

Sustainable and Regenerative Agriculture

Farming in a world of finite resources



by Michael Inwood

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Foreword

The converging issues of global food security, climate variability and the dependence of conventional agriculture on inputs derived from finite resources have made research into sustainable and regenerative agriculture a major priority for agricultural industries. Farmers, processors and retailers all need security of supply in their businesses. In order for production to be sustainable the loop needs to be closed on the production/ consumption cycle, with waste returning as a renewable input. For this to occur in a truly sustainable manner and operate indefinitely into the future it must also be in harmony with natural systems. The declining availability of arable land per capita highlights the need for efficiency of production.

Arable land per capita (ha in use per person)

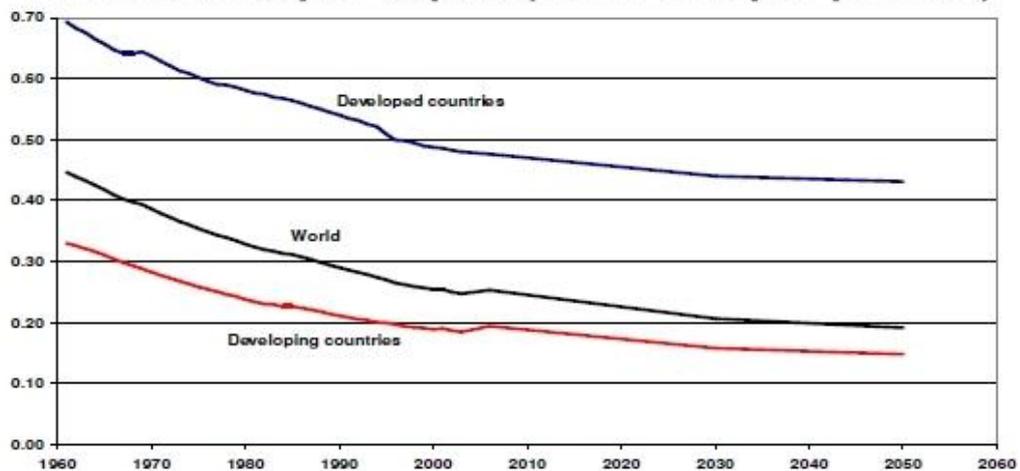


Figure 1: Arable land per capita

(Bruinsma, 2009)

Due to drought and desertification each year 12 million hectares are lost globally (UNCCD, 2012). China has been losing 1% of its agricultural land annually between 2000 and 2008 due to urban encroachment (Wang, 2011). New arable land is being brought into production but must be balanced with needs of the environment. Specific examples are the clearing of rain forest, large grasslands and other sensitive ecosystems. There is ultimately a finite amount of land available to agriculture.

A hybrid mix of innovative new (and some old) technology, as well as a renewed focus on the essential interaction between plants and soil biology will be central to increases in nutrient efficiency.

Regenerative agriculture involves management processes that reclaim and build natural biological function in the soil and environment to provide a buffer or “insurance policy”

against management practices or natural events that deplete the system. Historical agricultural practices have in some cases depleted the natural resources base and this is only corrected by management that encourages the restoration of ecosystem function. Farmers will not “run out” of nutrients such as phosphorus but nutrient resources will become increasingly expensive to extract at lower grades of concentration and decreased accessibility. This will obviously be a problem for conventional, high input agriculture.

Research, education, promotion and extension in agriculture should be a funding priority and not subjected to repeated budget cuts. All aspects of sustainable and regenerative agriculture, including the recycling of human waste streams and the use of novel biological inputs to increase nutrient efficiency should be thought of as an environmental imperative.

Producers should be open-minded, but diligent, in their search for new technology and products in the transition to a more sustainable production future. Agriculture’s reputation for products and product quality will dictate public perceptions and preferences which in the end will influence government policy. Governments must find funding to address future concerns limiting agricultural production.

In funding this report the Sidney Myer Fund have again maintained their policy of promoting and focussing discussion on natural resource management and sustainability

Definitions

For the purpose of this report the term “Sustainable Agriculture” is defined as agricultural production that does not deplete the resource base it utilises and does not negatively impact on the surrounding environment. “Regenerative Agriculture” meets the criteria for Sustainable Agriculture but also involves actively building the “system”, or resource base, it utilises.

Improvements in soil carbon levels are possibly one of the best and easiest measures of soil biological health. A system that is sustainably building soil organic matter and hence soil carbon is almost certainly regenerative.

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Abbreviations

IPM - Integrated Pest Management

WHP - Withholding Period

GM - Genetically Modified

AMF - Arbuscular mycorrhizal fungi

CSIRO- Commonwealth Scientific and Industrial Research Organisation

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Executive Summary

The convergence of a number of critical issues for world agriculture makes research into more sustainable and regenerative agricultural practice a high priority for everyone involved. Today the world's global economies and industries are faced with constant pressure to grow and increase output. This happens with the knowledge that many of the resources of the planet are limited and becoming more costly to provide. With world population projected to increase by about 30%, to nine billion in the next 40 years, global agriculture is front and centre in the battle to produce “more from less”, if this increased population is to be fed, clothed and provided with energy. More sobering are the UN upper population limits for 2050 at 11 billion and predictions that climate variability will increase. Everyone who eats has a vested interest in guaranteeing future supplies of sustainably produced and nutritious food.

Constraints in achieving sustainable increases in global food production.

- Conventional agricultural production is highly reliant on finite reserves of fertiliser inputs and fossil fuels.
- Available agricultural land is shrinking due to urban encroachment, protection for environmental conservation and in places deteriorating productivity from some previous management regimes (erosion, loss of soil health and condition).

“25 per cent of global land is already highly degraded.”

(Thomas, *The Challenge of Global Degradation and Scarcity*, 2012)

- A common thread in world agriculture is the drift of youth to urban areas, which results in an aging farm population and in the developed world, low applications for agricultural science courses and interest in related careers.
- Governments in the developed world are almost without exception cutting budgets for agricultural research and development
- Farm gate pricing in most developed economies is captive to world markets, predatory purchasing of large supermarkets and processors, and high fixed-cost structures
- In Australia returns for farm produce are not sufficient to fund the environmental and sustainability expectations and demands placed on primary producers by the community and government.

Potential solutions in achieving sustainable increases in global food production

- Rising input prices and cost sharing as a whole of community response, will increase the viability of businesses associated with the recovery, recycling and transport of nutrients from the waste systems of population centres.
- Addressing worldwide food waste. Food spoilage, storage and production losses, retail and domestic waste could be in the order of one third to a half of the increases required to meet projected global food demand by 2050.

“Almost one-third of food produced for human consumption—approximately 1.3 billion tonnes per year, which could feed the total global population of 7 billion—is either lost or wasted.”

(Thomas, An Overview of Global Food Losses and Waste, 2011)

- Increased R & D spending on a new generation of regenerative agricultural systems that are less reliant on external inorganic inputs and harness soil biology to access minerals in the soil and increase nutrient efficiency.
- The world needs the best people involved in agricultural research and innovation.
- Soils are built and regenerated by growing plants and soil biology.
- Increasing soil carbon levels are a key indicator of improved soil management and soil health.

Funding Sustainability

- The application of GST to basic food items, has been estimated to raise six billion dollars annually in Australia (Wright, 2011), a figure which is more than capable of compensating low income consumers, as well as providing a meaningful ongoing investment in the future sustainability of agricultural production.
- A recurrent funding source, would secure the future interests of food consumers by increasing the sustainability of the Australian food production system.

Community Partnership

- Food security is also a matter of national security.
- Environmental, social and economic arguments support the shift to more sustainable agricultural production whether this involves high or low input systems.
- The value of food and its true cost of production need to be communicated to consumers as more than an issue of price per weight.

- Recognising, prioritising and securing the long-term sustainability of agricultural industries over and above the short-term gains from mining.
- Recognising that grazing livestock are often essential to environmental sustainability, human nutritional requirements and global food security.
- Increasing soil carbon levels are a key indicator of improved land management and soil health.

The type of agricultural production systems that we would hope to operate within fifty years will be moulded by research, investment, and government policy and funding decisions made today.

Introduction

I am the third generation of the Inwood family to farm on “Toulon” on the Central Tablelands in NSW Australia. We are primarily a sustainable (and regenerative), superfine wool-growing enterprise incorporating some cropping and first cross lamb production. Since returning to Toulon after completing agricultural studies I have developed a real appreciation of the skill and innovation exhibited the farming community both now and historically. The challenges presented to us in agriculture today are different but no more daunting than those experienced by our predecessors.

As a child my father observed my grandfather plough with the use of a horse and now in his seventies he still works on our farm where we use a solar-charged electric vehicle to sow crops. The sorts of changes he has experienced could not have been foreseen in his youth. The solutions to many of our challenges today will be met with equally unexpected solutions.

Our on-farm involvement with holistic management and natural resource management projects was a natural lead-in to the study topic of Sustainable and Regenerative Agriculture and the more narrow focus of “Farming in a world of finite resources”. We have been investigating and implementing zero till and novel regenerative crop sowing techniques as well as soil building management techniques such as rotational grazing with strategic long rest periods for several years now.

Undertaking a Nuffield Scholarship during 2011 on this subject was an opportunity to find out where the world was heading. Over forty flights later and with numerous visits to research establishments, practitioners, consultants, fellow Nuffield Scholars and digesting an equal number of articles and research papers I feel equipped to report on many of these issues and more importantly put into practice much of what I have learnt. Researchers at Universities and research facilities specialising in organic and conventional production systems and soil science were visited in the USA including the University of California, Davis, Washington State University, University of Idaho, University of Montana, Rocky Mountains Research Station and Rodale Institute in Pennsylvania.

Chinese institutions were visited, such as the South China Agricultural University and the National Experiment Station for Precision Agriculture. In the Philippines the many divisions of the International Rice Research Institute gave an incredible insight into plant breeding and

the importance of maintaining the International Rice Gene Bank with all its genetic diversity. In Europe highlights were FiBL in Switzerland who host some of the longest running organic production trails in the world whilst in the UK Rothamsted Research has the world's oldest continuously running cropping trials.



Figure 2: A sample of research institutions visited

A Nuffield Scholarship allows for study across many scientific disciplines, but still anchored to the potential practical application in industry. Investigating how we will transition our industry to begin to use resources more efficiently and still remain productive, sustainable (or even better, “regenerative”) whilst we address the issues of global food security has been a very interesting and challenging topic. This report aims to indicate where some of the answers will be found.

Objectives

The core questions this report seeks to investigate are;

- How do we farm in a world with finite resources?
- What resources will be limiting first?
- Where will the big advances come from which will increase nutrient efficiency?
- How will soil biology be part of the solution?

There is a plethora of research, statistics and advice about the consequences of population growth and the food production task ahead. This is all framed with the necessity for production to be sustainable. There is much less information about how these targeted production figures and environmental outcomes will be achieved and funded on the ground.

Soil is the core asset which most limits agricultural productivity. This report will focus on soil related sustainable and regenerative management and inputs.

Inputs

Phosphorus

Modern agriculture has a high reliance on phosphorus inputs almost exclusively obtained from mining. Phosphorus is essential in every living cell and there is no substitute. Its supply and cost could be one of the first limiting factors in increasing world food production. As such phosphorus is a good case study of measures required to extend and protect available supplies of other limited inputs. Estimates of world phosphorus reserves vary and peak phosphorus has been estimated to occur anywhere from decades to centuries from now. The argument is only about the date, not the fact that the reserves are finite and phosphorus will become more scarce and expensive.

The world's largest reserves of phosphate rock are located at Bou Craa in the desert of the Western Sahara (territory largely occupied and controlled by Morocco). Morocco has been described as the Saudi Arabia of phosphorus. These reserves are owned by the Office Cherifien des Phosphates, a Moroccan state agency, but in effect, owned by King Mohammed VI and his Alaouite dynasty, which has reigned in Morocco since the 17th century. Canadian fertiliser firm PotashCorp (PCS) is the largest purchaser of phosphate from the Western Sahara (PCS was subject to a takeover bid from BHP Billiton in 2010). This reserve has been recently upgraded from around six billion tons to fifty billion tons (U.S. Geological Survey, 2012). This significant revision of a present mining resource takes some of the pressure off immediate resource concerns for phosphorus, however over 75% of world reserves of phosphorus now reside with one owner in one geographic location. This creates its own set of problems with regard to the potential monopoly of supply and future regional instability. An estimated 200-300 years phosphorus supply at present usage could become 100-150 years supply if agriculture is required to double production by 2050.

As more marginal deposits are accessed the cost of phosphorus will increase. Locating mining areas close to major populations is already an issue due to both urban encroachment and environmental impact. There are only two options for continued supply of phosphorus into agricultural systems; mine it or recycle it. Phosphorus is not actually used or destroyed as part of agricultural production, it is however moved about geographically. With increasing acquisition costs the economics of recycling phosphorus from what are now considered waste

systems will improve. The recycling of biosolids back into agriculture could supply up to 25% of agriculture's phosphorus requirements globally (McGrath, 2011).

Increasing nutrient uptake efficiency will also be critical in both reducing the cost of fertiliser inputs and extending the longevity of present phosphorus resources. The nature of highly water-soluble phosphate fertilisers means that more than 70 percent of phosphorus applied is being locked up in the soil as plant unavailable compounds (McNeil, 2012). The CSIRO estimates that A\$10 billion worth of fertiliser is locked up in Australian soils. Raising the nutrient uptake efficiency of phosphorus in fertiliser from around 25 percent to 50 percent would double the life of available phosphorus resources worldwide.

Plants and soil biota are able to access less soluble phosphorus fertilisers and the locked up phosphorus in soils. Some plant roots release exudates that can solubilise some of the unavailable phosphorus bank. Plants form relationships with fungi and bacteria that also work on the mineral surface of the soil to release nutrients not available to plants. The potential for soil biology to access plant unavailable nutrients is claimed to be much greater than conventionally accepted (Jones C. , Carbon that counts, 2011).

Nitrogen

Nitrogen is one of the most abundant elements in the earth's atmosphere, however nitrogen fertiliser remains a resource-intensive product to manufacture. A heavy reliance on natural gas in the production of nitrogenous fertilisers has their price pegged to the cost of energy worldwide. The ability of bacteria to fix nitrogen in a symbiotic relationship with legumes is an established method of accessing nitrogen for plant growth. This can either be directly for the legume crop or as a crop phase to build nitrogen for a later crop. This will not be enough on its own to secure global crop needs and augmentation of nitrogen supplies using manure and fertilisers will be required (Goulding, Trewavas, & Giller, 2011). Research into soil biology such as free-living nitrogen-fixing bacteria is being conducted with varying results but a free-living nitrogen fixer is limited in its ability to provide nitrogen to plants as it is not linked symbiotically to a plant which will provide its limiting resources. Peer reviewed trial data is scarce however product manufacturer trials of nitrogen-fixing bacteria are promising with yield increases in wheat of around 5-15% with up to a 50% reduction in rates of nitrogenous fertiliser (Mapleton AgriBiotec Pty Ltd, 2006).

Long term sustainability of nitrogen supplies in fertilisers would require the development of a method other than the Haber-Bosch process which requires methane from natural gas. Other methods available are presently not as effective and some have huge energy (electrical power) requirements. Alternative manufacturing, formulation and delivery methods including encapsulation and slow release technology will assist in increasing the efficiency of nitrogen fertilisers. The use of biochar can also minimise the negative impact on the environment from nitrates and emissions of nitrous oxide and methane.

Biochar

Biochar has attracted increased scientific attention in recent times due to its potential to improve soil characteristics and function.

“Biochar is the product of thermal degradation of organic materials in the absence of air (pyrolysis), and is distinguished from charcoal by its use as a soil amendment”

(Lehmann.J..Joseph.S., 2009).

Charcoal is a naturally occurring soil component and exists due to natural fire events that have occurred over time. In many cases hype and claims for biochar ahead of scientific investigation have led to misconceptions about what biochar is and how it interacts with the soil. Biochar can be produced from waste biomass feedstocks and removes these materials from landfill, decomposition or disposal through ocean outfalls which then helps address and prevent the loss of finite resources from agricultural systems. The pyrolysis process stabilises the carbon component and as well as producing biochar, produces more than enough energy to run the process as well to generate excess power.

What are the potential benefits of biochar in agriculture? Studies show the greatest positive effects are in highly degraded, acidic or nutrient-depleted soils. Other than increases to plant biomass and hence crop yields, soil applications in some studies have been shown to:

- improve nutrient storage and soil cation exchange capacity.
- increase soil carbon content.
- increase the soil water holding capacity.
- increase soil pH.
- decrease aluminium toxicity.

- decrease soil tensile strength.
- change the microbiology of the soil.
- decrease greenhouse gases emissions from the soil (nitrous oxide and methane).
- improve soil conditions for earthworm populations.
- improve fertiliser use efficiency.

(Jenkins & Jenkinson, 2009)



Figure 3: Electron microscope image, biochar pore structure
(biocharproject.org)



Figure 4: Biochar - organic matter after pyrolysis
(ANZBRN)

Biochar is not fertiliser although, depending on the source feedstock, it may have some nutrient value. The altered carbon structure of the biochar makes it relatively inert. This is how it is able to remain as a stable component of the soil for hundreds to thousands of years. The practice of adding biochar to the soil to enhance the soils agricultural value has been undertaken for over two thousand years. Some of the earliest examples are the “Terra Preta” soils of the Amazon. Biochar can be an effective carrier for microbial applications if the biochar is soaked or “charged” with solution prior to application.

There is still much debate about exactly how biochar interacts with the soil to produce changes in soil characteristics. Some potential explanations are that the biochar acts as a safe haven for soil microbes and in some cases dramatically increases the available habitat for biota and even provides hiding places for smaller sized biology to prevent predation. The biochar is also capable of maintaining zones of aeration, absorbing soil water and increasing nutrient storage. In this way the biochar may act as a form of “lifeboat” for soil biota when soil conditions are unfavourable. The potential response rate when conditions improve would then be much faster benefiting the system as a whole. Plant root hairs and fungal mycelium

are also capable of entering the biochar particles and accessing nutrients. It is possible that biochar also acts as a “soil pantry” by capturing nutrients that might otherwise be leached from the system. There is also evidence that nitrous oxide (N₂O) and methane (CH₄) emissions from the soil are suppressed by biochar (Sohi, Lopez-Capel, Krull, & Bol, 2009).

Some early studies into the value of biochar as a soil additive suffered due to a lack of knowledge regarding the varying outcomes of the pyrolysis process or potential function of biochar in the soil. Poorly manufactured biochar can potentially be toxic to plants. For this reason a major effort has been made recently by the International Biochar Initiative to establish standard specifications for biochar. Agricultural input costs are always critical in deciding the extent and type of use on farm. Biochar is not yet available from full-scale pyrolysis plants and as such costs are high. Transport costs and availability of the feedstock will in many cases dictate the location of the plant to produce biochar. Intensive agriculture such as horticulture and vegetable production, in close proximity to a production plant, would appear to be the best situated industries to benefit from biochar as a soil input in the short term. There is potential for accessing carbon credits from the application of biochar through the sequestration of carbon and suppression of other greenhouse emissions. This could decrease the cost of biochar until large scale production with resultant economies of scale is a mainstream activity.

In essence biochar is a solution for waste management with benefits to soil properties and biology that are still being understood. Biochar is a renewable agricultural input when produced from sustainably sourced feedstock and lasts an extremely long time. All of the broader community benefits in waste management and CO₂ sequestration (carbon credits) as well as on-farm benefits need to be fully evaluated to provide a cost benefit analysis of biochar as a soil additive.

Biological Control Agents

The huge diversity of soil microorganisms and the various ways they interact with the soil and each other is providing a large resource base for the development of biological control agents. An example of research in this area is the California based Marrone Bio Innovations (MBI) which produces natural pest management products for the agricultural and water treatment markets. Their products are derived from natural strains of microorganisms which are isolated and tested for novel and effective pest management activity. The modes of action of the

isolated biopesticides are combined in the final formulation to avoid resistance to a particular active ingredient. MBI's biopesticides are able to be utilised in organic production systems. However conventional producers are the largest market for some products due to satisfaction with product performance and heightened safety profile with shorter withholding periods.

There are many advantages with biopesticides that have efficacy levels equal to those of chemical pesticides. MBI can develop products in approximately three years and at a cost of around \$3 million (US) in comparison to chemical pesticides that take in the order of \$180 million (US) and up to 10 years to develop (Cordova-Kreylos, 2011). Some examples of biological control agents on the market are REGALIA®, an advanced biofungicide that controls a broad spectrum of agronomically important fungal and bacterial diseases. GRANDEVO®, an advanced bioinsecticide for the control of a broad spectrum of chewing and sucking insects and mites. ZEQUANOX®, the US industry's only selective and environmentally compatible molluscicide for the control of invasive zebra and quagga mussels (*Dreissena* species).

Biopesticides do need regulatory approval but also come with reduced risks as they are derived from biological, naturally derived chemistry.

Biopesticides or natural pesticides have the following features:

- Alternative modes of action to traditional chemical products, helping to stop the building of resistance (extending the life of traditional chemicals) and making them critical part of IPM programs.
- Minimal impact on humans and the environment.
- Generally less time to be registered than chemical products.
- Generally exempt from tolerances (no or low with-holding periods e.g. REGALIA® has a zero day pre-harvest interval).
- High levels of worker safety and short re-entry intervals after application.
- Naturally derived products are not alien to soil biota and are more harmonious with natural soil processes, while achieving the desired outcomes.

As more information is obtained about the effects specific chemicals have, allowable residue limits are generally only ever lowered or chemicals removed from use altogether. The argument is not for the removal of crop-care products but a debate about how these products

can be refined and developed so that they work in harmony with the biological system they interact with. Companies developing agricultural products are very aware of this need and in fairness many are moving in directions which have a more biological focus. This does not come without its own share of issues as the GM debate has highlighted. Plants genetically engineered to reduce reliance on chemical and fertiliser inputs have strong opposition from some quarters due to claimed unknowns in product safety and the potential for the same plants to become chemical-resistant weeds.

Biological control agents with little or no general environmental toxicity are a key tool and part of the solution to improving productivity, whilst transitioning from and reducing dependence on synthetic agricultural inputs. Effective “no risk” products are the Holy Grail for crop protection companies and in everyone’s best interest.

Biological Applications

It often takes several years to get a system up to speed biologically after changing the farming system. There are ways to potentially hasten this process including biological preparations to introduce or feed microorganisms and introducing organic matter into the system as compost, manures or biosolids. The main goal should be to start by encouraging multi-species plant growth with a view to having complete ground cover and a layer of protective organic matter on the soil surface. This also has the result of building soil organic matter and creating a habitat for soil organisms. The variety and diversity of plant species can have a large influence on the soil microorganisms present (Clapperton, 2011) . Systems that incorporate monocultures have a much reduced ability to foster soil biological diversity and the resultant plant/biota synergies that access mineral nutrients and build soil organic matter. Seed treatments are available to introduce improved soil organisms into a degraded system or system lacking in soil biological diversity through extensive cropping as a monoculture. There is little peer-reviewed literature on trials of biological applications and their effects on plant yield. Some preparations such as compost teas contain a variety of microbes at varying concentrations that can potentially interact. This could lead to varying combinations of microbes having the same, better, or worse effects than those of isolated examples. The potential for variability is enormous, and this leads to inconclusive results during testing. (Chalker-Scott, 2009)

Soil testing for deficiencies and indicators of soil health is becoming more available and extremely valuable in the hands of competent advisors who are looking at maximising plant

and soil biology potential. Standard tests can be inadequate when plant available nutrients are listed and all others quoted as “totals”. This may ignore the portion that becomes available with fully functioning soil biology. As is always the case, the nature and intensity of the production system will dictate the feasibility of investing in measures to build the system faster than letting nature take its own course.

Stretching our resources

Recycling

Historically in natural systems and village-based agriculture, products were grown and consumed locally with by-products and waste essentially returned to the local system. The concentration of consumption in highly urbanised areas has created a culture of “use and dispose” where the once valuable waste resources are now mostly relegated to land fill or ocean outfalls at considerable environmental cost. In Australia food waste makes up 35 percent of municipal waste and 21 percent of commercial and industrial waste (Department of the Environment, 2010).

“Almost one-third of food produced for human consumption—approximately 1.3 billion tonnes per year, which could feed the total global population of 7 billion—is either lost or wasted.”

(Thomas, An Overview of Global Food Losses and Waste, 2011)

Agricultural industries are required to reduce their environmental impact at all levels of production with a view to enhanced sustainability. It is incumbent on society as a whole to not squander the nutrients sent to them by the agricultural industries as food and fibre when the recycling of these nutrients is central to their own long term sustainability. This should be a partnership in sustainability and the costs should not be borne solely by the producer of agricultural products.

There are issues with the use of human waste or biosolids in agriculture. Heavy metal contaminants from industry as well as pathogens, human hormone products and chemotherapy drugs can all be found in some biosolids. Processing of the biosolids with lime and biological agents as well as composting and pyrolysis are all options and some product is currently utilised as fertiliser on farm. With present methods the cost of removing heavy metals is

prohibitive but application at median contaminant levels would be possible for 50 to 100 years at eight tonne/ha before toxic concentrations of heavy metals would become an issue (McGrath, 2011).

In areas of China with heavy metal contamination of agricultural land, work is being undertaken on plants that are specifically bred to not take up heavy metals, thereby allowing them to grow a harvestable product without the accumulated contaminants. The reverse concept is also being researched where plants are used for phytoremediation of contaminated land. These plants are bred to take up the soil contaminants which are then harvested and removed (Wang, 2011). This land is effectively not available for agricultural production for the period of remediation and the contaminated harvested material must be treated separately.

There has been debate about organic cropping systems fertilised with manure being able to yield as well as those fertilised with chemical fertiliser. Yields for manure fertilised crops at 35 t/ha have been able to match conventional crops with moderate fertiliser applications. The real issue is where the manure would come from if this form of fertilising alone was adopted not to mention the relative costs and potential levels of salting at these input levels. In order to provide enough manure for cropping programs in the UK and USA, the UK would need to increase their cattle numbers 3.5-fold and the USA seven-fold. This would mean a rise in US cattle numbers from 100 million to 700 million (Goulding, Trewavas, & Giller, 2011). Obviously land and feed limitations make this impossible. It will be a mix of technology, recycling, judicious use of available and enhanced inputs, along with improved nutrient utilisation, that will form the basis for sustainable inputs into cropping systems.

Micronising

One micron is a millionth of a metre. Micronising is the grinding of a material into a fine dust to increase its availability to plants and associated soil biology. Substances are ground to a size of five microns or less and can also be “chelated” which drastically increases the absorption rate (for some nutrients) by plants and animals. Chelation occurs when certain large molecules form multiple bonds with a micronutrient, protecting it from reacting with other elements in the nutrient solution and increasing its availability to the plant. There are both synthetic and natural chelating agents. In some cases chemicals can act as chelating agents and bind mineral ions in the soil, making the mineral unavailable to plants. By increasing nutrient efficiency, micronising and chelation can prolong the lifespan of finite agricultural resources.

Nanotechnology

One nanometre is one billionth of a metre. Nanoparticles are defined as being less than 100nm (nanometres) in size. It is also accepted that by definition nanoparticles exhibit novel properties that differentiate them from the bulk material. The potential of nanoparticles is set to revolutionise every facet of the way we live. They will have effects in agriculture but public perceptions of safety will dictate their use in food industries. Already many organic certification bodies around the world have banned manufactured nanoparticles from lists of approved inputs. The use of nanotechnology in creating unique materials for engineering and structural applications may not have the same perceived risks as those directly involved in the human food chain. There are two types of nanoparticles that are contentious. Firstly ultra fine particles and secondly engineered “molecular engines” that could potentially power nanobots for specific roles medicine and nature. The fact that nanobots could be self-replicating raises fears that they could “escape” the confines of their role and multiply uncontrollably.

A majority of biological processes occur at the nanoscale. Nanoparticles may react differently to the same substance at larger scale. Nano materials, even when made of inert elements like gold, become highly active at nanometre dimensions. This has led to a similar debate regarding these particles when used as agricultural inputs as that surrounding GMO’s i.e. there is no way of knowing the long term effects of nanoparticles on human health once in the food chain. Toxicity of the bulk material is not an indicator as to the toxicity of the same material at nanoscale. This could potentially mean new regimes of testing for the same substance at different sizes. The conversion of granules of agricultural inputs (N,P,K etc.) into nanoparticles would increase surface area contact and potential reactivity but also the uncertainty of how the particle would react. It might for instance become highly toxic to both plants and humans.

Plant breeding

Modern plant breeding techniques are producing highly productive varieties but the niche into which they will perform adequately is becoming smaller. A high level of precision is required to allow for weed control and moisture retention pre-sowing, narrow windows for planting, chemical seed treatments, seed depth at sowing, soil tilth, fertiliser type, depth at which fertiliser is banded, nitrogen applied, post emergent herbicides, reapplication of fertiliser/nitrogen, reapplication of selective herbicides, insecticides, fungicides and in irrigated crops

the monitoring and control of soil water levels. Proponents of biological and organic production systems claim that the need for most of the processes above can be reduced considerably or eliminated if management of soil conditions and biology are the central focus. Plant breeding should occur keeping the interaction with soil biology in mind. Solutions can also be found in the “rediscovery” and use of old plant varieties with advantages in these areas and the possible incorporation of their genes into new varieties. The development of the Sub1 rice varieties at the International Rice Research Institute is an example of a gene from one variety of rice being introduced to improve outcomes in new locally adapted rice varieties. The flood tolerant Sub1 or “scuba” rice is able to survive underwater for up to two weeks. This is a huge advantage in flood prone areas and highlights the importance of understanding and conserving the genetic diversity of plant species. (IRRI, 2012)

A criticism of modern agriculture is that, as well as developing systems that ignore the plant and soil biology relationship, we are breeding plants to produce in spite of the lack of soil biota. These varieties might have a much reduced ability to form symbiotic relationships within the soil biology. Empirical evidence from farmers who No Kill Crop and Pasture Crop indicates that the older crop varieties are more vigorous, resilient and able to compete in a multi species system. This observation would seem reasonable, as prior to the advent of post emergent herbicides, successful crop varieties needed to compete with any weeds present after sowing.

Genetically Modified Organisms

It is beyond the scope of this report to go into any detail regarding the potential and problems associated with GM technology. There are numerous reports and papers from both sides of the debate. Opinions canvassed during the study of this topic ranged from support to opposition and some with qualified support where the transfer of genes from like organisms i.e. plant to plant was acceptable and potentially less risky. The arguments for GM technology have been based on sustainability, food nutrition and food security issues. Arguments against GM have included those based on negative effects on human health, environmental impact, resistance issues, cross contamination of non-GM crops, ownership of genetic material, the potential narrowing of genetic diversity of the world’s main food crops and sustainability, food nutrition and food security issues. The debate in Europe over transgenic crop technology

indicates that “indirect benefits,” such as herbicide or insecticide tolerance, are not enough to win public acceptance.

Research work has and will continue to be conducted on GM soil organisms. Off target consequences are again a major concern in this area of the GM debate. In one example, genetically modified strains of *Penicillium rugulosum* were tested for their maize root colonisation and phosphate solubilizing activity. Both wild and GM strains were able to increase dry matter yields however the inoculation of the GM strain led to a significant decrease of the indigenous microbiota, as well as increased growth and P uptake by plants fertilized with single super phosphate (Reyes, Bernie, & Antoun, 2002). In another experiment *Klebsiella planticola*, a common soil bacterium, was genetically engineered by a German research institute to make ethanol for industrial purposes. The resultant sludge by-product was to be returned to agricultural fields as a soil additive. Further testing by another laboratory found the GM bacteria’s enhanced ability to produce alcohol made it potentially pathogenic to all plants in the field, if it were able to survive under field conditions (Nottingham, 2002).

The development of genetically modified soil micro-organisms is no less controversial than that of GM plants or animals. Care is needed in research and testing of organisms whose impact can be much greater than that of the selected genetic trait. Soil organisms do not respect fence lines and are not readily identified at the surface.

Living Soil

Soil biology is the study of biological processes occurring in soils. Many of these processes result from the activities of macro and microscopic flora and fauna. The size of soil organisms range from those which are visible to the naked eye (earthworms, insects and mites) to the major components which are microscopic. A teaspoon of fertile soil can contain hundreds of millions to billions of microbes. Estimates have been made which show over 15,000 species of soil biota per gram of soil (DPI, Vic, 2011). Most of these species have yet to be classified and their function in the soil understood. This huge diversity of species help to process, move and decompose organic matter, access and make available nutrients from mineral surfaces. They also help control and regulate aeration, water and nutrient cycles. Increased soil microbial activity also aids in suppression of some soil-borne diseases (Roget, 2006).

Plant and Soil Biology Interactions

The interaction between plants and the soil biota is the most complex and interesting area of sustainable and regenerative agriculture. The relationships and interdependencies occurring beneath the soil surface are still only just being understood.

“Plants do not exist as single organisms, but are more accurately viewed as a consortium consisting of a primary producer and many species of associated microbes.”

(Drinkwater & Snapp, 1997)

The soil ecosystem can be described as a digestive system for plants. Symbiotic fungal hyphae can exponentially increase a plant’s access to the soil and actively stimulate synthesis of amino acids, proteins, and other plant nutritive factors in addition to assimilation of water and nutrients, especially phosphorus (Hood, 1993). This relationship is brokered by the plant trading exudates (sugars, carbohydrates, proteins and oils) in exchange for a large variety of nutrients in plant-available form. In conventional agriculture the potential benefits arising from optimising these symbiotic relationships have for the most part been ignored, other than the use of nitrogen-fixing bacteria in legumes. More recently biological products have been researched and marketed with single applications or broader soil benefits. The isolation of strains of microbes for a specific purpose has been difficult and had variable documented success, other than for *Rhizobia spp.* and to a lesser extent mycorrhizal fungi (Richardson & Simpson, 2011). This is a new area of research and trial results are available from product manufacturers that are encouraging. Again there is a lack of peer reviewed data regarding trials of biological products. Understanding the role of microbes in sustainable agriculture and biotechnology covers a research area with enormous untapped potential productivity benefits.

Agricultural Interactions with Soil

Modern agricultural practice can be very antagonistic towards the optimum function of the soil ecosystem. Disrupt the “digestive system” and complications are inevitable. The degree of disruption to the soil ecosystem is highly dependent on the type of production system being used. An extreme of example of such disturbance is continuous full cultivation along with the full use of chemical fertilisers and chemical weed and pest control. The extreme example of the use of chemicals is in the practice of soil fumigation and sterilisation, such as is used in tobacco growing. The systems that have the least effect minimise soil disturbance and the use

of chemical inputs. Most high production agriculture lies somewhere between the two extremes of disturbance.

Retaining ground cover to protect the soil and the building of soil organic matter (and hence soil carbon levels) should be central aims in a regenerative agricultural system. The benefits of building soil carbon levels are many and help address many pressing issues in modern agriculture such as soil erosion, nutrient retention, nutrient uptake efficiency, water quality, water cycling, carbon sequestration and sustainability. The health of the soil, plants, animals and ultimately the quality of farm products will also benefit. Methods to build soil carbon involve the addition of organic matter such as green manure crops, cover crops, composts, biochar, and strategic grazing and cropping management involving retention and building of groundcover as growing plants and cropping residues. The system's biological potential will be maximised if soil nutrition is balanced through the judicious addition of deficient nutrients. Encouraging the soil's biological activity in conjunction with existing carbon sources from plants, contributes to soil organic matter in both the active pool of soil carbon and more stable forms (e.g. glomalin and humates). The rotation of cropping species and a diversity of plant species in pastures will, in turn, encourage greater diversity in soil biota and reduce the incidence of soil pathogens.

The value of soil carbon can explain approximately 60% of the variation in soil structure (measured as water stable aggregates):

- When soil carbon levels are below 2%, small increases in the carbon level can result in substantial improvements in soil structure (measured as water stable aggregates).
- Higher organic matter systems are likely to result in equal or better yields

(Fisher, Aumann, O'Halloran, Kirkby, Lacy, & Skjemstad, 2007).

The consequences of full cultivation vary depending on soil type. Reduced tillage plots at FiBL in Switzerland that received full cultivation and power harrowing but at a "reduced depth", still recorded increasing levels of soil organic matter, microbial biomass and microbial activity (Berner, 2011).

Intensive cultivation on more fragile soils can lead to decreased soil organic carbon levels and reduced aggregate stability. Results from the Highfield experiment at Rothamsted Research in the UK highlight the possible effects of cultivation on soil structure in a particular soil type.



Figure 5: Importance of soil organic carbon on aggregate stability

(Chris Watts, Rothamsted Research)

The permanent fallow treatment in the above picture has been ploughed several times a year to prevent growth of any plants since 1959. The permanent arable treatment was a three year ley and three year arable cropping rotation. The permanent grass is pasture that has been in place for at least 200 years.

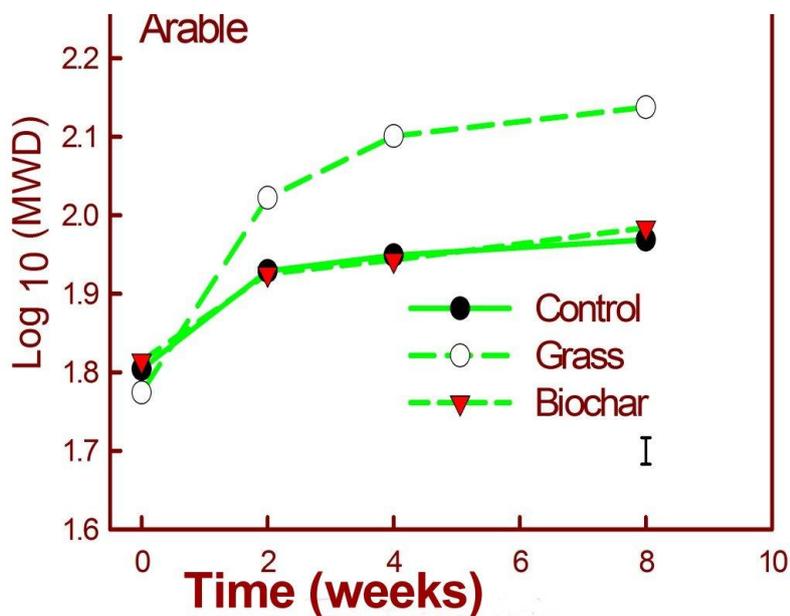


Figure 6: The effects on aggregation when organic materials are added to degraded (Highfield) soil. Increasing Mean Weight Diameter (MWD), which measures improved soil aggregate size.

(Chris Watts, Rothamsted Research)

In figure 6 the soils were mixed with grass, biochar or no amendment. The particle size distribution was measured on arable soils, which had been slaked following incubation at -5 kPa for up to 8 weeks. The treatments with added grass showed increased aggregation relative to the control. The treatments with biochar did not. This result with biochar would indicate that the addition of biochar alone with a possible lack of biological activity is akin to the addition only of a stable particle. The conclusion was that soil aggregation/stabilisation is biologically mediated. The addition of grass has stimulated the soil fungi which help to form aggregates in the soil by enmeshing soil particles with their hyphae and forming cross-links between soil particles, possibly in conjunction with other microorganisms.

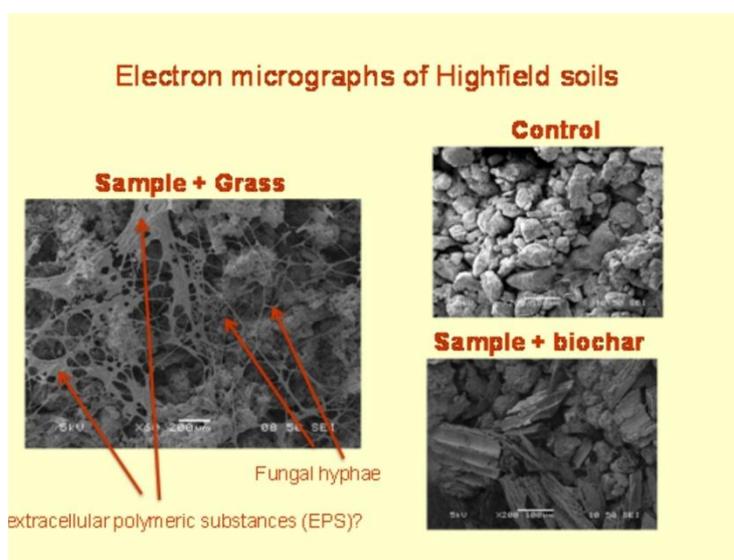


Figure 7: Electron micrographs of Highfield soils

(Chris Watts, Rothamsted Research)

As well as improving soil structure and water infiltration rates, for every 1% increase in the level of soil organic carbon an extra 144,000 litres of water is stored in the soil per hectare. in addition to the original water-holding capacity of the soil itself.

Factors which reduce soil organic carbon levels and therefore reduce the ability of soil to store water, include

- i) Loss of perennial groundcover
- ii) Intensive cultivation
- iii) Bare fallows

iiiv) Stubble burning and pasture burning

v) Continuous over-grazing.

(Jones C. , Soil Carbon and Water, 2006)

Pulses of disturbance are very beneficial to living systems but need to have planned outcomes. The least intrusive agricultural systems are holistic rotational grazing operations that utilise long rest periods (after pulses of grazing disturbance), are low input and allow for regeneration of plants in a diverse pasture-based ecological system that often includes, utilises and profits from native vegetation. In Australia native plants and soil biology that have developed and succeeded over millions of years in a soil type, topography and climatic environment must be efficient in their niche.

Modern agriculture requires increasing productivity to provide for the ever-increasing needs of global population growth. Most high-production agricultural systems are high input systems. The key to sustainable and regenerative agriculture will be to use inputs that are less disruptive to soil ecology and allow the harnessing of soil biology that enhances nutrient uptake efficiency in plants, soil conditions and the nutritional value of the end product. In the short term this will be achieved by a mix of inputs and technology that, when further developed, will ensure that production systems are in harmony with soil ecology.

Arbuscular mycorrhizal fungi

An example of a beneficial symbiotic relationship is the relationship mycorrhizal fungi forms with some plants. Arbuscular mycorrhizal (AM) fungi colonise the root of the host plant and enhance its access to surrounding nutrients and water. This is done (sometimes in conjunction with soil bacteria interactions) by providing greater access to soil area as well as being more efficient at sourcing and providing normally insoluble or plant unavailable nutrients, in a plant available form, in exchange for organic carbon from the plant.

The propensity for the plant to form this relationship to acquire phosphorus depends on the levels of plant available or water soluble phosphorus at the time. The plant will not actively seek the relationship if it has an excess of water soluble phosphorus fertiliser. Most favourable conditions for colonisation occur as part of a phosphorus starvation response in the plant. The lack of these conditions will also compromise the plants ability to access other essential nutrients. Therefore over-fertilising or the type of fertiliser provided is critical in management

decisions to promote the plant AM fungi relationship. Also tillage of the soil and some herbicide applications are detrimental to mycorrhizal fungi levels.

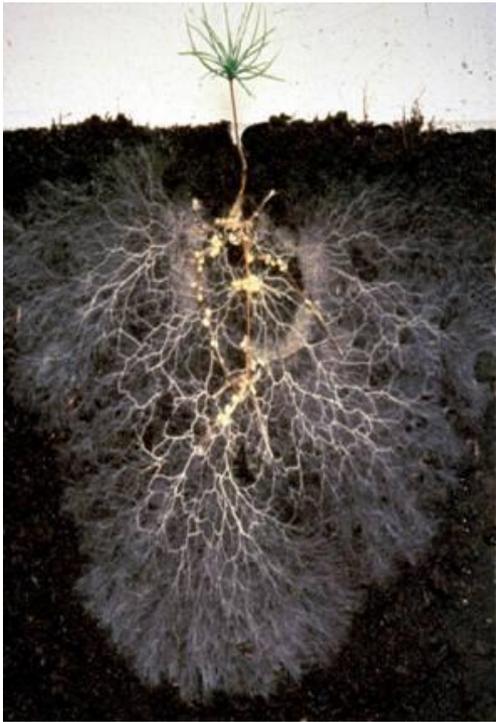


Figure 8: Plant roots colonised with Mycorrhizal Fungi
(AberdeenMycorrhizaResearchGroup)

The presence of arbuscular mycorrhizal fungi also improves soil properties or actively builds soil, an essential aim of regenerative agriculture.

“The absorptive area of mycorrhizal hyphae is approximately 10 times more efficient than that of root hairs and about 100 times more efficient than that of roots.....
Plants colonised by mycorrhizal fungi can grow 10-20% faster than non-colonised plants, even though they are ‘giving away’ up to 40-50% of their photosynthate to support mycorrhizal networks”
(Jones C. , Mycorrhizal fungi - powerhouse of the soil, 2009)

Glomalin is a sticky protein exuded from fungal hyphae that is effectively a soil glue. Glomalin is thought to account for 27 percent of the carbon in the soil and carbon dating has confirmed it lasts for seven to 42 years, depending on conditions. When glomalin combines with iron or other heavy metals it can last in the soil for 100 years (Nichols, 2008). Some plants such as some brassicas, which exude soil fumigants from their roots and will reduce the presence of the fungi in the soil. It is important to understand that when cropping these plants

that glomalin production will cease until mycorrhizal communities are re-established. There are however proven benefits in incorporating brassicas in crop rotations and cover crops such as improved soil structure and health, added nutrients as well as potential suppressing effects on specific weeds. (Frankenfield, 2012)

Managing biology

Plants influencing soil biology

Different plants have different root architecture and foster different components of the soil's biology. The use of plants to manipulate the soil biota is logical and natural. Soil biota varies depending on soil conditions. Plants can create varying soil conditions through their interaction with the soil and soil surface. This will occur due to different exudates from the plant and the actual root architecture. Soil microorganisms are influenced by the type of plant species present. These interactions can be manipulated through management. Some plants favour bacteria, while some favour fungi (Clapperton, 2011). A mix of plant species can foster a broader diversity in the soil biota than the sum of the individual plant species might predict. Species mixes used can be designed to maximise the potential of the soil biota as well as target specific nutrients that are present but not available. (Clapperton, 2011)

According to Jill Clapperton, principle scientist and President of Rhizoterra Inc., trial results in Canada and the US using only rotations of crop and cover-crop mixes, and without additional fertiliser, are yielding results similar to conventionally fertilised crops. The previous fertiliser history or innate soil fertility might dictate how long this process can continue. Interestingly, if even one plant species is dropped from the mix the yield decreases (Clapperton, 2011). Jill Clapperton is working with two farmers in Saskatchewan who are interested in variable seeding with plants to accumulate or release specific elements. To this end they are developing a variable species seed drill that will operate in a similar way to variable rate fertiliser technology. Instead of varying the fertiliser rate according to yield maps the drill will vary the species mix sown according to soil test results.

Cover cropping

Steve Groff from Lancaster County, Pennsylvania pioneered the “Permanent Cover Cropping System”. This system focuses on maintaining a permanent cover of cover crops and crop residues. Up to 21 different species are sown in the cover crops and in Steve Groff’s experience the more species the better the results. He is constantly looking for more species to incorporate into the mixes to fine-tune the interaction with the soil biota. The mix sown can be designed to suit the requirements of the following crop.



Figure 9: Steve Groff with a cover crop of 21 species

Cover crops are terminated prior to the sowing of the next crop either by crimp rolling, cold weather (frosts), or chemical application. In all cases the cover crop residue is left in place to protect the soil and the next crop which is sown directly into the residue.

Benefits Steve Groff has observed and recorded since 1982 are;

- Organic matter level has increased from 2.7 % to 5%.
- Soil erosion has been virtually eliminated (on 3% to 17% slopes).
- Weed problems have been reduced, leading to herbicide costs of one third of the costs paid by non-cover crop using farmers.



Figure 10: Steve Groff describes "Tillage Radish" as nitrogen storage containers



Figure 11 Steve Groff terminating a cover crop using a crimp roller

A list of some commonly used species in cover crops and the expected benefits;

Red Clover - fixes N, has a deep taproot.

Oats - excellent scavenger of nutrients, especially N.

Forage Radish - nutrient scavenger (N, P, Ca).

Cereal Rye - excellent scavenger of nutrients, especially N.

Hairy Vetch - fixes N

There are probably many further varieties of plants with unknown beneficial interactions with the soil and soil biota. The diversity of crop species used is an important resource for future research.

“Of the four percent of the 250,000 to 300,000 known edible plant species, only 150 to 200 are used by humans. Only three - rice, maize and wheat - contribute nearly 60 percent of calories and proteins obtained by humans from plants.”

(UN FAO, 2004)

No Kill Cropping

The No Kill Cropping method was developed by Bruce Maynard from “Willydah”, Narromine NSW. It is a simple concept but as a sowing technique it achieves the goal of increased biodiversity in a complimentary relationship with the existing soil and plant ecology. No Kill Cropping sows directly into the pasture or grassland with zero disturbance, no fallow period and uses livestock as nutrient recyclers. There is potential for grazing prior to sowing, during growth and immediately after harvest.

There are five Principles:

1. Sowing is done dry.
2. Coulter type implements are used (no tynes).
3. No herbicide or pesticides.
4. No fertiliser is used.
5. Good grazing management is essential. (Maynard, 2011)



Figure 12: No kill cropped oats sown in between salt bush alley ways

(nokillcropping.com)

No Kill Cropping has the least effect on existing ecology and is the cheapest cropping option available. Harvestable grain yields are not expected every year and are normally lower than conventional cropping methods. It is however an opportunity cropping method performed in association with rotational grazing. The method is undertaken in harmony with valuable grass and pasture ecology that would have to be removed for traditional monoculture cropping. No herbicides and pesticides are used to eliminate the possibility of damage to existing plant and soil biology. No fertiliser is used and by not having costs up front the return on capital is high whilst ecologically no simplification of the grassland occurs. A failed crop has a much reduced economic impact on the enterprise. Grain yields from this method will be intermittent and variable but should be seen as “bonus” grain production in addition to a grazing enterprise that can also utilise the grazing of crop and crop residues.

Inputs in this system are seed (and requirements for dispersal), animal impact and time. As harvestable yields are achieved infrequently the removal of nutrients is very low but the interaction and pulse of cropping disturbance stimulates the existing plant and soil ecology. Proponents claim that the natural regenerative processes in the soil utilising soil biota to unlock, recycle and bring new nutrients into play from the soil / mineral surface provides enough replenishment of nutrients required to sustain this system. No kill cropping mimics natural systems that have produced vegetation and been periodically harvested by animals for millions of years without human inputs. Included in the No Kill system on “Willydah” are a diversity of deep rooted tree and edible shrub plantings that raise the access to nutrients beyond a conventional cropping system. This system is being measured, experimented with,

modified and adjusted to fine tune results according to season, improved technology and availability of novel cropping species.

“Growing crops always involves the creation of artificial conditions and the loss of the natural balances and inherent stability of the original biological community.”

Alan Savory “Holistic Management” (1999)

“This statement is correct for every cropping system *except* No Kill. That is why No Kill is such a huge breakthrough- and break from the past.”

Bruce Maynard, Inventor “No Kill Cropping” technique

Pasture Cropping

Pasture Cropping allows for the manipulation of existing vegetation sometimes with herbicides to aid crop establishment and the use of fertiliser although at reduced rates. Yields can be as high as 80 to 90 percent of a conventional crop (Smith, 2010) but the extra value in the grazing component needs to be factored in as well. This grazing potential, as well as lower costs, can see net profits from Pasture Cropping higher than conventional cropping. Col Seis from “Winona”, Gulgong, (co-inventor of pasture cropping) states that “getting the soil ecology right” is essential prior to cutting back on fertiliser rates. This would indicate that enhancing the soil biology is fundamental to increasing the nutrient uptake efficiency and natural mineral cycling.

Changes since 1980 under the pasture cropping system have included:

- A reduction in fertiliser use. Col uses either no fertiliser or rates only 30 percent of conventional cropping rates (a saving of \$64,000 annually on 2010 prices).
- Soil organic carbon levels have lifted from 32 t/ha to 57 t/ha.
- Soil water holding capacity has lifted from 128,000 L/ha to 240,000 L/ha.
- Soil phosphorus and calcium levels (plant available), have lifted and in the case of calcium more than doubled (Cawood, 2010) (Jones C. , Carbon that counts, 2011).



Figure 13: Pasture Cropped Oats with perennial grass ecology still in place

(winona.net.au)

Conventional Cropping

Huge advances have been made in crop sowing technology in recent decades that have improved environmental outcomes and the sustainability of agricultural production. Conservation farming techniques, minimum and zero till, GPS guidance systems and controlled traffic methods have been developed, which together drastically cut soil disturbance, fuel usage and reduce compaction. In addition weed-seeking technology can reduce chemical usage by over 90 percent. Yield monitoring capabilities can map paddock fertility and direct fertiliser application at sowing can vary application rates according to fertility status. The ready adoption of these techniques indicates the desire and acceptance these new technologies, some of which are costly.

As the cost of agricultural inputs and food increases due to limited supply, newer alternative technologies and methods will become more viable in the marketplace and be adopted by the wider industry. Fertiliser inputs and fossil fuel supplies are tied to each other and are forecast to inevitably increase in price. Biofuels are a renewable source of energy for the agricultural sector but will attract criticism in the future whilst ever the practice drives up food prices for those crops and displaces potential land area from production of food products. Electric vehicles are feasible but better range via improved battery technology and faster charging are

needed. Options to charge electric vehicles using on farm wind solar or hydroelectric generation will provide tractors and vehicles with cheap, clean renewable energy.



Figure 14: 200hp solar charged electric vehicle performing No Kill Cropping (engagingnature.com, 2010)

Enhanced management of the plant and soil biology interaction and inputs such as new species of soil microbes, biopesticides, biochar, and recycled biosolids will become a financial, environmental and sustainability imperative. If these products and production systems can “deliver the goods”, in conjunction with the best of current cropping practice, they will form part of the ongoing adoption process in agriculture. Techniques that mimic and act in harmony with natural systems will always be less contentious than those that lead to greater long term unknowns such as future off target effects from GMO’s and chemical residues. The huge potential genetic diversity of plant species historically used in agriculture could still hold some of the keys to improving human nutrition, crop productivity and plant and soil relationships.

Since the 1900s, some 75 percent of plant genetic diversity has been lost as farmers worldwide have left their multiple local varieties and landraces for genetically uniform, high-yielding varieties.

(UN FAO, 2004)

Grazing management

The presence of grazing livestock in ecosystems is not just desirable but essential. In the push for more sustainable and regenerative agricultural systems, animal food production will be required not just for the protein contribution to food supplies but for ecosystem services to maintain a healthy naturally operating environment. Plant growth and regeneration cycles are best served by periodic grazing that enhances the building of soil organic matter and nutrient cycling (Soil Carbon Research Pty Limited, 2012). With the influence of previous worldwide agricultural practices having left some soils depleted and exposed to risk of loss through erosion and the forecast increases needed in food production, there is a great need on these soils for regenerative agricultural practices to rebuild their productive capacity.

Animals provide some 30 percent of human requirements for food and agriculture and 12 percent of the world's population live almost entirely on products from ruminants.

(UN FAO, 2004)

There is debate about the merits of intensive grain feeding and finishing of livestock and poultry on several levels, but there should be no argument as to the real need for animal production systems in productive areas of the world which are not suitable for cropping activities. Blanket objections to utilising animal protein ignore the basic fundamentals of a working and sustainable environment. Animals are an integral part of modern agricultural systems. If the system is operated in a holistic manner and focuses on soil and plant growth as the basis of production then animals become a powerful tool to manipulate plant growth, harvest and process excess vegetative material and aid in the spread of nutrients. Ruminants in particular are able to graze and digest vegetation and parts of crops which cannot be digested by humans. They are therefore an essential part utilising and recycling food production resources. Holistic rotational grazing systems of many types exist and perform these tasks successfully. They also do this whilst producing a surplus of food and fibre. In the natural world, breeding animals increase in number and if not controlled will increase past the level of a sensible carrying capacity. Harvesting this environmentally essential production of animal protein enhances both human nutritional outcomes and global food security.

Funding Sustainability

The value of food and the true cost of production of food need to be communicated to consumers as more than an issue of price per weight. Increasing food quality and nutritional

value should be the goal for first-world governments in addressing the rise in human health issues attributed to poor nutrition, poor eating habits and chronic dietary deficiencies. Increased crop yields from fertiliser and high production agriculture have helped feed the world, but declining nutritional value of modern food (Davis, 2004), contributed to by modern food processing techniques and the western diet has led to a host of human health disorders such as diabetes and obesity. This tends to go hand in hand with “progressive malnutrition”, a long-term deficiency in the complete spectrum of vital nutrients that support sustained good health. If the nutritional value of food was valued highly enough by the public the financial incentive for its production would increase. Product differentiation and taxes on products of high cost to health and health budgets could fund public awareness campaigns.

| Mineral | Average % Change |
|------------|------------------|
| Calcium | -29.82 |
| Iron | -32.00 |
| Magnesium | -21.08 |
| Phosphorus | -11.09 |
| Potassium | -6.48 |

† Fruits and vegetables measured: oranges, apples, bananas, carrots, potatoes, corn, tomatoes, celery, romaine lettuce, broccoli, iceberg lettuce, collard greens, and chard

(Bergner, 1997)

Food pricing as a percentage of income in the developed world is historically low and along with worldwide trends food pricing has decreased from being around almost half of income in the early 1900’s to around 10 to 15 percent today (Kerr, 2008). This is due to falling real prices paid to the farmer, resulting from increased supply, which in turn results from increased productivity. Despite recent increases in food prices this doesn’t translate to the farm gate price due to the market dominance and predatory purchasing of major food retailers and consolidation in the processing and export sector. There is a very real argument that returns on farm produce are not sufficient to fund the environmental and sustainability expectations and demands placed on primary producers by the community and government.

Discussions were held in Brussels with representatives from the European Commission responsible for Agriculture and Rural Development during study for this report. The reform of the European Union’s Common Agricultural Policy (CAP) will require that the significant

subsidies provided to European farmers are increasingly linked to environmental and sustainability outcomes “Greening the CAP” (Jones G. , 2011). Australian farmers are custodians of larger farms on average than any in any other country. (Eastwood, Lipton, & Al, 2004) The Australian landscape is generally older and more fragile than other continents and Australian land managers conduct their operations including environmental maintenance without the benefit of direct subsidies and payments, access to heavily subsidised crop insurance schemes or the low cost base of developing countries. Most Australian environmental funding operates voluntarily on a cost share basis with the farmer. This still potentially requires a financial, time and land area contribution by the farmer all of which can be limited depending on circumstances, leading to the oft-quoted saying that *'it's hard to be green when you are in the red'*.

Australia does not charge GST on food products. The forgone basic food GST revenue and possible increases in GST rate are being suggested as a method of funding all manner of tax breaks and program spending by various interest groups. There should be a moral imperative that *if* introduced, the basic food GST component be applied to the future sustainability of agricultural industries. The potential revenue to be raised from including the GST on basic food is in excess of six billion Australian dollars annually (Wright, 2011), a figure which is more than capable of providing compensation to low income earning consumers as well as providing a meaningful ongoing investment into the future sustainability of Australian agricultural production.

An investment of around 40 billion Australian dollars is already being made in the National Broadband Network to secure Australia's high tech communications future. Securing the perpetual sustainability of agricultural industries should similarly be a national priority.

Australia is, has historically been and will always be a food and fibre producing country with large tracts of land reliant on sustainable agricultural management. This will remain the case long after mining resources have been depleted.

There are areas of scientific research and agricultural practice that are effectively “on the outer” or stigmatised, sometimes due to the assumptions made by practitioners and sometimes because the science is lagging the practice on farm. This is an argument for more “bottom-up” practical research where potentially beneficial practice already being undertaken on farm can be collaboratively researched and subjected to the rigour of scientific examination.

Recommendations

Research funding for sustainable agricultural production

- **The role of soil biota and its interaction with plants**

This can contribute a considerable proportion of potential yield increases and is a formidable “free” workforce to address many limitations experienced with conventional agricultural practice. Soil macro and microorganisms can access nutrients from the soils mineral surface, liberate locked up nutrients, break down, recycle and build soil organic matter all whilst interacting with plants to supply nutrients and control soil pathogens. These interactions can produce healthy nutrient - dense plants that can be far more resistant to disease.

- **Paired plant breeding with soil biota and the rediscovery of older species**

Symbiotic soil organisms are usually very specific in the choice of host species. In order to maximise the relationship, single species crops potentially need a suite of soil organisms to interact with. In multi-species plantings the synergies and benefits are greater and more diversity of soil biota can be supported. Older “heirloom” varieties of plants can contribute significantly to the diversity of desirable traits within a species.

- **Biological and organic production with a focus on inputs**

These production methods are already focussed on maximising the potential of natural systems. Priority should be given to the development of inputs that are sustainable, effective and in harmony with natural systems and which are applicable to conventional agriculture.

- **Biological control agents for crop protection in cropping systems**

The use of effective natural biological crop protection products may remove many of the criticisms of modern agricultural production. If high production systems can utilise effective, sustainable natural products they will avoid perceived negative interactions with the environment and many potential health related issues with regard to handling, application and product residues.

Research priorities and directions set now will help shape future agricultural practice.

Recycling and waste

- Food spoilage - storage and production losses, retail and domestic waste could be in the order of one third to a half of the increases required to meet projected global demand by 2050. Tackle waste and we lower the pressure on the limited and shrinking availability of worldwide agricultural land and the finite resources needed as agricultural inputs.
- The recycling of waste streams is essential to stop the loss of nutrients from the production and consumption cycle and to extend finite reserves.

Farm-level actions

- There is a need to be willing to adapt and accept solutions from outside our traditional mindset.
- Technology as well as a mix of conventional, organic and biological production methods, will all need to be employed during the transition to a sustainable and regenerative production future.
- Training is needed in methods of minimising and rectifying potentially negative management decisions in the transition to newer, less damaging methods in the future.
- Enhancing the plant diversity in pasture phases and crop rotations will directly foster more and varied soil biota. Along with targeted biological inputs, this will also improve overall soil qualities and nutrient efficiency. Techniques such as Cover Cropping, No Kill Cropping and Pasture Cropping help address these needs.
- Regeneration of soils can be aided naturally through the skilled management of growing plants in a healthy soil biosphere.

Community Partnership

- The value of food and its true cost of production need to be communicated to consumers as more than an issue of price per weight.
- Returns on farm produce are not sufficient to fund the environmental and sustainability expectations and demands placed on primary producers by the community and government. These costs should be shared by all beneficiaries.
- The application of the GST in Australia to basic food items could raise annual funding for the purpose of enhancing environmental and sustainability outcomes for agricultural producers.

- Recognising, prioritising and securing the long-term sustainability of agricultural industries over and above the short-term gains from mining.
- Recognising that grazing livestock are often essential to environmental sustainability, human nutritional requirements and global food security.
- Increasing soil carbon levels are a key indicator of improved soil management and soil health.

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Plain English Compendium Summary

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| Project Title: | Sustainable and Regenerative Agriculture Farming in a world of finite resources. |
| Nuffield Australia Project No.: | 1111 |
| Scholar: | Michael Inwood |
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| Objectives | <ul style="list-style-type: none"> • Investigate sustainable and regenerative agriculture with a focus on soils and soil inputs. • Study factors which, in the future, may reduce resource limitations and increase nutrient efficiency. |
| Background | Population increases and the declining resource base for agricultural inputs, including fossil fuels and fertiliser inputs, is placing pressure on agriculture to produce more from less. Availability of agricultural land is being reduced through urban encroachment, degradation and contamination. How then does agriculture move forward and address the concerns over future global food security, environmental impact, sustainability and food quality? |
| Research | Studies were undertaken in the USA, Canada, UK, Switzerland, Italy, the Philippines, Thailand, Ireland and China. Research facilities, consultants and agricultural practitioners were visited and relevant research papers and publications studied. |
| Outcomes | The lifespan of existing finite resource inputs need to be extended by increasing the efficiency of fertilisers and recycling food waste and human biosolids. Global food waste and spoilage must be addressed as this saving in food alone could feed billions of people. Plant interactions with soil biology are key to sustainable and regenerative agricultural practice and improving human nutritional outcomes. Regenerative agriculture builds soil using natural processes. The continued development of biologically friendly inputs is essential to soil and human health. |
| Implications | Both the protection of the soil as an asset and the reversal of degradation need to occur now. Funding levels and research need to be increased commensurate with the level of global concern over food security. |
| Publications | |