technology and a deeper knowledge of the arts and trade. With the Neolithic Revolution, came societal inequality, a decline in nutrition, and a rise in infectious diseases (Blakemore, 2019).

The Neolithic Revolution set the foundations for current society where human settlements are heavily dependent on agriculture to provide enough food to sustain these communities.

This coincides with Nuffield International's vision that 'Agriculture is the foundation for a stable society'.

The world population is estimated to reach 9.7 billion people by 2050 (United Nations Division, 2019) as displayed in Figure 1.

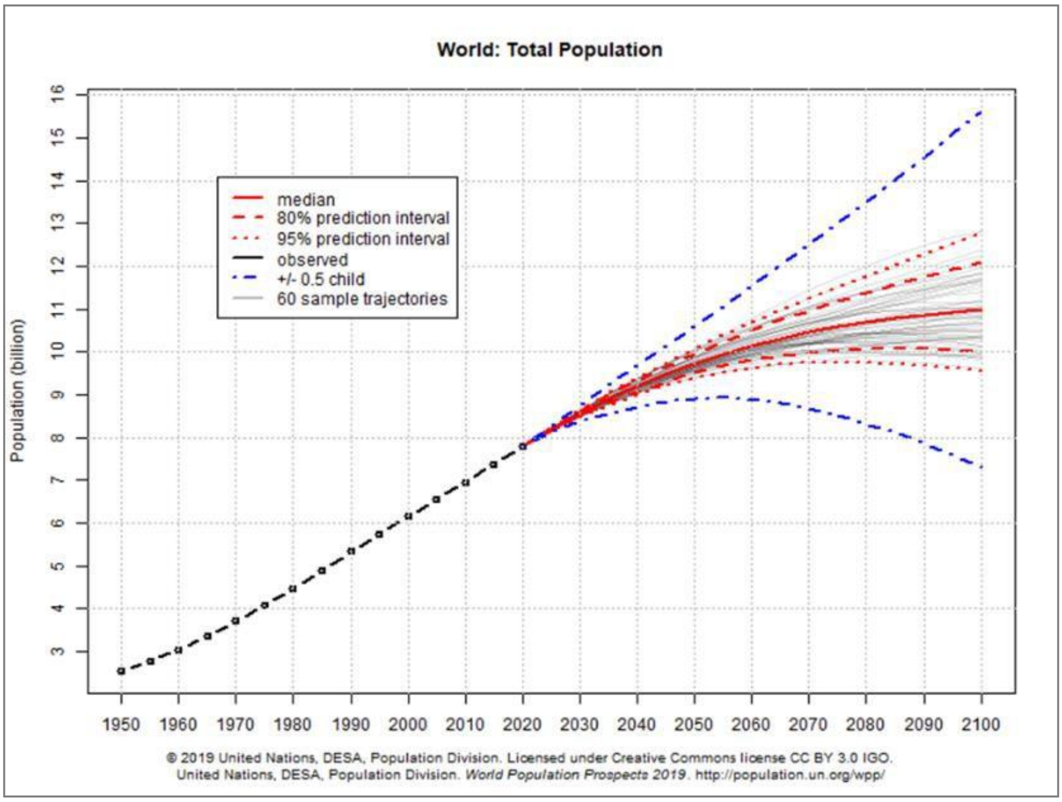

Figure 1: Global population predictions (United Nations, Population Division).

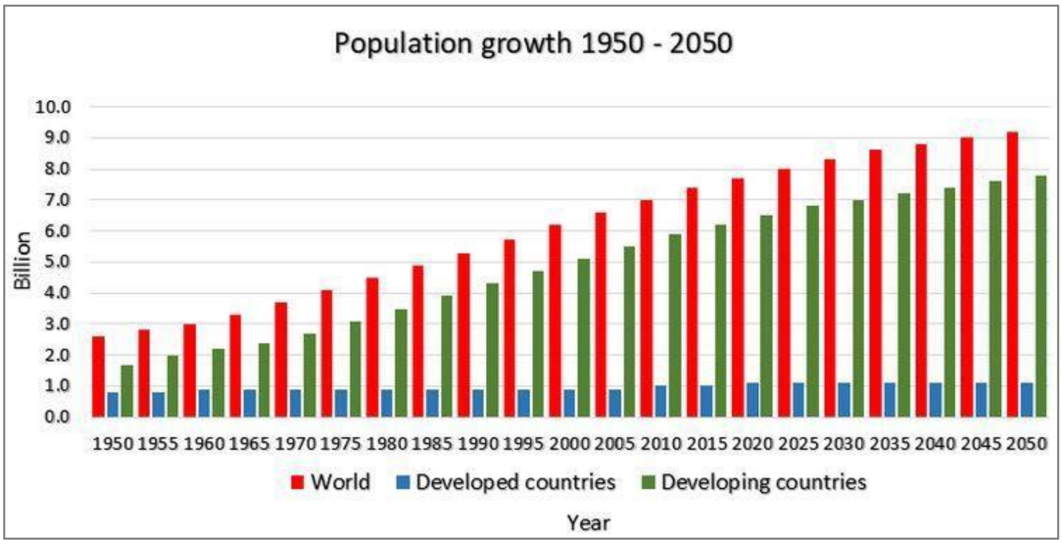

Figure 2: Global population growth 1950 to 2050 (Food and Agricultural Organization (FAO) and World Bank).

Figure 2 highlights where the projected global population growth is going to come from regarding both developed and developing countries.

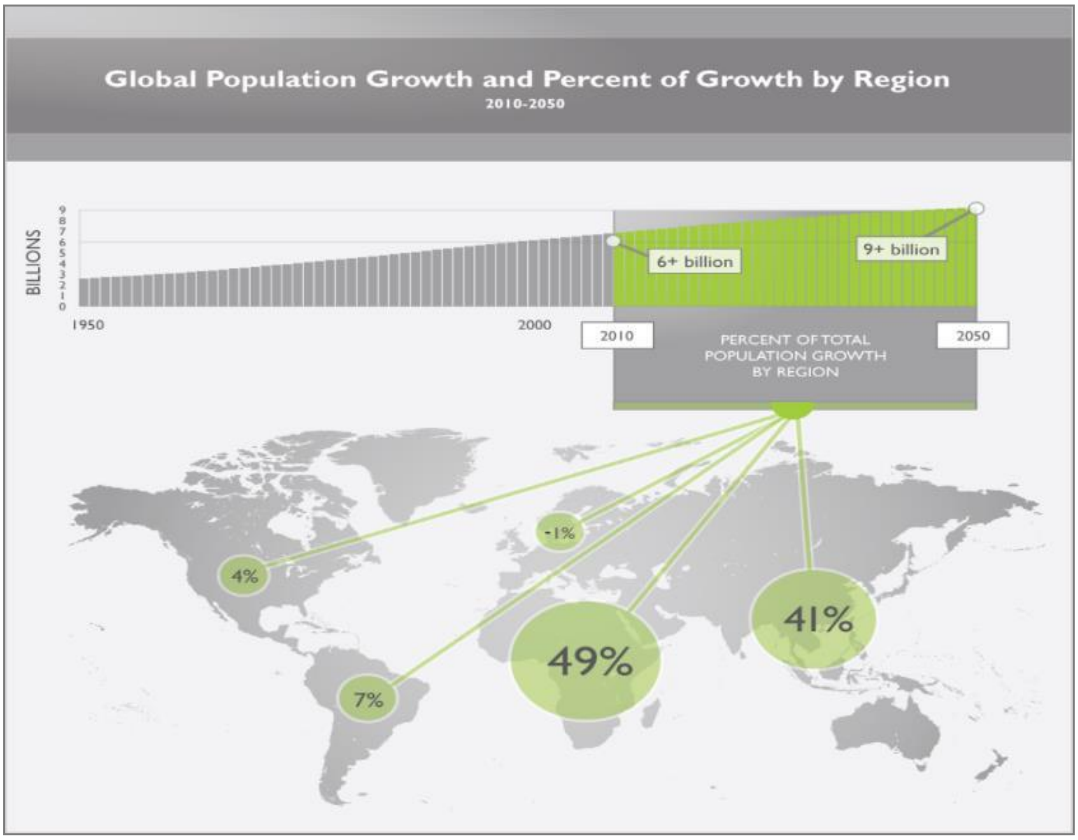

Figure 3: Global population growth by regions 2010 to 2050 (Silva, 2018).

Figure 3 highlights the population growth around the world, with Africa having the highest growth at 49% followed by Asia at 41%.

This projected increase in global population would require agricultural production to increase by between 60 and 70% to meet food demand in 2050 (Silva, 2018). This will take into account:

1. Changes in dietary requirements – increased economic growth in these regions will lead to an increase in animal protein requirements. In 2016, global meat production was 318 million tons, in 2050 the FAO estimates an increase to 455 million tons. In 2016, 36% of cereal production went into stockfeed.
2. A significant percentage of grain production will be used in the production of biofuel. Around 40% of US corn crop is used in ethanol production.
3. An increase in urbanisation, especially in Africa and Asia. Currently, 55% of the world's population live in urban areas, and this will increase to 70% in 2050. Urbanisation will increase production pressure on current agricultural land.

There are 1,500 million hectares of arable land globally. Around one-third of this land has been threatened by erosion, seawater, and pollutants degrading soil health and biological productivity. The majority of global fertile land is already used in agriculture and therefore the expansion of new agricultural land will only be in certain regions. The increase in arable land globally will only be by 200 million hectares, mainly from Latin America and Sub-Saharan Africa, as expanding arable land is not an option for many countries. The destruction of rain forests in the Amazon will release more carbon stored in the soil into the atmosphere. Figure 4 illustrates arable land usage worldwide, as well as in both developing and developed countries. In developed countries arable land remains static.

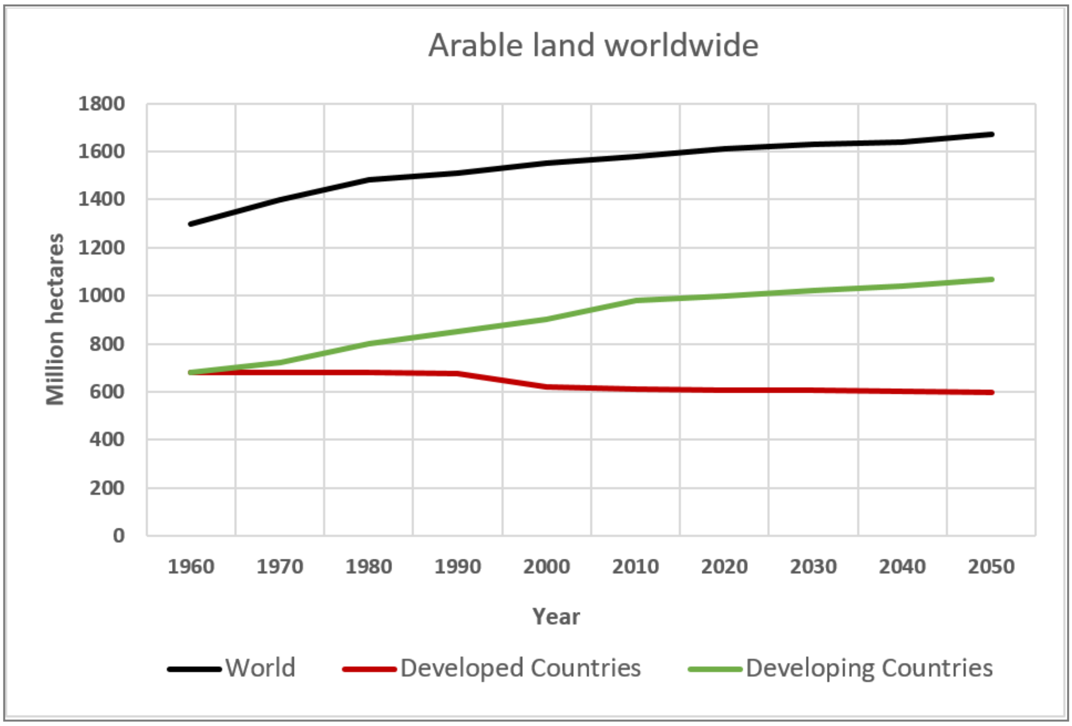

Figure 4: The availability of global arable land (FAO and World Bank).

The opportunity for increasing current global agricultural productivity is to adopt a more sustainable approach so as to ensure there is sufficient food to feed the world in 2050 (Sliva, 2018).

Agriculture globally takes a consumptive approach, where more resources are used than are replaced with each crop, resulting in a gradual degradation of the land. Productivity on these farms is not sustainable and so diminishes over time with the land remaining productive only in the short term. The following are normally associated with these conditions:

- Use of technology to increase yield and mask soil degradation;
- lack of emphasis on the soil microbiome;
- over-use of agricultural crop protection chemicals leading to resistance; and
- over-use of inorganic fertilisers leading to problems such as acidification.

In developing countries agriculture is being concentrated on producing more food and agricultural produce. The order of priorities is as follows:

1. Increasing yields.
2. Crop protection.
3. Human health, environmental and social aspects.

Prioritising one aspect over the other in production leads to many problems related to sustainability in agriculture (Meerman *et al*, 2008). Illustrating this are increased problems with soil erosion, soil nutrient depletion, increased pest problems, public health hazards and environmental pollution.

Agricultural development strategies should be developed by integrating all the factors involved in the agricultural production of a specific product in a specific area. This is known as Integrated Crop Management (ICM).

Chapter 2: Integrated Crop Management

There are several definitions of ICM, and these definitions have developed and changed over time. Let's consider these definitions going back at far as 1993, as outlined in Table 1 below.

Table 1: Various definitions of ICM

INSTITUTION	DEFINITION
1993, Australia, the Victorian potato crisping research group	"Integrated Crop Management is defined to include integrated pest management in a wider context that includes crop plant breeding and general husbandry as well as pests and disease control."
The University of Reading quoted the British Agrochemical Association, in conjunction with Linking Environment and Farming (LEAF) and Sainsbury's:	"ICM is a method of farming that balances the requirements of running a profitable business with responsibility and sensitivity to the environment. It includes practices that avoid waste, enhance energy efficiency and minimize pollution. ICM combines the best modern technology with some basic principles of good farming practice and is a whole farm, long term strategy."
Pan-African Bean Research Alliance (PABRA)	"ICM is an holistic approach to improved crop production and protection, including pest and disease, soil, fertility, water and post-harvest management practices."
Bioline AgroSciences (French ICM company)	"ICM is a pragmatic approach to the production of crops. This can include such things as IPM, soil, social and environmental management. The approach to ICM is aiming to combine all aspects of crop inputs and management to achieve the needs of the producer and consumer."
AgriBusiness GLOBAL	"Integrated crop management is a holistic approach to crop management, integrating agricultural and environmental management practices such as optimal site selection , crop rotation, and optimization of crop nutrition, soil, and water management, as well as environment, energy, and waste management and integrated crop protection strategies, in accordance with local conditions, climate, and requirements
Integrated Crop Management Systems in the EU – a report for the European Comission DG Environment	It is an environmentally sensitive and economically viable production system or process which uses the latest available techniques to produce high quality food in an efficient manner

ICM is an holistic farming system, which considers all aspects of the specific farm as well as considering socio economic and environmental factors with a view to long-term sustainability (Afrane Okese, 2019). This concept is illustrated most effectively by the graphic below (Figure 5).

Figure 5: Integrated Crop Management graphic (Author and Teicher,H.2019).

2.1: Site Selection

The economic success of a new crop depends on several factors (Watt, D.S., 2006). The factors which contribute to selecting a farming area or new crop depend on the following:

1. Climatic Factors:
   i. One needs to match the growing crop to the climate, working with nature and not fighting it.
2. Availability of irrigation water.
3. Soil and terrain.
4. Market demand.
5. Availability of processing.
6. Socio-economic factors (Afrane Okesa, 2018):
   i. Infrastructure, incorporating access roads, electricity, water, telecommunications, health facilities, police stations, and other.
7. Some of the soil and water constraints being overcome; for example, through irrigation, as is the case with the citrus industry in the Beitbridge area, Zimbabwe.

2.2: Soil Health

Good soil health is what makes sustainable agriculture possible, and the quotes below on the subject of soil health highlight the importance thereof:

"All life depends upon the soil…There can be no life without soil and no soil without life; they have evolved together."

Dr Charles E. Kellogg, Soil Scientist & Chief of the USDA's Bureau for Chemistry and Soils

"Soil is a living ecosystem, and is a farmer's most precious asset. A farmer's productive capacity is directly related to the health of his or her soil."

Howard Warren Buffett

"The nation that destroys its soils destroys itself."

Franklin D. Roosevelt

Soil health has been described as "the continued capacity of the soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health" (Pankhurst *et al*., 1997).

Pankhurst and co-authors, members of an international FAO workshop have developed this definition:

> Soil health is the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots; recycle essential plant nutrients; improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production (FAO, 2008).

This definition could be extended to include the perspective of the ecosystem, since healthy soils do not pollute their environment and can reduce climate change by increasing or maintaining their carbon content. Soil is vital to all types of agricultural production, it is finite and needs to be cared for and carefully maintained, however, many current soil management systems are not sustainable. In Europe, nitrogen deposition threatens around 70% of nature and in Sub-Saharan Africa, the lack of fertiliser means that the soil nutrients used by the crop are not being replaced, leading to soil degradation (Hettelingh *et al*, 2008).

Soil contains a diverse group of living organisms linked through a complex food web as seen in Figure 6. The trophic levels are seen in Figure 7, which describes the various levels in the energy pathway.

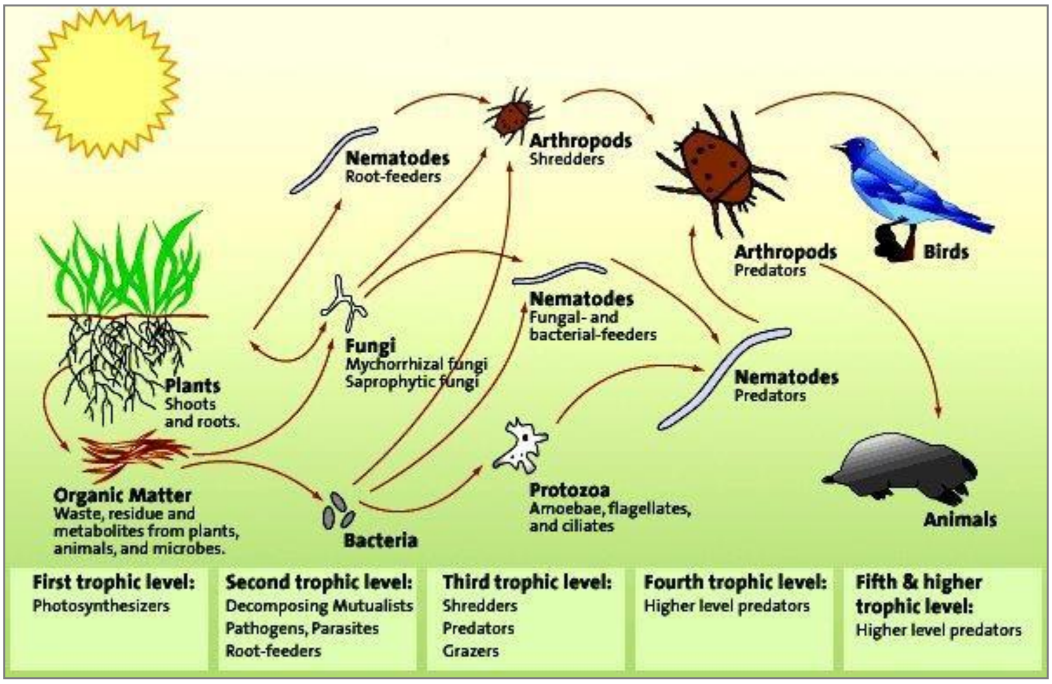

Figure 6: The soil food web (Abdelnabby, H).

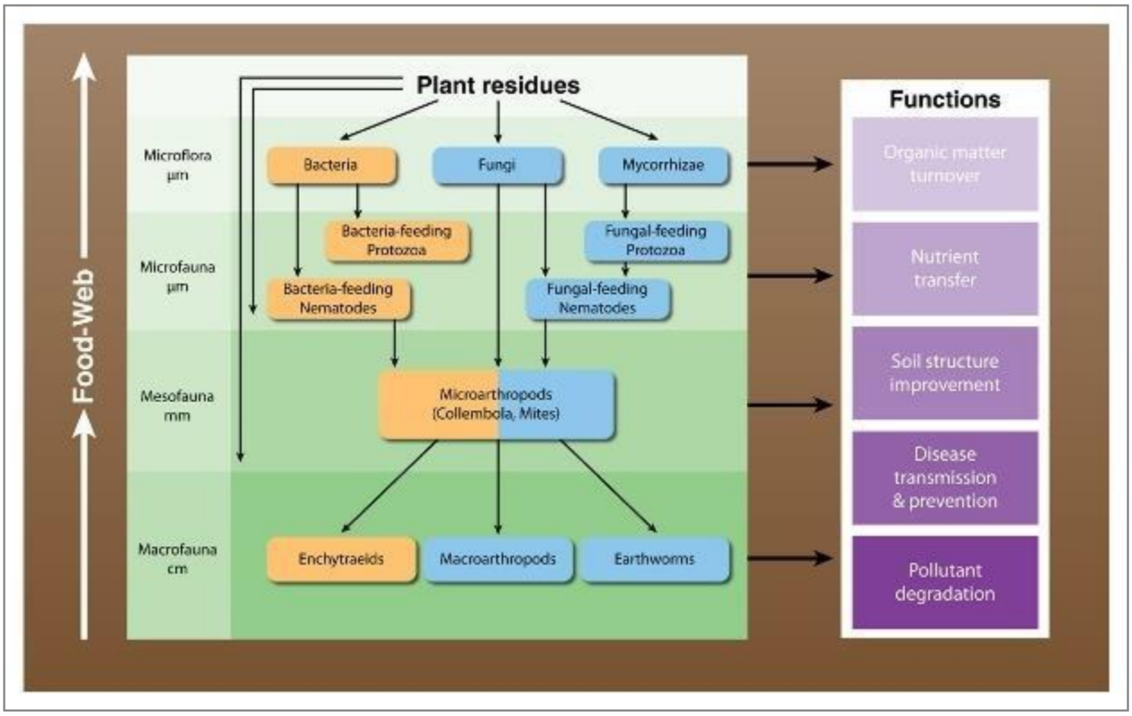

Figure 7: Trophic levels in a soil food web (Gupta, V.V.S.R 1997).

The soil can be healthy or unhealthy depending on the management of the soil. The two important aspects of a healthy soil are:

1. Rich diversity of its biota.
2. High content of non-living organic matter.

Healthy soils tend to tolerate pests and diseases better (Weber, 1996).

Soil biota is the biological life of the soil. The Soil Quality Institute describes the soil biota as "consisting of the micro-organisms (bacteria, fungi, archaea and algae), soil animals (protozoa, nematodes, mites, springtails, spiders, insects, and earthworms) and plants".

Soil biota interactions with air and water dictate the soil's potential to store and release nutrients and water to plants and provide the correct environment for sustained plant growth. The United States, with some of the world's most fertile soils, has had decades of agricultural abuse that have now taken their toll, depleting the soil of essential nutrients, and killing off bacteria and fungi, which create organic material essential to plants (Schiffman, 2017).

Rick Haney, who works for the USDA research service in Texas, had an interview with 'Yale Environment 360' titled "Why it's time to stop punishing our soils with fertilizers". Haney says "Our mindset is that if you don't put down fertiliser nothing grows. But that's just not true and it never has been". In the interview, Haney describes how research is confirming the value of methods such as ploughing less, growing cover crops, and using biological control for pest control. Haney also stressed the importance of unbiased research, since this is often done by the corporations that benefit from over-use of chemicals and fertilisers.

Haney also highlighted that "Soil will come back if you give it a chance. It is very robust and resilient. It's not like we have destroyed it to the point where it can't be fixed. The soil health movement is trying to bring those organic levels back up and get soil to a higher functioning state".

When Haney was asked what has caused the decline in soil quality his answer was "There is a lot of tillage, no cover crops, a system of high intensity (chemical-dependent) farming, that the soil doesn't function properly. The biology is not doing much. We are essentially destroying the functionality of soil, so that you have to feed it more and more synthetic fertilisers just to keep growing this crop" (Schiffman, 2017).

Finally, to end with a quote from Rick Haney "We need to work with the natural system instead of trying to fight against it".

2.3: Regenerative Agriculture

Regenerative agriculture is an holistic land management practice, which ensures the conservation and rehabilitation of agricultural farming systems. Regenerative agriculture is about farming with nature, not against it (Dean, Z. 2020). Regenerative agriculture improves soil health mainly through practices that increase the organic matter in the soil, concentrating on:

- topsoil regeneration;
- improving soil health;
- increasing biodiversity;
- improving water infiltration;
- improving bio sequestration; and
- mitigating climate change.

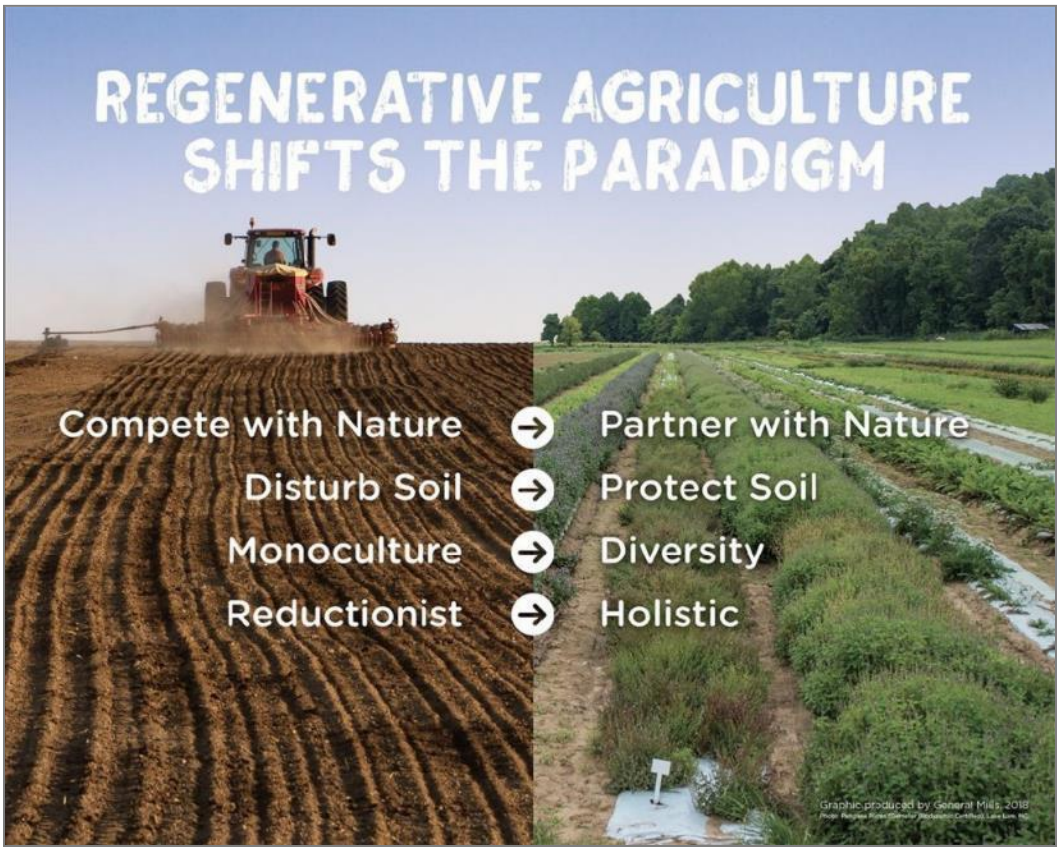

Figure 8: Representation of the paradigm shift in regenerative agriculture (author unknown).

Regenerative agriculture requires a paradigm shift as seen in Figure 8.

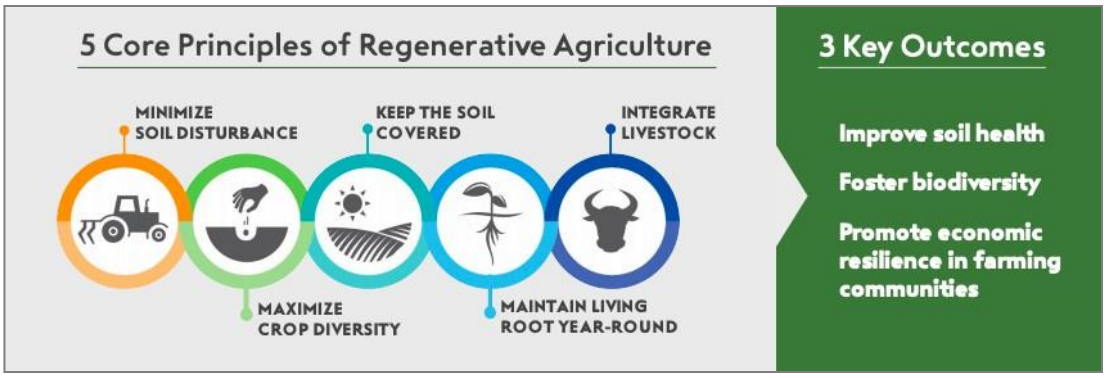

Figure 9: The five core principles of regenerative agriculture (author unknown).

Figure 9 highlights the five main principles of regenerative agriculture, which ultimately lead to a more sustainable farming system. Every farming site is unique and when applying these principles, this needs to be taken into account.

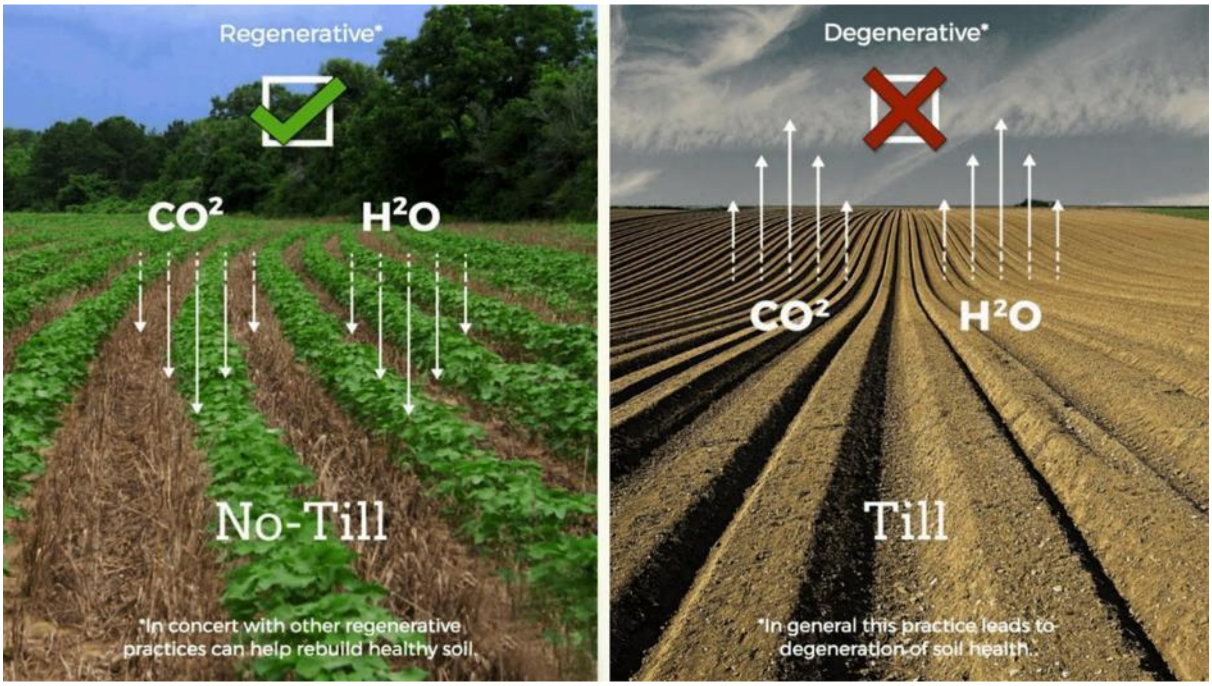

Figure 10: The differences between regenerative and degenerative agriculture (author unknown).

Figure 10 illustrates that regenerative agriculture acts as a carbon dioxide and water sink, which could contribute towards mitigating the effects of global warming.

2.4: Water Management

Water is a critical input for agricultural production and plays a major role in global food security. Irrigated agriculture accounts for 20% of global agriculture and contributes 40% of global food production (World Bank, 2020). Of the 1.5 billion hectares of global agricultural land, this means that 80% is rainfed and accountsfor 60% of global agricultural output. With rainfed agriculture the water applied is dependent upon the rainfall pattern of the region, and not the farmer.

Globally, irrigated agriculture can produce yields that are two to three times higher than those of rainfed agriculture. A consistent and reliable supply of water is important for high value cropping systems, but many agricultural boundaries have little room for expansion, so the global need to maximise the available water is important. There is evidence to suggest that improved farm water management can reduce water-related yield gaps significantly. In a study published in *Environment Research Letters* by a group of researchers from Germany, Kenya, Australia, and Sweden they indicated that, by optimising rainfall use and irrigation, global agricultural production could be substantially increased (Jagermeyr, J. *et al* 2016).

"Crop water management is largely underrated approach to reduce undernourishment and increase resilience of smallholders" – Jona Jagermeyr, lead author, Potsdam Institute for Climate Impact Research. These researchers, using biophysical simulations using vegetation dynamics, can identify wherethere is spare water to be found. These simulations are too rough to simulate agricultural productionconditions, but they are suitable for identifying where it is possible to potentially increase yields. An exampleof this is where the yield increase potential of crop water management is possible in countries like China,Australia, Western US, Mexico, and South Africa (Rockstom, J, 2016).

The study included several ways to improve water management, from low-tech solutions to large innovations. Water harvesting by collecting water runoff from excess rainfall to supplement irrigation when required is an example. Mulching is another example, where soil is covered by crop residues, thereby ensuring that the soils retain more moisture and lose less due to irrigation (Rockstom, J. 2016).

California farmers experienced the most intense drought in its history from December 2011 to March 2017 (Boxall, B.2017). The period from the end of 2011 to 2014 being the driest period of all (Hanak *et al*, 2015). The drought killed 102 million trees – 62 million in 2016 alone (Deamer, K. 2016).

Many farmers in California got through this drought by relying on groundwater reserves. Pumping groundwater in 2014 in California was unregulated but this has since changed. The Sustainable Groundwater Management Act (SGMA) was passed in 2014, and agencies in particularly high-priority, over-drafted basins had until 31 January 2020 to file their plans to make groundwater resources sustainable by 2040.

SGMA requires local Groundwater Agencies (GSAs) to develop and implement Groundwater Sustainability Plans (GSPs) for managing and using groundwater. Each GSP must consider the following sustainability indicators:

- groundwater – level declines;
- land subsidence;
- seawater intrusion;
- groundwater – storage;
- interconnected surface-water depletions; and
- water-quality degradation.

Planning tools used for the GSPs include:

1. Modelling

   Computational models, including computer simulations are used to describe the hydrological cycle, including the use and movement of water. They consider the landscape, aquifer system and water cycle. They also have to provide a framework to organise data, and a knowledge and understanding of hydrological systems. Models are important for water resource planners to answer planning, scientific, and operational questions.

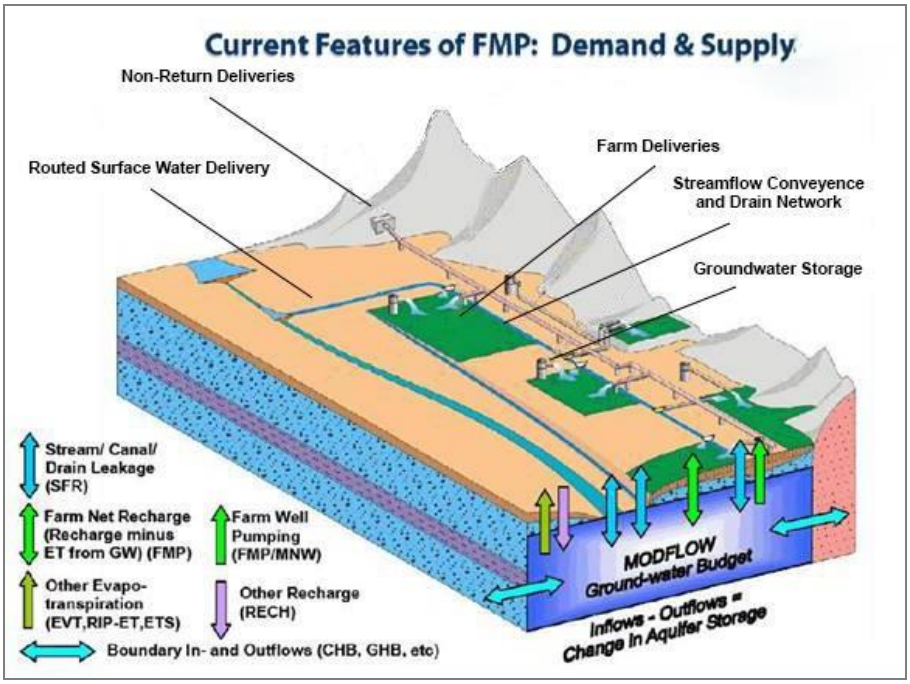

Figure 11: A model showing the water inflows to and outflows from a farm as simulated by the farm process.

2. Data

   Groundwater level monitoring is important for understanding the groundwater basin, determining direction of groundwater, and trends in groundwater storage. This will indicate if one is achieving one's water management goals. To be SGMA compliant each GSP must be able to provide data to demonstrate that they are achieving their sustainability targets.

Figure 12: Data map displaying the level of the groundwater in California.

Farms like Terranova ranch in California have spent millions of dollars on groundwater recharge. They have taken water from the Kings River to recharge the San Joaquin Valley aquifer. This will earn Terranova groundwater credits so that they can use groundwater when required in the future.

TOMAS OVALLE For The Times

DON CAMERON, general manager of Terranova Ranch in Helm, Calif., is using high flows off the Kings River to recharge the San Joaquin Valley aquifer.

POURING IT ON

The idea of flooding cropland to replenish groundwater basins is taking hold in California

BY BETTINA BOXALL

HELM, Calif. — The water spread into every corner of the fields, beckoning wading ibises and egrets as it bathed long rows of sprouting grapevines.

Several inches had covered the vineyard ground for a couple of months. But rather than draining it, Don Cameron was pouring more on.

"This is not about irrigation," the sprawling farm's manager kept telling his quizzical workers. "It's about recharge. ... I want all the water you can get into the grape fields now."

After a drought-busting winter, reservoirs up and down California are dumping water to make room for spring snowmelt.

There is so much water in the state's vast plumbing system that for weeks, the big government water projects have reduced exports from the Sacramento-San Joaquin Delta. San Luis Reservoir, where the projects park water on its way south, is full.

Yet there is [See **Water**, A12]

Figure 13: A newspaper article illustrating what farms like Terranova are doing for their groundwater recharge.

In California in 2014 *CUSEA (Cultivating a Healthy Food System)* published ten ways in which farmers were saving water during the historic drought of 2014. These were:

i. Drip irrigation

Drip irrigation is a class of micro irrigation that allows water to slowly drip into the root zone of plants. This system can potentially save water, by reducing evaporation and nutrients.

In Israel, 1959, Simcha Blass (a retired British Water Agency employee) found inspiration in a dripping faucet next to a thriving tree. He applied his knowledge of micro irrigation to an improved drip method – the Blass system, which overcame clogging of the low volume of water by adding wider and longer passageways to the emitter. Blass went on to patent his design with his partner Kibbutz Hatzerim to create an irrigation company called Netafim (Young, J. 2017). Netafim Africa quotes drip irrigation as:

> Drip irrigation is the most efficient water and nutrient delivery system for crop irrigation. It delivers water and nutrient directly to the plant zone, in the right amounts, at the right time. This ensures that each plant gets exactly what it needs when it needs it for optimal growth. Thanks to this method of irrigation farmers can produce higher yields while saving water, fertilise, energy and even crop protection products.

ii. Capturing and storing water

It is vital the agricultural sector manages its water demand to sustain agriculture as well as conserve water supplies such as strategic aquifers. Dams can store water for use during the dry season. By integrating water harvesting and storage structures in a planned manner it is possible to have a 'water buffer' to reduce one's vulnerability to seasonal variations in rainfall and drought (http://www.fao.org/land-water/water/water-management/water-storage/en/).

iii. Irrigation scheduling

Irrigation scheduling is where irrigation programme managers apply the correct frequency and length of irrigation. The purpose of irrigation scheduling is to maximise efficiencies by applying the correct amount of water required to replenish water levels. Correct irrigation scheduling saves water and energy (https://www.sherburneswcd.org/irrigation-scheduling.html).

iv. Drought-tolerant crops

The drought tolerance of crops is their ability to maintain their biomass production during drought conditions (Ashraf,M. 2010). Between 2005 and 2015 during the drought, the FAO recorded US$29 billion in losses in agriculture in the developing world (Martignago, D. 2020). Plant breeders need to produce varieties that are tolerant to abiotic stress and have better water and nutrient uptake efficiencies. They can do this by conventional breeding or biotechnology, which is a controversial subject but would appear to be very effective. Going forward, the use of drought-resistant crops can contribute significantly to crop success.

v. Dry land farming

Dryland farming is the cultivation of non-irrigated crops and maximises natural rainfall or moisture conditions.

vi. Rotational grazing

Rotational grazing is a system whereby livestock are moved from paddock to paddock to ensure the regrowth of the pasture. Good pasture management increases its water absorption and reduces water loss due to runoff, ultimately helping with drought conditions (Shiozaki, J. 2014).

vii. Compost and mulch

Decomposed organic matter improves the soil structure, which in turn increases a soil's water-holding capacity. Mulch spread on top of the soil also helps the soil retain moisture, as well as breaking down and adding to the soil's organic matter. (Shiozaki, J. 2014)

viii. Cover crops

Cover crops are planted to protect bare soil and they reduce weeds, increase soil fertility and organic matter, thereby reducing soil erosion and compaction. Cover crops make it easier for the water to enter the soil as well as improving the water-holding capacity. A survey of 750 farmers was done in 2012 by North Central Sustainable Agriculture (https://www.sare.org/wp-content/uploads/SARE-CTIC-CC-Survey-Report-V2.8.pdf) in which they found the farmers with cover crops were 11 to 14% more productive when compared with conventional farms during drought years. At Frog Hollow Farm, Bentwood California, they grow fruit organically and Al Courcheesna is adamant about how important cover crops are for his farming operations (https://www.froghollow.com/blogs/news/11356713-8-benefits-of-cover-crop-in-organic-farming) (Shiozaki, J. 2014).

ix. Conservation tillage

The Dust Bowl of the 1930s was created by deep ploughing and the loss of perennial grasses followed by drought and soil erosion. Conservation tillage uses specialised machinery, partially tilling the soil leaving at least 30% of crop residue on the surface. This practice increases water absorption, reduces evaporation, compaction, and erosion (Shiozaki, J. 2014).

x. Going organic

The Rodale Institute in a 30-year farm systems trial found that corn grown in organic fields had a 30% greater yield than traditional fields during periods of drought. A soil rich in organic matter and microbial life serves as a sponge to deliver moisture to plants (Shiozaki, J. 2014).

2.5: Soil Moisture Monitoring

Irrigation should be able to supply the water-holding capacity of the rooting depth of the crop. Over irrigation will lead to water draining past the root zone, causing a nutrient deficiency through leaching, whilst also reducing both the efficiency of the nutrients and water use. Over irrigation will also lead to too much water in the root zone reducing the amount of oxygen, creating stress in the plant. (Prince, R.2019).

One way to measure soil moisture is using soil capacitance probes, which detect how easily anelectric charge moves through the soil. The probes consist of multiple sensors taking recordings at various depths, with the readings continuously logged through a radio frequency or data logger connection. By generating a graph of soil moisture over time, the rise and fall as well as the slope of the graph lines will highlight the amount and rate of drainage occurring in the soil (Prince, R. 2019). These sensor outputs help one minimise drainage, retain nutrients or leach salts if required.

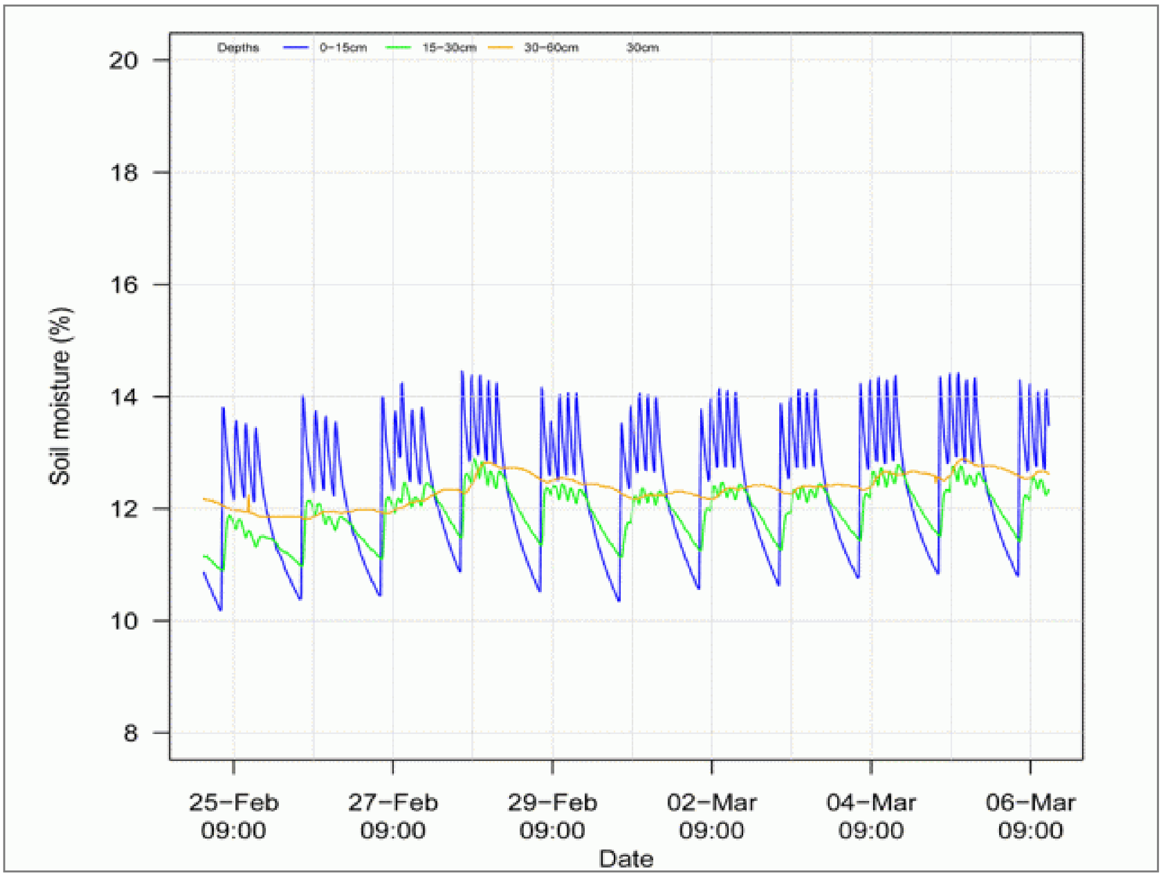

Figure 14: An example of a graph obtained from a soil moisture capacitance probe's data (Prince, R. 2019).

2.5.1: The use of the Internet of Things in the future of Irrigation – Smart Irrigation

The internet of things (IoT) is the network of physical objects – 'things' embedded with sensors, software, and technologies to be able to connect and exchange data with other devices over the internet.

Smart irrigation technologies enable farmers to irrigate more precisely. Using IoT sensors, growers can monitor soil moisture levels in the root zone of their plants as well as weather conditions, by the use of their own weather stations, and they can also measure the electric conductivity of the soil. This will ultimately lead to more efficient use of their water resources (Bass, T. 2016).

2.6: Crop Rotation

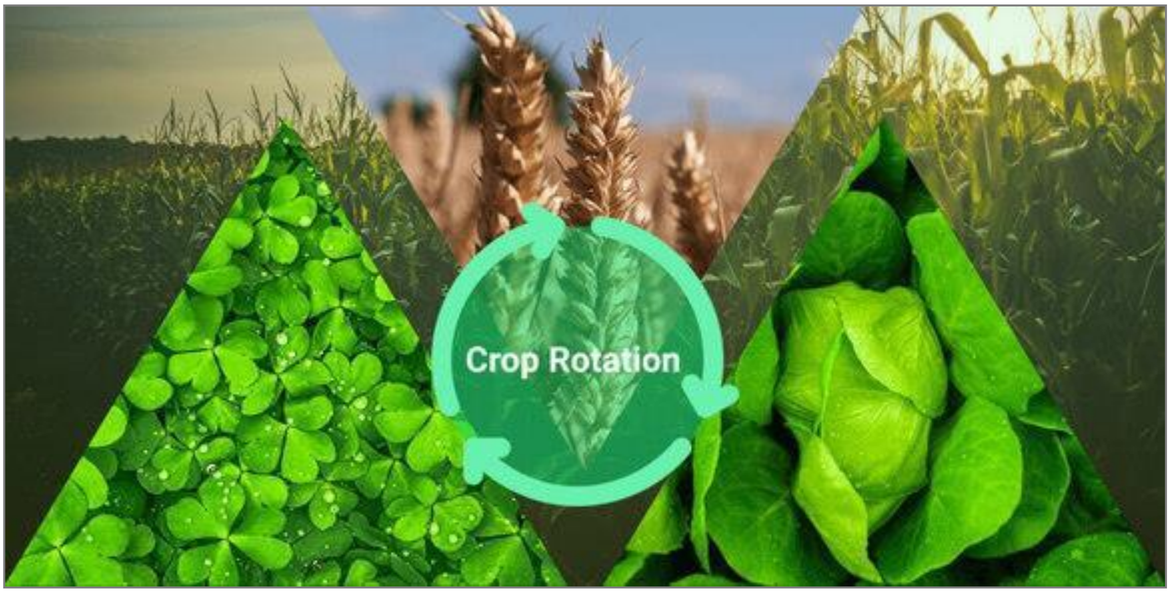

Figure 15: Crop rotation graphic (author unknown).

"*We have a better understanding of how developing good soil health takes a comprehensive approach and it starts with a diverse crop rotation*" – Dr Sieglinde Snapp, Michigan State University.

Crop rotation refers to the different crops grown on the same piece of land over a period of time. The crops grown are carefully planned to enhance the soil nutrients, thereby controlling pest populations, supressing weeds, and ensuring soil health (Reza. R. 2016).

A crop rotation, for example, will cycle through cash crops (i.e., vegetables), cover crops (cereals) and green manures (legumes). The actual crop rotation will depend on the area in question and the critical part of the crop rotation is to understand which crop takes and which gives back to the soil. For example, a nitrogen-depleting crop should be followed by a nitrogen-fixing crop (Reza, R.2016).

The main concept of crop rotation is for the crops themselves to sustain soil health rather than fixing soil health through fertilisers, pesticides, and herbicides (Reza, R.2016).

The advantages of crop rotation are:

1. Improved soil fertility and structure:

   Crop rotation improves the physical and chemical properties of the soil, increasing fertility. Nitrogen-fixing legumes fix atmospheric nitrogen, which is then available for the next crop to be planted in the rotation.

2. Disease control:

   Rotating a non-host crop after a host crop prevents pathogens being transmitted from one crop to the next. An example of this is reducing the soyabean cyst nematode populations by 50% when rotating soyabean with wheat or corn.

3. Pest control:

   Crop rotations can be used to manage insects that are not mobile and use the host crop as a source of food but once hatched will not have the same food source.

4.Weed control:

Incorporating cover crops in one's rotation provides competition for weeds, crowding them out and reducing weed populations in future crops.

5.Increased organic matter:

Crop rotation will add more organic matter to the soil. An increase in organic matter will improve water infiltration and water-holding capacity. An increase in organic matter also improves soil structure, as well as the chemical and physical properties of the soil.

6.Helping control erosion:

Crop rotation limits soil erosion from wind and water by reducing the amount of exposure the soils has, and by supporting low till or zero till.

7.Improved biodiversity:

Crop rotations improve soil biodiversity by having different crop residues and root types. In addition, the soil microbial life is helped by rotating a crop with a high carbon-to-nitrogen ratio (i.e., maize) with one that has a low carbon-to-nitrogen ratio (i.e., soyabeans).

8.Increased yield:

Correct crop rotation can increase a farmer's yield; maize and soyabean rotated with each other can increase yield by 10% when compared to a crop being grown continuously.

9.A reduction in commercial risk:

The various rotation crops will have different weather tolerances; for example, some might be more susceptible to drought than others and increase the risk of crop failure due to climatic conditions. Growing different crops also means harvesting crops at different times and allows farmers to spread the harvest period over a less concentrated time, as one would with one crop (Reza, S. 2016).

2.7: Crop Nutrition

Crop nutrition is a vital science that affects all aspects of agricultural cropping systems, environmental sustainability and human health and wellbeing (Six, J. 2011).

The WHO definition combines health as a human right requiring physical and social resources to achieve and maintain. 'Wellbeing' indicates a positive rather than a neutral state, putting health as a positive aspiration. Plants naturally obtain oxygen, carbon dioxide and water. In addition to this, they require 14 mineral elements, including macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur(S). The balance are the micro-nutrients chlorine (Cl), boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), nickel (Ni) and molybdenum (Mo) (White, P. et al, 2010).

Plants usually acquire their nutrients from the soil, and a deficiency in any one of the above elements leads to a reduction in plant growth and a reduction in crop yield (White, P. et al, 2010).

2.7.1: Fertiliser Management for Optimal Productivity and Sustainability

Crops require essential mineral nutrients for optimum production. Excessive amountsare a waste of money as well as being detrimental to the environment. An insufficient supply of fertiliser in large quantities and/or mineral elements with low phytoavailability in soils can lead to reduced cropproduction (White, P. et al, 2010).

In many soils there is rarely enough phytoavailable N, P and K, hence the need for synthetic fertilisers during the early rapid stages of growth of crop life in intensive and extensive cropping systems. Synthetic fertilisers are also required where mineral deficiencies occur in animals or humans and one needs to increase these minerals in the edible portions (White, P. et al, 2010).

There is a financial and environmental cost to using mineral fertilisers, hence the need for their efficient use in agriculture. Fertiliser efficiency can be achieved by better agronomic practices or by genetically modified crops (a contentious subject) which acquire and/or utilise mineral fertilisers more efficiently. Genetically improved crops can be addressed by conventional breeding or a biotechnology approach (White, P. et al, 2010).

Sustainable crop production is achievable when both crop production and quality can be achieved consistently without compromising profitability or the environment.

Low phytoavailability of essential mineral elements or excessive concentrations of toxic mineral elements in the soil can limit agricultural production. These can be addressed by agronomic practices as well as crop breeding. In recent years, researchers have identified traits and genes that can increase yields on soil, which have low phytoavailability or toxic mineral concentrations (White, P. et al, 2010).

Essential minerals required by humans and other animals enter the food chain through plants. The concentrations of mineral elements in the plants are important; if there are not enough vital minerals this can lead to deficiencies. Up to two-thirds of the world population may be at risk of mineral deficiencies, with Fe and Zn being the most common (White, P. et al, 2009; Stein, A. 2010). Concentrations of mineral elements in plants can be increased by careful application of mineral fertilisers, as well as by growing genotypes with higher mineral concentrations (White, P. et al, 2010).

2.8: Agricultural Environment, Energy, and Waste Management

2.8.1 : Agricultural Environmental Management

Several of the factors discussed in ICM contribute significantly to agricultural environmental management. The United Nations' definition of sustainable land management (SLM) is "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions".

TerrAfrica's definition of SLM is "the adoption of land use systems that through appropriate management practices enable land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources".

(http://www.fao.org/land-water/land/sustainable-land-management/en/)

TerrAfrica is a US$4 billion partnership that started in October 2005. The partners involved are the African Union, World Bank, European Commission, and regional Sub-Saharan African governments. Their aim is to prevent desertification and land degradation in Africa through sustainable land management.

In a land-use system its productivity and sustainability will be dictated by the interaction of land resources, climate, and human activities, as shown in Figure 16.

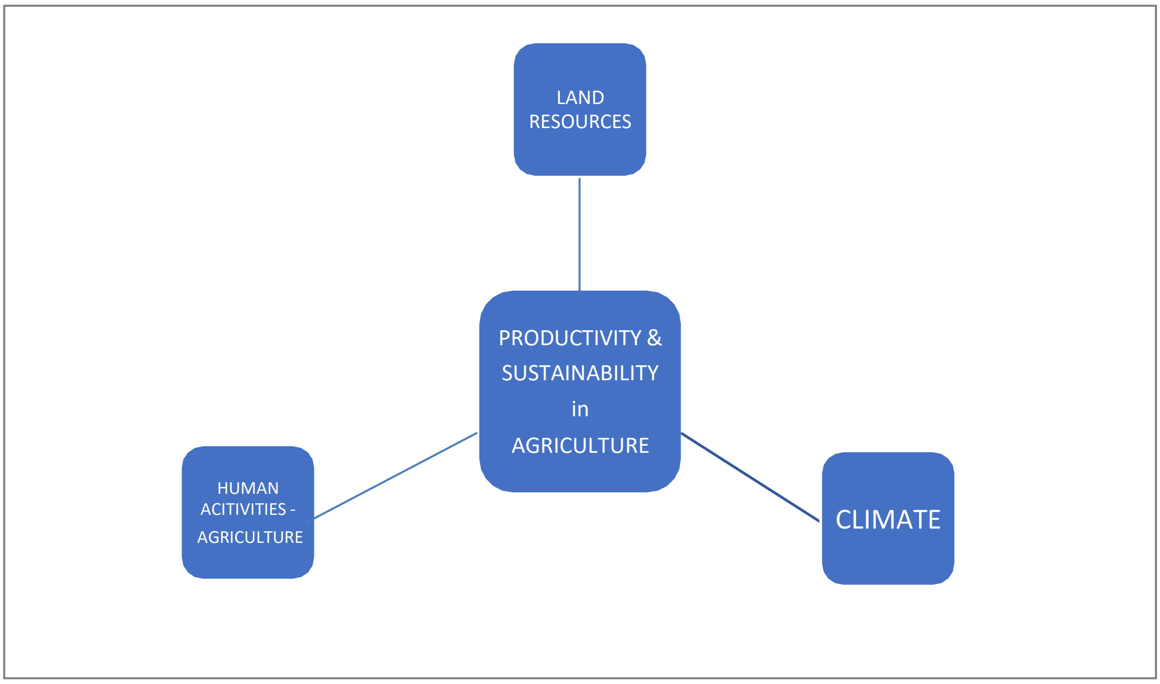

Figure 16: Illustration of the interaction for sustainable agriculture (Author).

With the current global climate being so unpredictable, it is critical to select the right land use for the land in question. Certain crops grow better in naturally suited conditions, for example, macadamia nuts grow well in Chipinge, the eastern region of Zimbabwe because both climatic and soil conditions are optimal for them. One also needs to consider implementing SLM to ensure the sustainable use of one's natural resources.

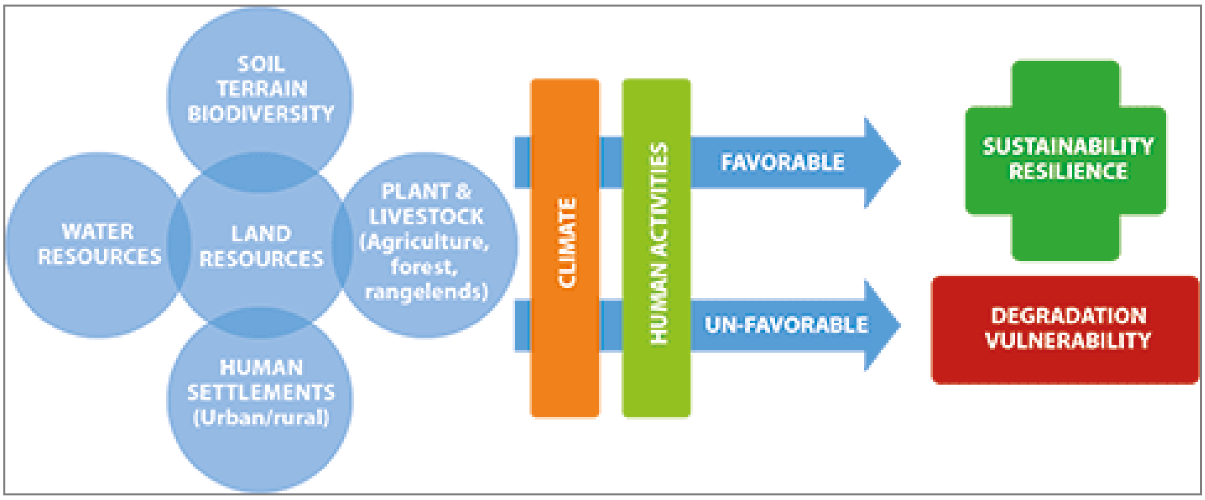

Figure 17: Illustration of correct or incorrect land use, leading either to sustainability or degradation of the agricultural environment (FAO, CLIMATE_SMART AGRICULTURE Sourcebook, Module B.& Sustainable Soil/Land Management for Climate-Smart Agriculture).

SLM takes a holistic approach with the goal of a productive and healthy ecosystem through the integration of social, economic, physical, and biological requirements. (http://www.fao.org/land-water/land/sustainable-land-management/en/).

2.8.2 : Agricultural Energy Management

Energy is a critical component of agriculture, and it needs to be managed carefully to enhance viability and ultimately, sustainability. Energy fuels the agricultural ecosystem and biosphere in which farmers operate (Hasanuzzaman, M. 2019), as illustrated in Figure 18.

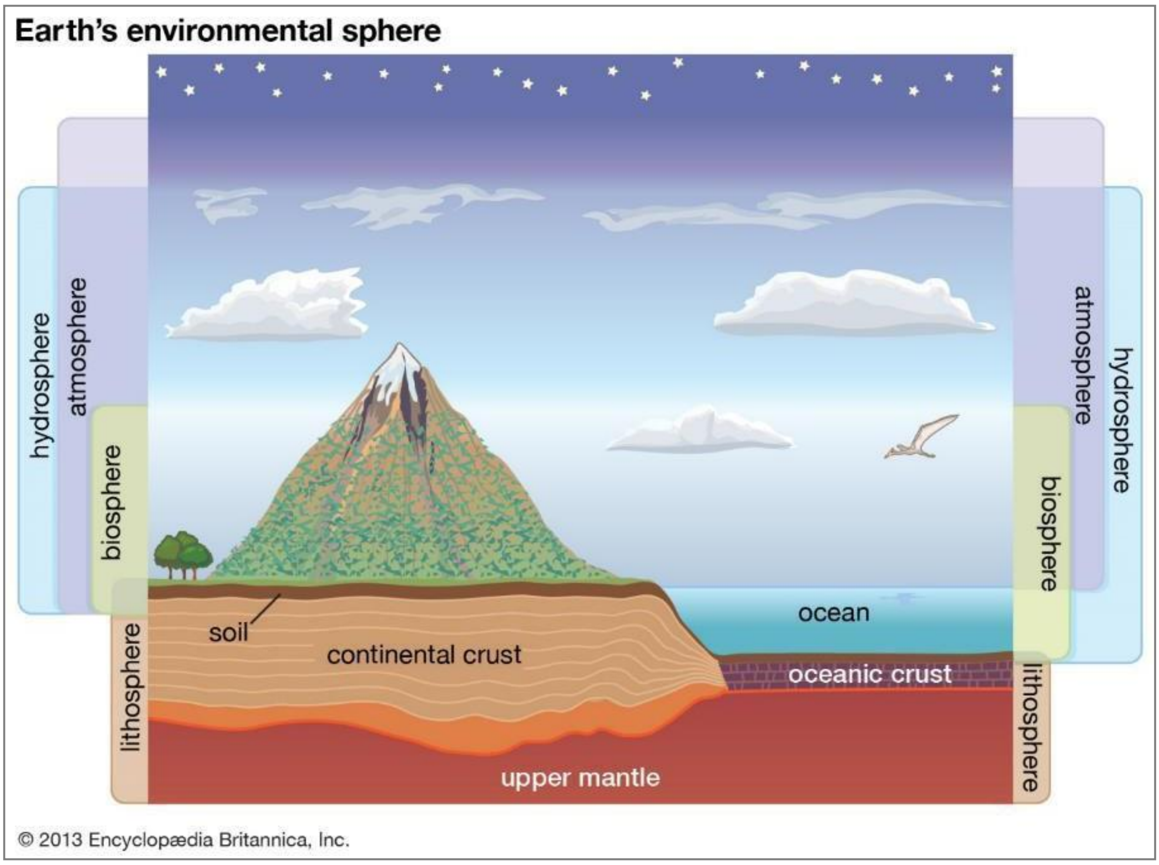

Figure 18: Illustration of the earth's environmental spheres.

Energy flows through the ecosystem, entering as solar energy converted by photosynthesis in plants and algae into biomass. When this energy is utilised, i.e., grow or reproduce a lot of heat, energy is lost in the ecosystem and is no longer available for use (Hasanuzzaman, M. 2019).

Agriculture uses the energy in the ecosystem to convert solar energy into various forms of biomass – food, stockfeed, fibre and fuel. The modernisation of agriculture has incorporated vast amounts of energy to improve yields with this increase in energy coming from non-renewable fossil fuels. The return on energy investment is lower than what is put in with regard to the crop that is harvested. With regard to energy intensive farming, changes need to be made for sustainability to be achieved (Hasanuzzaman, M. 2019).

Energy inputs are required at every stage of agricultural production, from the manufacturing and application of chemicals to the diesel requirements of the large tractors that plant seed and the combine harvesters that harvest crops to electricity for animal houses. This enormous energy consumption has left farmers exposed to high energy costs as well as volatile energy market fluctuations that affect fertiliser prices. If correctly implemented, energy efficient systems can help the farmer reduce his energy demand without affecting the farmer's productivity (Levine,A.2012).

Energy is becoming a larger part of farmers' operating costs. Farmers and ranchers can reduce input energy costs, look after their soil and water resources, reduce their reliance on fossil fuels, and save money by conservation practices that promote energy conservation and efficiency (Gulkis, A. *et al*., 2010)

2.8.3 : Energy Conservation and On-Farm Generation in America

Agricultural interest in alternative energy and energy conservation has increased in the United States recently, which is due to the unstable fuel market as well as a move to more sustainable and renewable energy sources. Concurrently, technologies that conserve energy, and convert feedstocks to biodiesel and ethanol have improved dramatically. Farms throughout America are generating their own power using wind turbines, solar systems and anaerobic digestors. Excess power is sold back to the grid. Other producersare making their own biodiesel or ethanol as well as researching new energy related crops.

2.8.4 : Energy Conservation and Efficiency

Increasing energy efficiency and conserving energy reduces farmers' reliance on fossil fuels, reduces greenhouse gas emissions, and saves farmers money. Zero-till production uses less energy than conventional systems. USDA claim that around 15% of agricultural production costs are energy related. The quickest, cheapest, and cleanest way to reduce these costs is by improving energy efficiency.

Figure 19: A zero-till planter planting into maize stover in Argentina on our GFP at Monte Castillo near Rosario.

Several farms have increased energy savings by improving efficiency on all farm energy driven processes. Examples such as tractor and field efficiency, improving machinery maintenance, utilising new dairy cooling systems, high-efficiency motors, and low-energy lighting consumption. Significant energy savings are also achieved through better designed agricultural operations. Examples such as insulation, proper siting and design of farm buildings, energy efficient greenhouses, and switching to micro-irrigation (Morris *et al.*2019).

2.8.5: Renewable Energy

Renewable energy is collected from sources that can be replenished whilst they are being used. The main types of renewable sources are sunlight, wind, rain, geothermal, and biomass (Morris *et al.*2019).

Renewable energy sources are normally region or site specific. In the USA, the Midwest has very good wind potential and the Rift Valley in Kenya has excellent geothermal potential. In California, there is excellent solar potential where the aforementioned Terranova Ranch has two solar farms. Southern Zimbabwe has exceptional solar energy and Nottingham Estate in this region has a 2 MW solar system. Chipinge, Tanganda Estates, in eastern Zimbabwe has several large solar farms with the latest German technology, including a 1.6 MW installation at its Jersey Estate (Figure 20). In the United Kingdom, on our GFP we visited Sir James Dyson's farming operation – Beeswax Dyson Farming where he has two anaerobic digestors – Figure 21 illustrates the effectiveness thereof.

Figure 20: The 1.6 MW Solar Farm at Jersey Tea Estate.

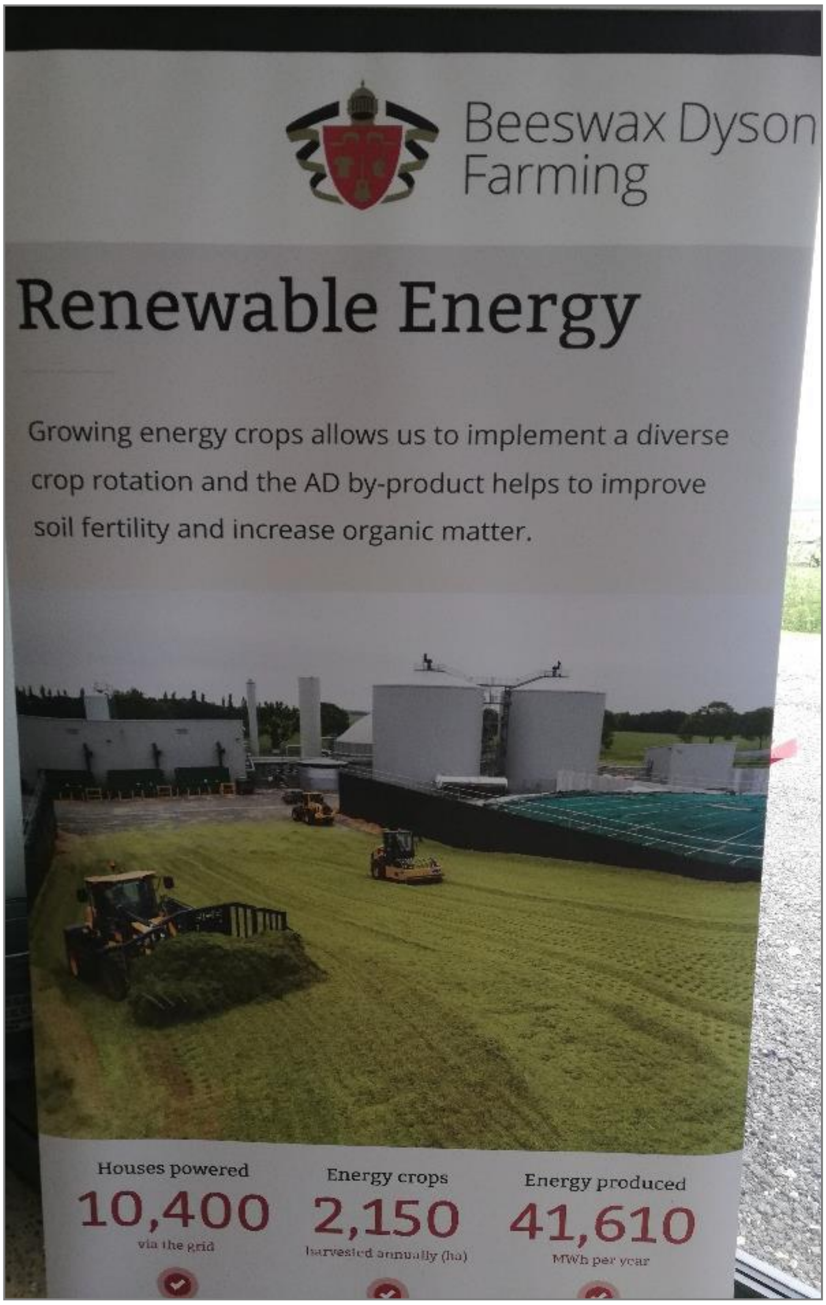

Figure 21: A drop banner illustrating how much renewable energy Beeswax farming contributes to the national grid.

Beeswax farming contributes 41,610 MW per year off 2,150 ha of energy crops, and this in turn powers 10,400 houses. Energy crops allow Beeswax farming to have a more diverse crop rotation and improve soil fertility and increase organic matter in the soil.

2.8.6 : Saving Energy in Agriculture

1. Fertiliser and pesticide use:

   A large proportion of the energy consumed in agriculture is used in commercial fertiliser and other chemical production. If farmers could reduce their fertiliser and chemical inputs they would reduce their energy requirements and improve their profitability. Strategies to reduce fertiliser and chemical inputs include precision farming, the use of cover crops, nitrogen-fixing crops in rotation, integrated pest management, and composting (Hasanuzzaman, M. 2019).

2. Irrigation:

About 25% of the energy used in irrigation in developing countries is wasted due to low pump and motor efficiency. Incorrectly designed irrigation systems lead to incorrect soil moisture levels, crop stress, a reduction in yields, and a waste of water. Energy can be saved by using the following:

- Efficient and correct irrigation pump sizing, including variable-speed pump motors.
- Correct maintenance of irrigation schemes.
- Using more efficient irrigation systems such as low-flow drip or microjet (Hasanuzzaman, M. 2019).

3. Farm vehicles:

   Significant energy savings can be found in tillage systems and tractor fuel efficiency. Tractor fuel efficiency can be improved by proper tyre inflation, regular maintenance, and reduced idling. Reduced-till or zero-till cropping systems can lead to large savings in energy, if the situation allows for this system. Benefits of zero-till are an increase in crop yield, increased soil moisture, and less tractor time in the field. Precision farming leads to less time in the field, thereby saving energy. Proper equipment sizing is also important for saving energy, as well as reducing equipment wear (Hasanuzzaman, M. 2019).

4. Energy conservation in the future:

   Sustainable food production is linked to more efficient use of energy as well as less reliance on fossil fuels. More sustainable use of energy in agriculture lies in including more biological inputs, which are renewable and can normally be grown on farm as a cover crop for example, or zero-till.

   Energy conservation strategies:

   - Using minimum tillage systems;
   - agricultural practices that reduce water usage and loss, thus reducing the energy required for irrigation;
   - correct crop rotations that help the soil recover without using synthetic inputs;
   - developing the use of renewable energy to replace fossil fuels;
   - developing on-farm renewable energy sources; and
   - using electricity more efficiently, ensuring machines are doing the correct job (Hasanuzzaman, M. 2019).

   Increasing biological energy:

   - Human energy is an integrated part of the energy flow in agriculture;
   - return of harvested plant nutrients to the soil where from whence they came;
   - use of manures to improve soil quality and fertility;
   - increasing the use of biological control and integrated pest management; and
   - improving the beneficial soil fungus in the roots to reduce external inputs.

   Lowering cultural energy Inputs of agroecosystems:

   - Improve the use of nitrogen-fixing crops and green manures;

- increase the use of biological pest management through cover cropping, intercropping, and encouraging beneficial insects more; and
- plant crops that are adapted to the environment they grow in, as opposed to changing the environment the crops grow in (Hasanuzzaman, M. 2019).

2.8.7 : Agricultural Waste Management

With the rapid growth of the world's population, the increase in urban migration has resulted in a greater demand for food. This has in turn led to a large amount of agricultural waste at farmer and city levels (Sabiiti, 2011).

It is estimated that around 998 million tonnes of agricultural waste is produced every year. Agricultural waste includes all residues from all types of agriculture including horticulture, livestock, poultry, dairy products, and cropping. Waste will come in two forms, either from crude agricultural products or from processed agricultural products. Waste is the non–product output of the agricultural process whose value is less than the cost of collection, transportation, and processing for beneficial use (Obi, F. *et al*. 2016).

The Chartered Institute of Wastes Management (CIWM), founded in 1898, defines agricultural waste as "having been produced on a farm" in the course of farming. Agricultural waste can comprise natural and non-natural waste. The CIWM definition of non-natural agricultural waste includes discarded pesticide containers, plastic bags, plastic sheeting, tyres, batteries, clinical waste, old machinery, oil, packaging waste, and several other non-natural items used on a farm, and which is discarded.

CIWM mentions a range of hazardous wastes that can include used syringes and needles, unused animal medicines, asbestos roof sheeting, and waste oils.

Common natural waste, according to CIWM, includes slurries and manure. A survey in England taken in 2003, showed 93% of all agricultural waste was manure and slurries. These are used as a fertiliser on the agricultural premises. Regulations still need to be followed regarding groundwater, causing some restrictions on the spreading of manure to land. The composition of waste will depend on the type of agricultural activities involved being either liquid, slurry or solid. Agro-waste is made up of:

1. Animal waste – manure and animal carcasses.
2. Food processing waste – for example, only 20% of maize is canned and 80% is waste.
3. Crop waste – for example, sugarcane bagasse, corn stalks.
4. Hazardous and toxic agricultural waste – for example – pesticides, insecticides, and herbicides (Obi, F. *et al*. 2016).

A sustainable approach to agricultural waste is required for an efficient disposal system (Hai, H. 2010). Agro-waste may cause health and environmental issues, hence the need for safe method of disposal of waste (Sud, D. 2008).

2.9 : Crop Protection

In agriculture, crop pests are organisms that cause damage to agricultural products. Pests include:

- Weeds;

- vertebrates – birds, rodents, or other mammals;
- invertebrates – insect, tick, mite, or snail;
- nematodes; and
- pathogenic microbes – bacteria, viruses, or fungi that cause disease to plants (https://extension.psu.edu/pests-and-pesticides-in-agriculture)

FAO estimates that up to 40% of food crops are lost through pests and diseases annually. This is a substantial amount of food that could be saved through better crop protection and would help fill the growing global requirements.

2.9.1 : Rachel Carson – *Silent Spring*

A woman who has inspired scientists – and has provided invaluable insight for this report – with her pioneering writing since 1941, is Rachel Carson.
(https://www.fws.gov/refuge/Rachel_Carson/about/rachelcarson.html).

As the Aquatic Biologist to the US Fish and Wildlife Service, and subsequently, the Editor-in-Chief of all Fish and Wildlife Service publications, Carson wrote a number of insightful articles and books that highlighted concepts such as 'ecology'. Rachel went on to resign from Fish and Wildlife Services and wrote full-time. Her final book, published in 1962 – *Silent Spring* – described in detail the danger and threat to the ecosystem caused by harmful pesticides; this in an era post-WWII, when many synthetic pesticides were developed with military funding. Carson's principal debate is that synthetic pesticides have destructive effects on one's natural environment as often the effects of the pesticide are seldom limited to the target pest and she felt a better term would be 'biocides'. DDT is an example of this at the time. Carson also accused chemical companies of deliberately spreading misinformation as well as public officials accepting the data from these chemical companies autocratically. There are four chapters in the book which discuss detailed cases of human pesticide poisoning, cancer, as well as other illnesses caused by pesticides (Tjossem. S, F. 1995).

Carson anticipated the ramifications of target pests developing resistance to the pesticides being used, with a depleted ecosystem being infested with invasive species. The book finishes by suggesting a biotic approach to pest control as alternative to chemical control (Lear, L. 1997)

National Geographic (2020) describe biotic factors are any living component that affects another organism or shapes the ecosystem. Carson did not call for total ban on DDT but rather, careful use and not indiscriminate over-use as this would result in resistance in the target pest, and an inability to reduce the target populations.

Lear (1997) quotes Carson:

"No responsible person contends that insect-borne disease should be ignored. The question that has now urgently presented itself is whether it is either wise or responsible to attack the problem by methods that are rapidly making it worse. The world has heard much of the triumphant war against disease through the control of insect vectors of infection, but it has heard little of the other side of the story – the defeats, the short lived triumphs that now strongly support the alarming view that the insect enemy has been made actually stronger by our efforts. Even worse, we may have destroyed our very means of fighting."

Carson was also quoted as saying “Malaria programmes are threatened by resistance among mosquitoes” (Lear, L. 1997). Carson quoted the advice given by the director of the Dutch Plant Protection Service: “Practical advice should be spray as little as you possibly can rather than spray to the limit of your capacity “

Figure 22: Rachel Carson, 1940 U.S. Fish and Wildlife Service employee photo.

2.9.2 : Pesticide Resistance

Pesticide resistance is where an agricultural pest has a reduced susceptibility to a pesticide, which previously controlled the pest (https://www.pbs.org/wgbh/evolution/library/10/1/l_101_02.html). Resistance cases have been noted in all classes of agricultural pests. The Insect Resistance Action Committee (IRAC) defines pesticide resistance as:

“Resistance may be defined as a heritable change in the sensitivity of a pest population that is reflected in the repeated failure of a product to achieve the expected level of control when used according to the label recommendation for that pest species.”

Figure 23 below highlights how pest resistance to a certain pesticide can occur through random natural mutation.

A small number of the resistant (red) pests are present in the pest population through random natural mutations. When a certain pesticide is applied the susceptible (blue) pests die, while the resistant pests survive, thereby on their genes to the next generation. When the same certain pesticide is applied again, the percentage of resistant individuals increases (Grigg-McGuffin, 2019).

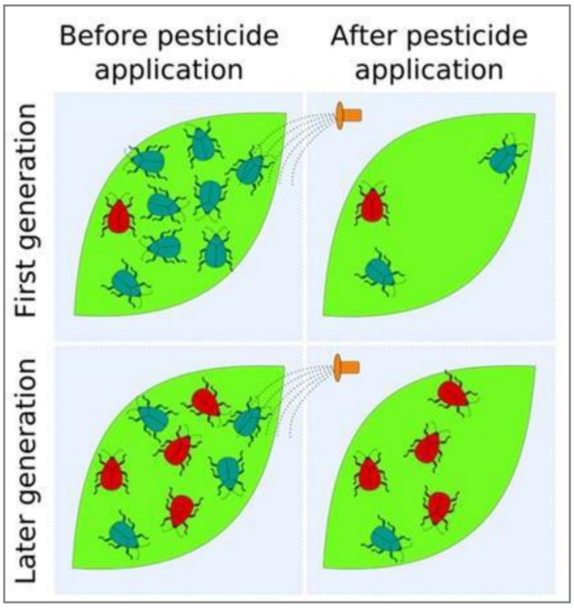

Figure 23: Illustration of how pesticide resistance occurs (Grigg-McGuffin, 2019).

Not all pest control failures are due to resistance. There are other factors such as product selection, timing, rate, spray coverage, spray-water PH, and weather conditions that also affect the success of the spray.

Newer pesticides employ a more specific mode of operation, having a 'single site' compared to older pesticides, which have a broader action. This single-site chemistry only needs one change in the genetic make-up of the pest, and this will lead to resistance, hence this is known as a 'high risk' pesticide, whereas the broad spectrum option is known as a 'low risk' (Grigg-McGuffin, 2019).

2.9.3 : Resistance Management Strategies

1. Know which chemical groups you are spraying and use them in rotation.
2. Limit one's applications from a single chemical group in a growing season, especially with single-site pesticides.
3. Know the active ingredient (AI) of a pesticide and know when a product has two AIs in it.
4. Use different types of pest control strategies – resistant varieties, scouting models, orchard sanitation and biological control.
5. Make each spray as efficient as possible – has the product label been read, is sprayer correctly calibrated, is the pest active at the right stage in its life cycle, is the correct rate being applied as well as the spray coverage being sufficient (Grigg-McGuffin, 2019)?
6. Promote biological control by using pesticides that are less harmful to beneficial insects. Also provide a habitat that is not sprayed for these natural enemies.

2.9.4 : Integrated Pest Management (IPM)

FAO definition of IPM is as follows:

> Integrated pest management means careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or

> minimise risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to ago-ecosystems and encourages natural pest control mechanisms.

The IPM Institute of North America definition of IPM is:

> Integrated Pest Management (IPM) is a sustainable, science-based, decision-making process that combines biological, cultural, physical and chemical tools to identify, manage and reduce risk from pests and pest management tools and strategies in a way that minimises overall economic, health and environmental risks.

University of California definition of IPM :

> IPM is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimises risks to human health, beneficial and nontarget organisms, and the environment.

Dr Pete Goodell, PhD in Entomology and Nematology for the University of California (UC), is a Cooperative Extension Advisor in the San Joaquin Valley, and his view on IPM is as follows:

1. When one thinks of IPM one has to think of the total ecosystem, considering all things including land, air, water, social, and especially, maintaining the productivity for the farmer who is trying grow a crop.
2. A key to IPM is its dependence upon information for pest management. Information based upon scientific knowledge, as well as years of experience in the specific field.
3. IPM refers to pest management, not pest control, as it is trying to prevent the pest from reaching economic thresholds, not necessarily eradicating the pest. Action thresholds are important.
4. Pest management requires monitoring in the field to see what is there as well as taking note of what natural enemies are present. Looking after one’s natural enemies’ inventory is very important.
5. IPM is an integrated approach that combines cultural control, biological control, and chemical control. The chemical control needs to be specific and fit in with one’s ecosystem.
6. Successful IPM programmes are implemented by incorporating them into the existing pest management programmes.

> IPM ensures long-term prevention of the pest and minimising damage by helping manage the ecosystem. IPM prevents the pest from becoming a problem. For example, by growing a crop that can withstand pest attacks by using disease-resistant plants. IPM means that you look at the environmental factors that affect the pest. This information is critical to make conditions that are less favourable for the pest (https://www2.ipm.ucanr.edu/What-is-IPM/).

Scouting and correct pest identification of one’s crop will give you the information required on what action will should be taken.

IPM programmes have an integrated strategy approach. These IPM strategies are often grouped as follows:

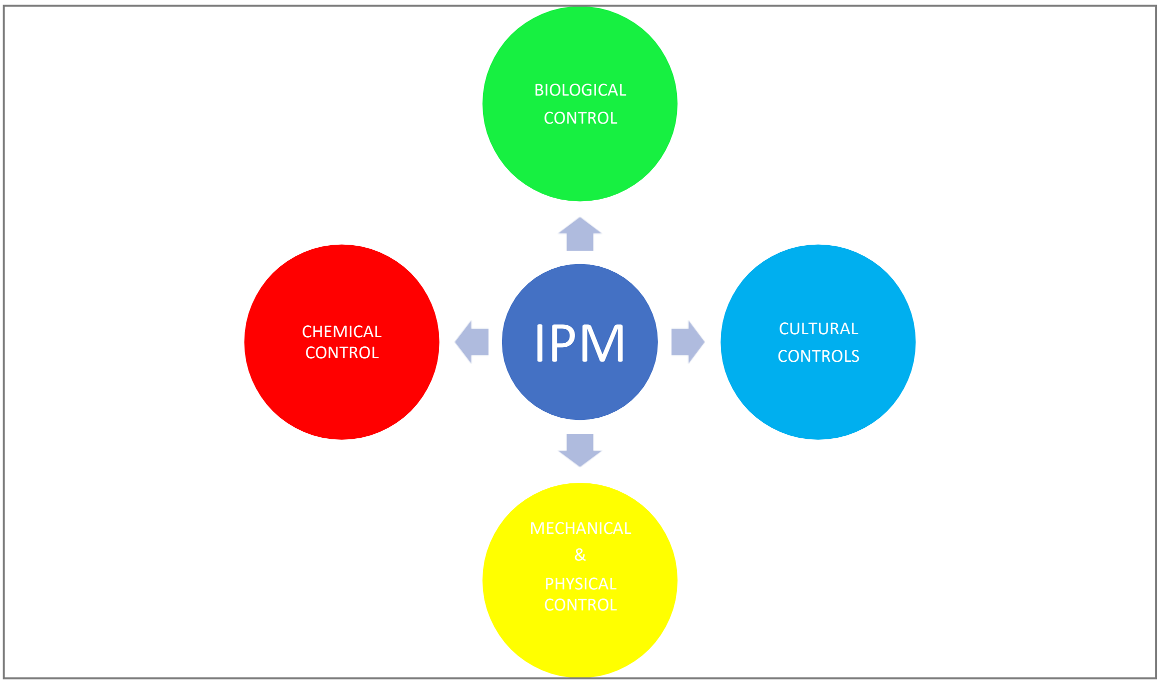

Figure 24: The combination of management methods used in IPM.

2.9.4.1 Biological Controls

The use of 'natural enemies' – predators, parasites, pathogens, and competitors. Agricultural pests have many natural enemies.

Biological control is broken up into four sections:

1. Macro biologicals:

   These are visible to the naked eye. An example of this is *phytoseiulus persimilis*, a predatory mite, used to control two-spotted spider mite in greenhouses and outdoor crops. It only feeds on spider mite only, which makes it a very efficient biological product. The chemical stress from red spider chemicalsis removed and the quality of one's crop increases significantly.

2. Micro biologicals:

   A beneficial microscopic organism, especially a bacterium, virus, or fungus. An example of this is *trichoderma asperellum* – this is used to control pythium, fusarium and rhizoctonia. The trichoderma also can solubilise bound-up phosphate as well as having a bio-fertiliser action. *Paecilomyces lilacinus* is another type of microscopic organism that can use the egg, juvenile, and female parthenogenic nematode as a host.

Figure 25: Paecilomyces lilacinus hyphae on a root knot nematode egg.

3. Semiochemical controls:

   A semiochemical is a marker or signal chemical that transmits information between individuals of the same species – pheromones.

   Pheromones have been used successfully in mating disruption in orchard systems, this is where you fill the orchard with female pheromones so the male cannot locate the female and hence prevent breeding.

Figure 26: Mating disruption in a stone fruit orchard in California, on an organic production system seen on our GFP.

Pheromones are also important in helping control new pests such as *Tuta absoluta*, fall army worm, and false codling moth.

Figure 27: Pheromone used for monitoring in organic stone fruit orchard in California.

4. Botanical controls:

   Botanicals are products derived from plants. They degrade rapidly and are therefore considered safe to the environment. An example of this is food-grade garlic liquid, which has nematocidal properties as well as being used as a repellent.

2.9.4.2 Cultural controls

Cultural controls are practices that reduce pest establishment – for example, minimising over irrigation, removing weeds on the sides of fields that can harbour pests or using pest resistant varieties.

2.9.4.3 Mechanical and Physical Controls

Mechanical and physical controls kill a pest directly. For example, yellow stick-rolls as used in intensive horticultural fields such as blueberries, which attract and kill insects by sticking them to the roll.

2.9.4.4 Chemical Controls

Pesticides are only used when required in combination with other management strategies. Pesticides are applied in a selective manner to reduce the effect on non-target organisms, people, and the environment.

2.9.5 New Integrated Pest Management Paradigm

Previous IPM models considered the ecosystem with regard to pest management. With the advancement in agricultural technology, globalisation, ever-changing consumer trends and modern communication tools there may be a need to revisit the IPM paradigm (Dara, 2019).

Dr Dara from the University of California Cooperative Extension has come up with a model that may be appropriate. Dara built his model on earlier IPM foundations that were based on ecological and economic principles. It is expanded to include management, business as well as sustainability principles and incorporates the value of research and agronomic advice. The new IPM model contains four components of IPM (as illustrated in Figure 28) which are:

1. Pest management options.
2. Knowledge and resources to develop management strategies.
3. Management of information and making timeous decisions.
4. Sharing of information.

The business aspect of this model covers the producer, consumer, and seller. The sustainability aspect covers economic viability, environmental safety and social acceptability. This model considers the human, environmental, social, and economic factors that influence the food production.

Figure 28: New IPM paradigm with its various components and influencing factors (Dara, S. 2019).

Chapter 3: Sustainable Agriculture Around the World

There are several excellent examples from around the world, where farmers have adopted sustainable practices by employing holistic agricultural management on their farms. ICM is one such holistic approach and several aspects of ICM can be seen in the examples below.

3.1: Monte Castillo – Argentina

In Argentina, on a 7,000-hectare cropping farm near Rosario called Monte Castillo, which comprises 4,000 ha soya (avg. yield 5t/ha), 2,000 ha maize (avg. yield 12.5 t/ha) and 1,000 hectares wheat. They employ double cropping per annum, on all-dry land. Zero-till since 1992, this is a highly sustainable operation, with massive amounts of passion from the family.

Figure 29: The surface soil in which the crops are grown; zero-till since 1992. This illustrates the large amount of organic matter in the soil.

Figure 30: Combine harvesters at work at Monte Castillo, note the organic matter left behind.

Figure 31: Zero-till planter into maize stover.

Christine, who runs Monte Castillo alongside her two sisters and their husbands, picked up a handful of soil, smelled it and said to our GFP group "I love my soil". It is all about soil health to Monte Castillo and this is evidenced by the sustainability of their operation.

3.2: Longridge Wine Estate – Stellenbosch, Western Cape, South Africa

Longridge wine estate is situated at the foothills of the Helderberg mountains. Longridge is a biodynamic vineyard that is minimising the impact they have on their environment. Jasper Raats is the Cellar Master and General Manager. Jasper is quoted saying "our goal is to produce world-class wines in a natural way, applying the age-old traditions of natural winemaking and respecting our land by not using any herbicides, pesticides or chemical sprays".

In 2011, the soils at Longridge were overworked from traditional chemical farming, with low soil health. Longridge took the approach of 'letting nature do its job'. Cover crops were grown, Nguni cows were introduced to make organic compost, which was incorporated back into the soil, and geese were used to control snails and other insects. They used a zero-till seed machine for all the cover crops and they rolled down the cover crops with a roller to retain the moisture during the drier months, which also served to keep the temperatures down. They introduced micro-organisms in the form of trichoderma and mycorrhizae.

Figure 32: Organic manure piles at Longridge from the Nguni cows.

During the recent drought, the rejuvenated soils had a much better water-hold capacity. Soil moisture probe readings showed a 30% higher moisture level in the areas that had benefitted from the compost and cover crop programme, illustrating how a healthy soil performs in more extreme weather conditions.

Longridge has also taken care in growing the correct varieties for their climate and soils. They grow Chardonnay and Chenin Blanc grapes and they produce a Chardonnay, which is in the top 10 in South Africa and the No. 1 in Stellenbosch. They also produce Merlot, Cabernet Sauvignon and South African Pinotage wines.

Figure 33: A young vineyard with a diverse cover crop, lucerne, at Longridge that is providing nitrogen.

3.3 : Fritz and Colin Breytenbach – Robertson Valley, Western Cape – South Africa

Fritz and Colin Breytenbach are brothers and run a vineyard at the end of the Robertson valley. Fritz is Jasper Raats' Godfather and Jasper kindly organised a visit due to the brothers' love for their soil. Fritz said that life begins at 70 and he is really enjoying life! The brothers have spent a lot of time getting the soil right with regards to nutrition and getting their calcium and magnesium ratios into balance. They embraced soil health by having a full cover crop. The interesting point is that they were yielding 28 tonnes of grapes per hectare while their immediate neighbours were achieving around 14 tonnes. Their neighbours had no covercrop in between the vines and kept the soil clean of all plant material. Colin indicated they used quite an integrated approach incorporating all aspects of farm management. These were interesting people who clearly have a passion for the soil.

Figure 34: Colin Breytenbach showing me the condition of his soil.

Figure 35: Picture of Fritz and Colin Breytenbach discussing their holistic farming approach.

3.4: Biodynamic Farming

The Biodynamic Association refers to biodynamics as an "holistic, ecological and ethical approach to farming, gardening, food and nutrition". Biodynamics was founded by the philosopher and scientist Dr Rudolf Steiner, whose 1924 lectures to farmers promoted a new way of integrating scientific understanding whilst recognising spirit in nature. Biodynamics has continued to evolve since the 1920s through collaboration of farmers and researchers. Around the world, biodynamics is alive in thousands of thriving gardens, farms, vineyards, ranches, and orchards. Biodynamics can be practiced anywhere food is grown with adaptation to scale, landscape, climate, and culture.

Figure 36: Biodynamic and organic blueberries grown using micro-organisms at Matetic in the Rosario Valley next to Casablanca Valley in Chile as seen on our GFP tour.

Figure 37: A view of the Matetic biodynamic and organic vineyard in the Rosario Valley, Chile on the GFP tour.

3.5: Organic Farming

Rodale Institute, started around 1940 by J.I. Rodale, states that organic farming is a production system that regenerates the health of soils, ecosystems, and people. “Organic farmers rely on natural processes, biodiversity, and cycles adapted to local conditions rather the use of synthetic inputs like chemical fertilisers, pesticides and herbicides. GMO are not allowed in organic farming”.

One point of interest is that organic produce is the fastest growing sector in the supermarket trade in the USA.

3.6: Langgewens Research Farm, Moorreesburg, South Africa

Langgewens research farm is near Moorreesburg in the Western Cape and is part of the Department of Agriculture of the Western Cape Government. The area is known as the Swartland, where 360,000 ha of wheat, 14,000 ha barley and between 16,000 and 18,000 ha of canola are grown. This area is in a Mediterranean climate, and 15 to 20 years ago the majority of the wheat was monoculture. Today, around 95% of the crops grown in the Swartland area are zero-till.

Figure 38: The countryside in the Swartland area, South Africa.

It was a privilege to meet Dr Johann Strauss at Langgewens research farm and hear how their conservation agricultural (CA) approach is helping increase crop yields and viability in the area. CA is founded on three principles – zero-till, continuous ground cover, and diverse crop rotations (Strauss, J. 2021). At Langgewens, Dr Strauss has been doing long-term CA trials and this innovative approach is now entering its 25th year.

Table 2: The eight different systems included in the Langgewens long-term crop rotation trial (Strauss, J. 2021).

SYSTEM CODE	ROTATION SYSTEMS	LETTER SEQUENCE
A	Wheat-Wheat-Wheat-Wheat	WWWW
B	Wheat-Wheat-Wheat-Canola	WWWC
C	Wheat-Canola-Wheat-Lupin	WCWL
D	Wheat-Wheat-Lupin-Canola	WWLC
E	Wheat-Medic-Wheat-Medic	WM^{g}WM^g
F	Wheat -Medic + Clover-Wheat -Medic+Clover	WMc^{g}WMc^g
G	Wheat-Medic-Canola-Medic	WM^{g}CM^g
H	Wheat-Medic+Clover-Wheat-Medic+Clover	WMcs^{g}WMcs^g

Note: Crop phases grazed by sheep; with Saltbush pastures to rest medic+clover pastures

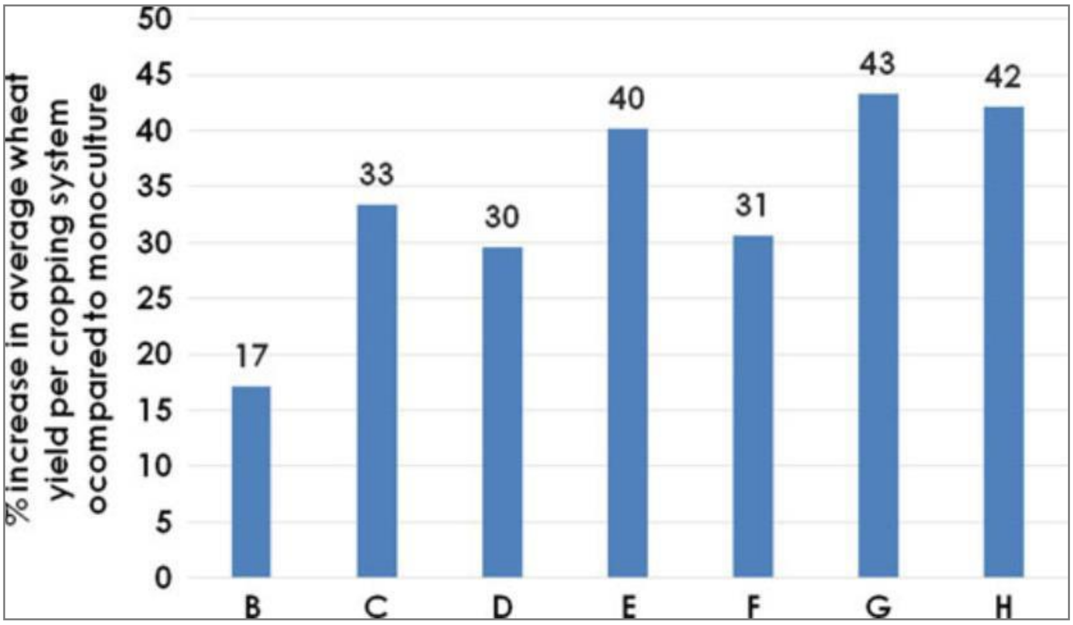

Figure 39: Wheat yield increase in the different cropping systems compared to continuous wheat (Strauss, J.2021).

Figure 39 shows a 43% increase in the average yield as compared to the monoculture of wheat. The treatment was wheat-medic-canola-medic with sheep grazing the medic.

Table 3: Example summary of gross income on an average wheat farm in different trial system scenarios (Strauss, J. 2021).

SYSTEM CODE	LETTER SEQUENCE	AVERAGE GROSS MARGIN (R/HA)	INCREASE IN GROSS INCOME COMPARED TO MONOCULTURE (%)	TOTAL GROSS INCOME (RAND)	GROSS INCOME RANKING
A	WWWW	2281		1824554	8
B	WWWC	2765	21	2211825	5
C	WCWL	2712	19	2169306	6
D	WWLC	2557	12	2045751	7
E	WM^{g}WM^{g}	3359	47	2687105	2
F	WMc^{g}WMc^{g}	3052	34	2441596	3
G	WM^{g}CM^{g}	2909	28	2327127	4
H	WMcs^{g}WMcs^{g}	3670	61	2936208	1

Table 3 highlights how profitable CA is compared to mono cropping, which is really exciting for the future of the farmers in that area.

There are several other benefits of the CA system being done by Langgewens which are:

- Improved water efficiencies;
- improved nitrogen efficiencies, and the use of less nitrogen due to the legumes fixing nitrogen;
- improved soil health;
- reduced disease cycles, and assistance with weed management;
- reduced stock feed bills due to animals eating cover crops;
- improvement in the quality of the meat produced off cover crop pastures; and
- improved farmer resilience to drought through CA.

To end with a quote from Dr Strauss, which highlights the work he is doing, whilst having the best interests of the farmer at heart: “You can’t be sustainable if you are not profitable”.

3.7: Flamingo Horticulture

During this Nuffield journey, there has been some inspiring initiatives by agribusinesses who employ various aspects of ICM as a route to sustainable farming whilst increasing yields. The one business that embodies this and sets the gold standard for the future of intensive agriculture, is Flamingo Horticulture. This dynamic business highlights what can be achieved, even with limited resources if you are willing to think outside the box.

A forward-thinking agribusiness specialising in export cut flowers, fresh produce and plants, Flamingo Horticulture is a world leader in their field. They operate on a business model that is an end-to-end vertical integration.
Currently, Flamingo produce around 4.1 million rose stems per day (1.2 billion rose stems per year), one million bouquets per year, and they do 100 tonnes of vegetables per day into their markets. The majority of the rose stems are grown in Kenya and Ethiopia, East Africa. The vegetables are grown on both their own farms and those of their partners, and these are currently spread across 17 countries.

Figure 40: Aerial view of Kingfisher Farm, Naivasha.

Figure 40 is an aerial view of Kingfisher Farm in Naivasha, one of several Flamingo production sites, which comprises 180 ha of vegetables and 120 ha of flowers. Richard Leask (2019 Australian Nuffield Scholar) and I were fortunate enough to do a crop walk through the roses, around several greenhouses, with John Meijer, Managing Director of Kingfisher, and his management team. The team were really focused on maximising production whilst taking into account an IPM/ICM approach.

It was interesting to interview Mr Ian Mitchell, the Technical, Agronomic and Procurement Director for the Flamingo Group. A highly qualified agronomist, Ian also holds the BASIS and FACTS certification, and he took the time to outline the history of the Group as well as its sustainability journey. This is an incredibly dynamic group constantly changing to meet the market's needs.

Flamingo grew tenfold from 1994 to 2007. In 2001, Dudutech was started as the biological control division of Flamingo, initially set up to deal with the leaf miner problems the farms were experiencing. In 2001 this was an entirely different way of thinking about pest control but serves to illustrate the forward-thinking culture of the Group, and the establishment of its own biological control company highlights how important sustainability is to Flamingo. 2001's 'different' is now the norm, and in fact every year different chemicals that growers can use for their various markets are removed from the list and they have to find biological solutions. Flamingo's IPM strategy started the IPM movement in the region, ultimately making food safer to eat in the developed markets. Dudutech is currently the largest biological control company in Sub-Saharan Africa and was sold to Bioline earlier this year.

Figure 41: Photograph of Author with Dr Vitalis Wekesa, head of production at Dudutech with Richard Leask in the background on a tour at Dudutech.

The following quote on sustainability has been taken from the Flamingo website:

> As an agricultural business we are intimately linked to the natural environment and we understand the volatility, uncertainty, complex and ambiguous factors (VUCA) affecting our and our partners operations. Our top line sustainability commitments are guided by our business pillars: Our farming, Our people, Our stakeholders, Our communities, Our customers.

All of Flamingo's produce is accredited by the following certifications:

100% Global Gap	100% Fairtrade	MPS on flowers	LEAF	SMETA

These accreditations are not easy to come by and illustrate that Flamingo takes considerable care of their production and markets. Earning these certifications signifies that they are farming in an environmentally friendly manner, and that they look after their staff and the environment in the best possible manner.

This care and concern is demonstrated by a quote from the website:

"Sustainable and responsible sourcing with strategic partnerships with growers and customers".

With these esteemed certifications for their products, Flamingo can access valuable markets in the United Kingdom and Europe, and they will undoubtedly ensure consumer confidence in the brand, making Flamingo their product of choice.

Ian indicated that they manage their resources very closely. For example, their watermanagement is very important, so they aim to grow the right crops at the right time and give them the correctwater requirement.

Flamingo are also carbon neutral for the year ending 2020 for all products coming from Africa, i.e., no net release of carbon dioxide into the atmosphere, especially as a result of carbon offsetting. Again, this highlights Flamingo's commitment to sustainability in a bid to offset global warming in these modern times.

"Everything has a finite resource." – Mr Ian Mitchell, the Technical, Agronomic and Procurement Director for the Flamingo Group.

Chapter 4: Sustainable Development Goals (SDGs)

Figure 42: The sustainable development goals adopted by all the United Nations Member States in 2015.

Nuffield aligns itself with the SDGs and while agriculture does not contribute to all the SDGs it does so to at least ten of them. ICM will contribute significantly to achieving these SDGs as well as having sustainable farming systems that will enable farmers to feed the ever-growing population by the year 2050.

CONCLUSION

The global population is increasing rapidly and food requirements will need to increase by 60 to 70 % from current production by the year 2050. Currently, 1,500 million hectares of land are being used for the global output of which one-third of this land has been threatened by erosion, seawater, and pollutants that are degrading soil health and biological productivity. Only 200 million additional hectares will come into agricultural production, which provides only around 13% increase in agricultural output, leaving a deficit of around 45 to 50%.

Farming needs to embrace holistic farming practices such as those found in ICM to be able to increase yields and maximise every resource available to a farmer. This will ensure viability for the farmer as well as a sustainable farming system.

Every element of ICM gives the farmer and agriculture an opportunity to improve efficiency, and if all sections are improved upon this can lead to a significant improvement in crop yield.

An example of this is under 'water management' where 40 % of the world's crops are produced on 20% of the arable land. This 20% could possibly improve efficiencies but other options are to increase the irrigated crop area, which will increase production to two or three times what it was before.

Crop Protection is another area where there are significant efficiencies to be made, FAO estimates that up to 40% of food crops are lost through pests and diseases annually. Pest management programmes can be greatly enhanced through Integrated Pest Management.

In the previous century, Rachael Carson highlighted that all natural organisms are linked, hence her concern for the killing of non-target organisms – it would upset the balance of nature. Global agriculture needs to embrace nature and stop fighting it. ICM is a way for agriculture to embrace nature's massive power, thereby improving the efficiency and viability of farmers.

RECOMMENDATIONS

Each agricultural site globally is unique, so when ICM is incorporated into their operations, this needs to be borne in mind.

Figure 43: Integrated Crop Management graphic.

The following recommendations are proposed:

- Look into each section of ICM and see where the efficiencies can be. Elements such as Site Selection might not be able to be changed but the other six sections may well be.
- A paradigm shift in mindset to accept that one needs to work with nature and not against it is a critical concept to adopt.
- Only through an integration of the various elements in ICM will there be enhanced sustainability as well as increase in yield and quality of one's agricultural produce.

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PLAIN ENGLISH COMPENDIUM SUMMARY

PROJECT TITLE:	**INTEGRATED CROP MANAGEMENT AS A SUSTAINABLE FUTURE FORGLOBAL AGRICULTURE**
Scholar:	Philip Weller P.O. Box BW 1779 Borrowdale Harare
Phone:	+263 77 230 2006
Email:	plwtonsberg@gmail.com
Objectives:	The main objective of this report is to present a model for Integrated Crop Management, which will contribute to a sustainable future for global agriculture. The report will concentrate on the following: • Introducing the global population dynamics, how we got there and where the population is going; • Highlight the shortage of fertile land globally and encourage farmers to maximise their land productivity; • Introduce the concept of Integrated Crop Management as a solution to holistic sustainable global agriculture; • Discuss each concept of Integrated Crop Management; and • Encourage Agriculture to embrace a holistic farming approach by working with all elements of Integrated Crop Management, and especially nature itself.
Background:	Globally, there is a need to increase agricultural production to feed the growing population by 2050. Agriculture has little fertile land left to develop globally, so it needs to maximise the natural resources it has through Integrated Crop Management. Technology needs to be used to address the issues of increasing yield and masking soil degradation, the lack of emphasis on the soil microbiome, the over-use of agricultural crop protection chemicals that lead to resistance, and the over-use of inorganic fertilisers that lead to acidification.
Research:	There are examples of sustainable agriculture around the world. It was important to find examples of sustainable farming to illustrate how this has been achieved and where it fits into Integrated Crop Management. On my GFP, several sustainable farming operations were visited, as well as Kenya and South Africa. Due to covid my personal travel was extremely limited.
Outcomes:	Integrated Crop Management is a holistic approach to crop management, which involves the following: site selection, soil health and regenerative agriculture, water management, crop rotation, crop nutrition, environment, energy and waste management, and crop protection. One of the main recurring themes is that in order to achieve true sustainability in agriculture one needs to embrace nature and work with it and not against it.
Implications:	A simple model of Integrated Crop Management can be implemented to enhance the sustainability of one's agricultural operation.
Publications:	Presentation at 2021 Nuffield Presentation, Harare