Sodic Soil Management

Increasing profitability in southeast Australian farms

A report for

By James Hawkins

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Executive Summary

Australian farmers are losing profits and competitive advantage globally due to lost yield and fodder potential because of soil constraints. Farmers can have huge crop and pasture losses caused by waterlogging and hard setting soils in “normal” seasonal conditions which weighs heavily on non-impacted areas to make up lost potential and meet operating expenses.

Australian farmers can improve productivity, profitability, and resilience by understanding their underlying business fundamentals and crafting a strategy to modify management and invest in long term operational amelioration interventions. Overcoming soil constraints needs to be approached holistically as a part of the whole farm management plan as all decisions impact on the resource allocations in other areas. Soil amelioration should not be seen as just the chemical or physical addition or modification but at all farm management levels including crop and pasture selection/rotation, tillage interventions, chemical and fertiliser selection, and integration of livestock.

The detrimental impact of continuous cropping and tillage on Australian soils is increasingly understood and being managed through reduced tillage yet minimum tillage does not go far enough to address bio-physical constraints associated with sodic, dispersive soils. Farmers need to understand the soil and its performance under different seasonal conditions to craft the plans to improve their performance.

This report provides an outline of the issue, the means of categorising and mapping soils, the various management modification possibilities as well as an understanding of amelioration options including an extensive outline of amelioration machinery options. The report aims to inform farmers facing soil constraints with a greater depth of understanding of the issue and associated tools to overcome them.

Modern sensor technology, digital software and algorithms are now at a point where they can be cost effectively utilised by farmers to categorise soils and understand the performance at a farm, paddock, and individual square meter level. Phytoremediation of soils through well planned crop and pasture selection especially with the use of perennial pastures and managed grazing is critical to managing sodic, dispersive soils. Physical, chemical, and biological constraints associated with sodic, dispersive soils can be overcome with strategic deep placement of organic materials and nutrients.

In the next five years the depth of understanding of soil constraints and their best amelioration options will greatly increase thanks to private and public research active at time of writing.

Table of Contents

Table of Figures

Foreword

My journey has been a colourful one and I am humbled with the opportunities provided. Since leaving school I have run my own agricultural businesses, starting as a hay baling contractor, and now run a pork management company and broad acre grazing enterprise. Despite not working directly in the family farm operations, our businesses work in tandem and complement each other. I get joy having such a strong connection to my family, the land and agriculture. I am grateful for the opportunity to be a custodian of the land and want to pass it on functioning in a way that can be sustained for hundreds of years beyond my days.

The family properties are managed by my sister Tara, father Peter with the assistance of both of their partners Rob and Susan and employees Bruce and Darleen. The family operation is a diversified, irrigation (small seeds), meat, wool, grain, and oilseeds producer in the West Wimmera shire of Western Victoria. The farms are in a medium rainfall zone with a mix of soil types including hostile clay subsoils which can be dispersive causing waterlogging and hard-setting periods limiting the crop and pastures performance below rainfed potential.

The Hawkins family are always looking at innovative strategies to maximise production, minimise costs, improve sale value and operate sustainably long term. This search for improvement involved attempts to better understand factors which limit crop and pasture performance. Based on rainfall, we determine that our soils were potentially limiting productivity. After research and investigation, it was hypothesised that the chemical constraints relating to dispersive and hard setting soils were a critical factor limiting productivity. The focus then turned to potential strategies to overcoming this.

My father Peter identified research into subsoil manuring being undertaken in the Western Victoria which began my journey researching soil amelioration and subsoil manuring. This journey has led us to on-farm trials beginning in 2016 across a variety of paddocks, soil, and crop/pasture types. In 2017, I undertook a master's thesis at Marcus Oldham College, focussed on the potential to improve sodic soils through subsoil manuring in an irrigation setting. Prior to being awarded the Nuffield Scholarship in 2018 I intended on beginning a PhD focussed on subsoil manuring as I have a great desire to improve soils and increase farmers productivity.

The aim of the Nuffield study was to better understand sodic soils, how to categorise our soils/subsoils and quantify the negative impacts of the subsoil constraints. With the greater understanding the intent was to find amelioration strategies around the world and machinery to perform the amelioration. I visited many farms, engineering firms, agricultural services companies, research bodies and universities across 12 countries all thanks to the generous support of those that I visited, those at home doing the hard yards in my absence and the significant financial investment by Rural Bank and Nuffield Australia. Much has been learnt and a commercial scale subsoil composting machine born as a result of my travel. I hope that the machinery and this information has helped add value to the sector.

Acknowledgments

Nuffield is an organisation unlike any other, and I will forever be grateful for the opportunities which they have helped create. The marriage of businesses and individuals who have the financial desire to invest in the future of our industry such as my generous investor Rural Bank and those of us on the ground trying to push our part of the industry forward is both simple and ingenious. The opportunity to travel to countries all around the world and meet, listen and learn from agricultural business, research bodies, government departments and a lot of generous people is humbling, mind expanding, heart-warming and gives a perspective beyond belief. Rural Bank my generous investor is an organisation with origins serving the Australian people and continue to provide amazing services to rural Australians and provide generous support to young Australians like myself. Jodie Dean and Nicola Raymond deserve a special mention for running such a tight ship and herding the ever-enthusiastic cats which are Nuffield Scholars. You do a role which I don't envy but deeply admire.

This acknowledgements section could and should be 10,000 names but I am limited to 10,000 words so I will do my best to summarise the infinite appreciation I have for those who have helped me. There are a core group of people who helped keep the wheels turning in my absence:

- Napoleon Amonoy with the support of his son Jairus run the pig farm with such amazing dedication and professionalism.
- Julianne Boak ensuring the continued operating of my enterprises and trying to juggle the pieces after having me throwing random spanners into the gears.
- Rohan Brown from Green Taylor Partners for keeping the numbers in order.
- Klynton Krause for always being on the other end of the phone wherever in the world and whatever the time of day for sage (and sometimes not so sage) advice.
- My father Peter and sister Tara and their partners Rob and Susan for always filling the gaps I've left behind.
- A special note to my mum Anita for being incredibly strong facing such headwinds while I was in North America.

The Nuffield journey is only possible due to the incredible generosity of the hosts in whatever corner of the globe we find ourselves. These could be Nuffield brothers and sisters or wider contacts or random folks who have a relevance to our topics or add value to our understanding of the industry. Special mention to: Rick Bieber, Bud Davis, Robert Borrill, Joe and Kate Uphus, Josh and Trish Olton, Will Harris, Jo and Paul Marks, Torkild Birkmos, Laars, Annemette, Charlotte, Josephine and Anne-louise Riis, Dan and Maria Christensen, Fabian Chopin, Krone Germany, Frank Harney and many many more.

I acknowledge those on the 'Africa' Global Focus Program tour, for your patience and understanding and amazing insights and experiences I will forever be grateful, Josh Oulton,

Alison Larard, Dr. Solis Norton, Turi Macfarlane, Andrew Slade, Colm O'leary, Dr. Jenna Ross and Shannon Notter. Plus, our amazing host including Dr. Sarah Flowers, Wayne Dredge, Dave Fulwood. A very special mention to the late great Nuffield Scholar David Stanley our co-host in Kenya, you were an incredible teacher and inspiration for what I would aspire to be as a Nuffield scholar, farmer and human you truly embodied what it is to be a scholar.

Figure 1: Nuffield Scholars during Africa GFP 2018 with Kenya host Dr Sarah Flowers (right) with Jackie and Mandy Kenyon son of one of the first four Nuffield scholars from 1947

Abbreviations

ESP: Exchangeable sodium percentages

GRDC: Grains Research and Development Corporation

NVDI: Normalized Difference Vegetation Index

SAR: Sodium absorption ratios

SOC: Soil Organic Carbon

SSM: Subsoil Manuring

TSM: Top Soil Mapper

Objectives

The primary objectives include:

- What is sodic soil and how does it impact on farm productivity?
- How are sodic soil identified and characterised?
- What are some of the farm management changes which can ameliorate soils and improve farm productivity/profitability?
- What are soil amelioration options?
- What are possible ameliorants?
- What is the best machinery for soil amelioration?

Chapter 1: Introduction

A farmer who has an intricate knowledge of soils, climate and agronomy have the best chance at maximising the production from their available land resource. Farmers must manage soil, sunshine, rainfall (rainfed or irrigated), human, technology, livestock, finance and market resources, and the farmer who manages this best will be profitable long term.

Farmers should be identifying what are the most limiting factors constraining production and then analysing the options for addressing yield and fodder limitations. Soil structure (waterlogging and hard setting soils) and chemical constraints associated with sodic and dispersive soils are a significant constraint on productivity in many areas of Australia's cropping and grazing areas (Orton et al., 2018). (Orton et al., 2018) displays that the national cost of sodic soil constraints has been estimated at $1.4 Billion AUD and within south-west (SW) Victoria alone over $300 Million with the potential to gain 1,300 jobs to the area if these constraints were completely overcome (Nicholson, 2016).

Ameliorate the word is derived from the latin adjective "*melior*" which means better and improve which is the intention when we look at ameliorating soils, it is the process of modification or addition with the intention of improving the functioning of soil.

Farmers have an intricate connection to their land and its performance year to year and understand that certain soil types under different seasonal conditions will suffer losses in grain or fodder yield potential. The key is to quantify real costs of soil constraints before analysing the potential rate of return from any amelioration strategies.

Long term amelioration of soil constraints is challenging and requires a deep understanding of the soils chemical, physical and biological system function and limitations (Gill, Sale, Peries, & Tang, 2009). Having the understanding provides a greater chance that a farmer can apply the appropriate amelioration technique to the appropriate soil.

While traditionally soil amelioration is referring to as a treatment such as gypsum or deep ripping, soil amelioration is a management action. Soil amelioration can come in the form of modified crop or pasture rotations, changed enterprise mix (crop/livestock) and through chemical, physical, biological amendments or a combination of strategies.

The addition of calcium-based soil ameliorants is often effective yet short lived and struggle to address the subsoil bulk density issues and don't allow salts to leach out of the root zone. Deep tillage is another soil amendment which can temporarily reduce soil constraints. Certain crops and pasture species are better suited to handling sodic, dispersive soils and the way plant species are managed can contribute to the impact of the constraint.

Increasing knowledge is being gained into the impact of organic amendments as a means of ameliorating sodic, dispersive subsoils and one method is subsoil manuring. Subsoil manuring is a method of deep placement of organic material into a deep tilled rip line to activate microbiology, increase root penetration, proliferation and improve drainage of water to reduce waterlogging.

When considering strategies to overcome these soil constraints farm managers must assess the best allocation of their available resources and each farm has its own specific resource mix.

Crop and pasture rotation modification as an amendment tool can be both low costs yet effective and sustainable. The addition of livestock into a cropping property can increase potential crop and pasture species diversity such as the addition of perennial pastures, plus build resilience and reduce the impact of sodic, dispersive soils.

Chemical ameliorants through the application of lime or gypsum are a relatively low cost and effective short-term tool for amendment yet should be supported by other means if the impact is to be sustained. When analysing the economic and productive impacts for physical amelioration or a combination of physical and chemical amelioration such as subsoil manuring the costs and soil impacts can be significant and should be thoroughly modelled and a rate of return understood. Where possible a soil amelioration intervention should be trialled on the most suitable soil types over multiple years to understand the responses under local conditions. While costs can be significant the potential nutrition and soil structural improvements can provide a long-term solution to sodic, dispersive soils and when combined with good pasture and crop management can drive a massive improvement in the long-term productivity of the treated soils.

The availability of soil amelioration machinery has been a major limitation to the broad uptake of subsoil manuring, and this Nuffield project aims to address the potential machinery limitation.

It is in the art of understanding the soils and the farms best allocation of available resources feeding into good management decisions that chemical, physical and biological constraints associated with sodic, dispersive soils can be overcome and the farms productive potential reached.

Chapter 2. Understanding Sodicity

2.1 Soil constraints economic impact

It is estimated that 17% of Australian agricultural soils are said to be sodic at an economic cost of $1.3 Billion AUD per annum (Orton et al., 2018). This provides the potential to increase farm and national profitability from the sector if effective dispersive soils management strategies can be implemented.

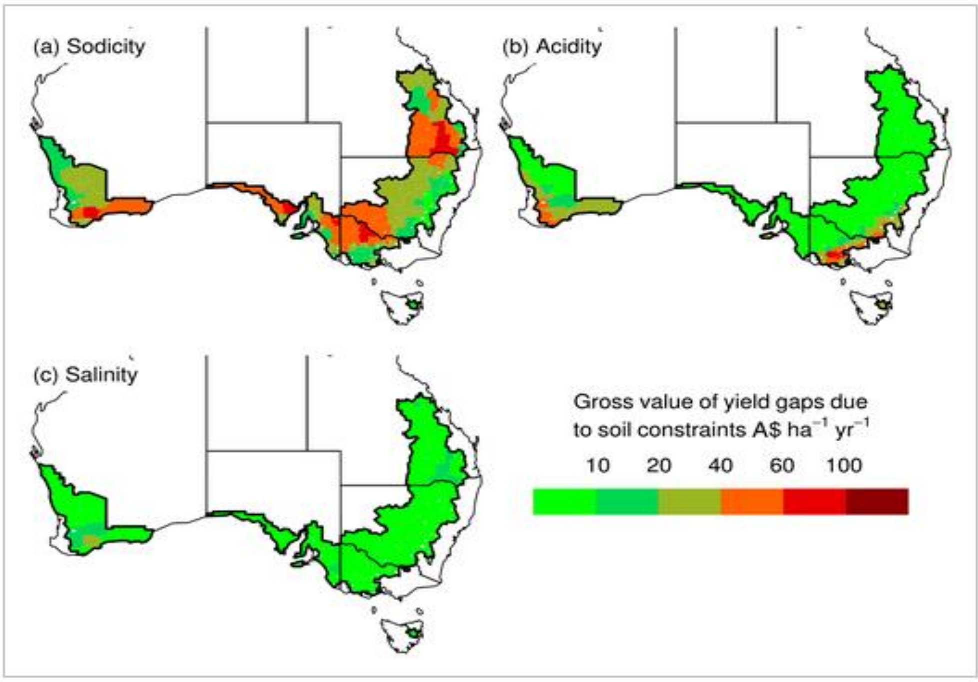


Figure 2: Gross value of yield gaps in Australia due to the three soil constraints sodicity, acidity and salinity Source: (Orton et al., 2018)

2.2 Soil dispersion and impact of sodium and dispersive elements.

Soil is a highly complex system composed of a huge number of sub-systems and interactions with millions of chemical reactions and functions occurring every second, when the soil is impacted by major chemical and physical constraints associated with sodicity, soil system function falters and potentially collapses. Dense clay sub soils have limited the amount of leaching of soil components like dissolved salts such as sodium out of the root zones of many Australian agricultural soils. It is the interaction of clay particles with these accumulated elements such as sodium and magnesium which cause soil structural degradation which inhibit plant performance and overall farm productivity.

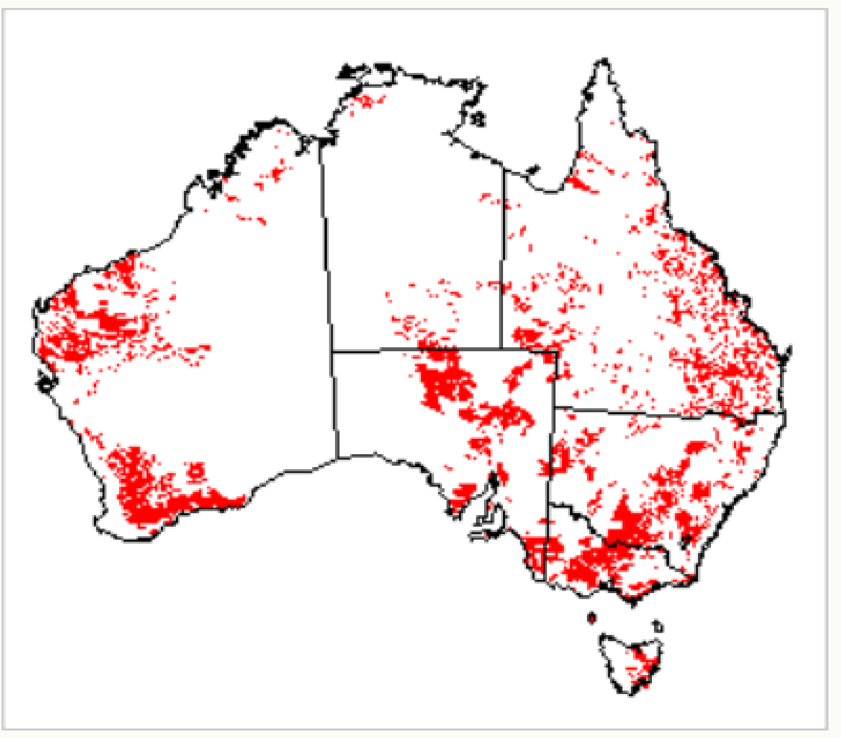
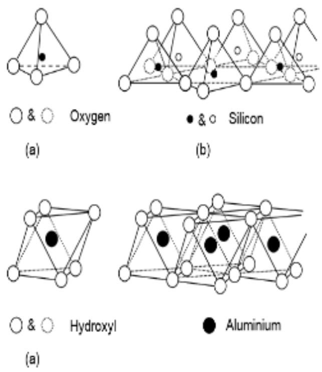


Figure 3: Sodosol soils in Australia Source: (Naidu, Sumner, & Rengasamy, 1993)

2.3 Digging deeper into sodic soil

Clay at the atomic level are alumino-silicates with a sheet lattice structure as can be seen below and through a process known as isomorphous substitution aluminium silicon particles can be substituted by other metal atoms such as iron, magnesium or calcium resulting in a charge imbalance and a negatively charged outer layer. Exchangeable cations are then absorbed to balance this net negative charge and it is in the type and amount of cation which binds to the clay particles which determines the degree of dispersion or flocculation.



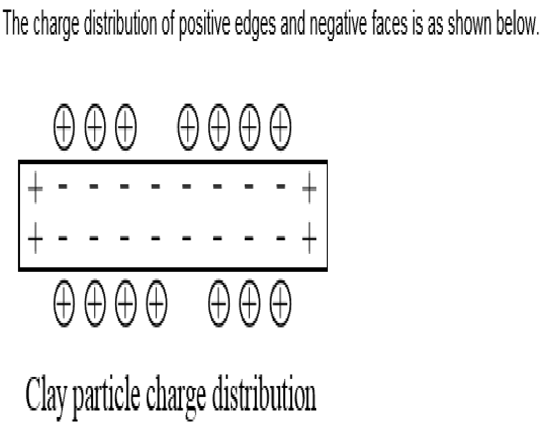


Figure 4: Clay partile structure (Left) Illustration of clay particle charge distribution (Right) Source: (Van Rees, 2014)

2.4 Absorbed water layer

Due to waters polarity, when the soil profile receives rainfall or irrigation water the negatively charged outer layer of the clay particle attract the polar hydrogen end of the water molecule eventually becoming surrounded by an absorbed water layer. The type of absorbed cations within the clay particle such as divalent cations Mg++ and Ca++ or Na+, K+ determines the amount of water molecules required to balance the charges of the particle. The divalent cations result in half as many monovalent ions required to balance the charge resulting in a thinner absorbed layer.

2.5 Flocculation

When the soil conditions mean there is a thin absorbed layer the positive end of clay particles can get close enough to the negative length of another particle forming a relative degree of disorder with many open pore spaces. Figure 5 represents the “card house” with the interactions described.

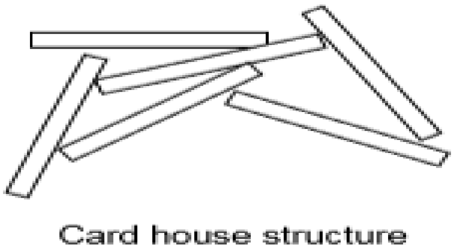


Figure 5: Illustration example of floculated clay particles Source: (Van Rees, 2014)

2.6 Dispersion

When clay particle formation means a thick absorbed water clay layer the positive edge to negative face charges is buffered and the attraction reduced resulting in lower attractive forces (reducing the strength and stiffness of the soil) and the particles form an ordered parallel sheet structure (Figure 6).

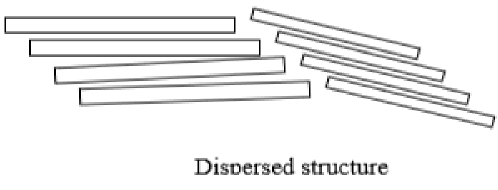


Figure 6: Illustration example of clay particles in dispersive soils found in Australia Source: (Van Rees, 2014)

The reduced inter-particle attractive forces mean that the overall strength is reduced and the soil is more prone to dispersion, reduction in pore space vital for gaseous exchange and reduction in free water available for plants (Van Rees, 2014).

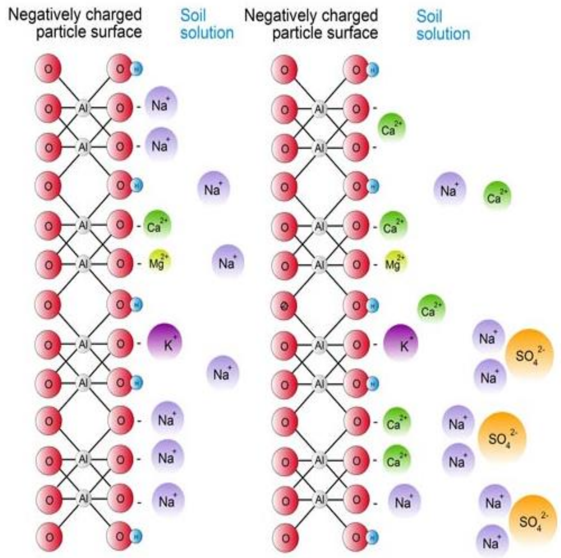


Figure 7: Example of a clay particle and various ions in soil solution impacting on dispersion Source: (UNSW, 2007)

Traditionally the mechanism for estimating soil dispersion has been through sodium absorption ratios (SAR) and exchangeable sodium percentages (ESP) and the formulas are:

SAR = Exchangeable {(Na)/(Ca+Mg)-0.5)

ESP = Exchangeable {(Na)/(Ca + Mg + Na)} x 100

However due to K being excluded and Mg having the same vale as Ca Regasamy and Marchuk (2011) propose a new formula known as the "cation ratio for soil structural stability" (CROSS) which has the formula of:

CROSS = (Na + .56 K)/ (Ca +0.6 Mg)0.5

Case Study 1: South Dakota State University, Dr Cheryl Reese

The Mid-West and Great Plains regions of the USA is an agricultural powerhouse and has traditionally been known as America's breadbasket with corn and soybean dominating the view as the author crossed each state. While it was hard not to be highly impressed by the scale and productivity of these agricultural areas it soon became evident that there is a growing problem with saline or sodic seeps causing partial to total crop loss on the impacted land. Dr Cheryl Reese (Figure 8) is an expert in soil/crop science especially in sodic and saline soils and was generous enough to give me her time for framing the sodic and saline issues growing across the Mid-West and Great Plains. The extent of sodicity varies in different regions of North and South Dakota yet can be as bad as 20-30% with considerable economic losses as a result.

Causes of saline soil seep issues

Salts are indigenous to the soils in the area due to historic inland seas, yet the land use change and wide uptake of annual cropping has led to the salts being deposited in concentrated land areas. Increases in annual rainfall since the 1980's is leading to soil water leaching and rising water tables bringing salts up to low areas of fields. Increased prevalence of arable production which replaced livestock and native perennial prairie grasses to the now common corn and soybean which includes a greater degree of tillage, nitrogenous fertilisers, leeching of excess water etc. The capillary action with reduced water use and increased leaching is bringing deep salts with the movement towards the surface

Presentation

High salt and sodicity issues on soil surface causing a loss of soil cover and exposure to rain and wind erosion as well as a partial to total loss of crop or pasture in that region.

Traditional management of South Dakota farmers

Tile drainage has been used by many farmers to reduce the excess water bought up through the capillary action. Tile drains have been seen to have varied success at a high cost. The use of tile drains can have the secondary impact of removing the water and leaving a high concentration of Na which causes a greater degree of dispersion resulting in the tiles becoming blocked and reducing their effectiveness.

Research based management strategy recommendations

San Diego State University recommend several steps for understanding and addressing the issues of sodic saline soils beginning with defining the impacted area through EC and ground truthing. The second main recommendation is to establish vegetation on the surrounding areas with the saline tolerant high-water use species such as lucerne to increase soil water uptake and reduce the leaching. In the impacted areas a high use of calcium ameliorant such as elemental calcium chloride, gypsum, or elemental sulphur in conjunction with the sowing of a high tolerance perennial species such as tall wheat grass and gradually increase coverage over time. Dr Reese also recommended the potential for surface applying animal manures or crop residues initially to "stabilise and improve soil structure".

Figure 8: Dr Cheryl Reese at Dakota State University in Brookings South Dakota Source: Author

2.7 Soil and plant conditions and the impact of dispersion

Plant roots need a well-hydrated and well aerated soil environment of low osmotic pressure, with adequate nutrients and low toxicity. Plants have optimum and threshold levels for the chemical composition, soil pore space and moisture levels and when outside of these thresholds plant health is impacted and crop yield potential reduced. In relation to Australian "sodic soils" the level of dispersion caused by Na and K and Mg which is often associated with a high pH due to accumulation of bicarbonate and carbonate ions causing what is known as alkalinity. It is the combination of dispersive cations Na and K in an alkaline soil which appears to have the greatest impact on soil structural stability and crop performance. Sodic dispersive soils are often associated with low organic carbon levels which as seen below impacts on the soils ability to mineralise nitrogen. When dispersed the soil becomes anoxic which also impedes nitrogen mineralisation which compounds the impact of low organic carbon levels.

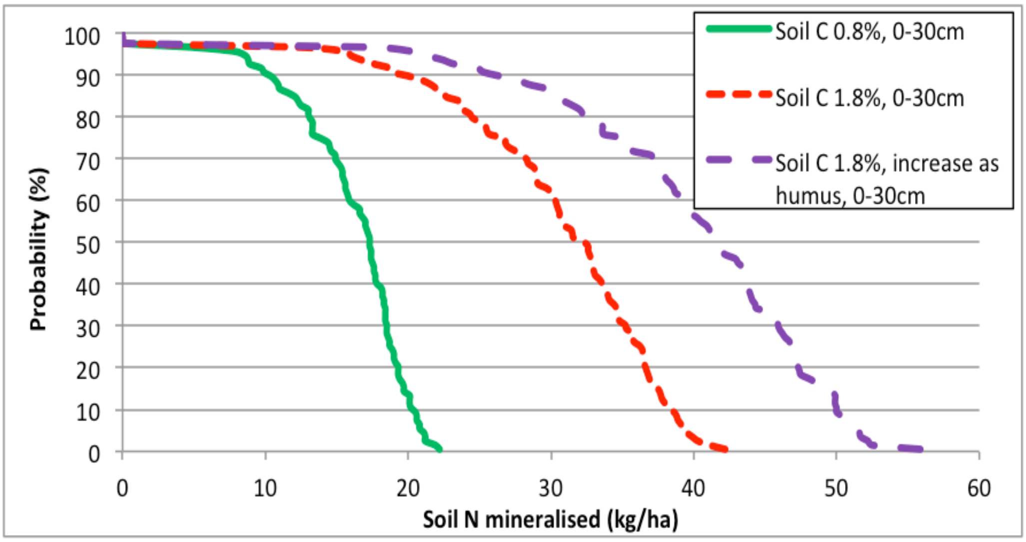


Figure 9: Simulation of soil nitrogen mineralisation at different soil organic carbon levels Source: (Van Rees, 2014)

2.8 Subsoil accumulation of salts

Globally it is estimated that both primary and secondary salinity and sodicity makes up a total land area of 1 billion hectares (Orton et al., 2018). Primary salinity naturally develops over long periods from wind, rainfall, ocean mists, weathering of rocks etc while secondary salinity is caused through human born mismanagement of the land through land clearing, poor plant selection, tillage, irrigation, soil additives such as nitrogen fertilisers etc. Regional rainfall levels as well as sub soil porosity impact on the number of salts which are retained or leached from the soil with lower rainfall areas and heavy clay sub soils reducing the degree of leeching.

2.9 Transient salinity

Much of Australia's sodic and saline soils are caused by transient salinity, a process where salts accumulate over thousands of years due to clay sub-soils restricting the movement of salts from the soil. In a cycle of restricted movement, the accumulation of sodium and salts in the clay sub-soil causes soil dispersion and structural degradation which inhibits water and salt leeching further exacerbating the accumulation of salts. Rengasamy 2002 – Barrett Et al* estimate that 67% of dryland cropping areas in Australia are impacted by transient salinity.

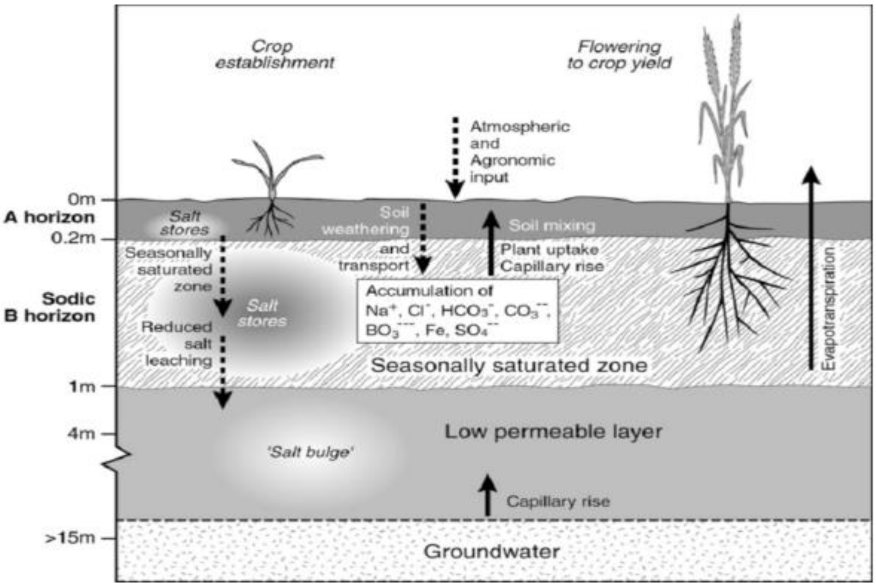


Figure 10: Illustration of mechanisms of transient salinity in Australian soils Source: Rengasamy 2002 – Barrett Et al.*

2.10 Impact of sodicity on plant and crop performance

The impact of soil sodicity on plant health is relatively complex and continues to be researched but to summarise it high sodium levels have detrimental impacts on soil structure, osmotic potential of soil water and the presence of toxic ions". The soil structural changes can be seen above* and the soil water dynamic is in relation to osmotic pressure of soil water due to high ESP. The soil water dynamic is incredibly important in Australian dryland cropping due to relatively low growing reason rainfall and high evapotranspiration rates due to high ambient temperatures and low humidity in many areas. The high ESP levels causes an osmotic pressure imbalance between plant root and soil water and the higher the ESP the reduced ability for the plant to uptake soil water and can lead to "green water" which is unused soil moisture unavailable to plants due to the high ESP and osmotic pressure imbalance. At a soil water EC of 2.8 – 5% of green water remains, 22dSm-1 – 50% etc. showing the extreme impact of the salt levels on plant water uptake.

Toxic impacts of sodic soils are the high levels of dissolved ions especially Na+ and Cl- in the rhizosphere causing metabolic stress on the plant's roots leading to necrosis of plant root and leaf cells.

Nutritional impacts of high salt levels are said to have a lesser effect on plant growth than soil structure, osmotic impacts and toxicity yet there are impacts of high ion levels on plants uptake of other elements. High Na+ levels can inhibit plants uptake of K+ and Ca2+ causing plant stress and function limitations.

Chapter 3. New Technology for Better Soil Characterisation

Historically, soil mapping has been labour intensive, cumbersome and expensive through means such as grid sampling and lab analysis of soil samples extracted. We're now in an age where sensor technology and algorithm-based software are readily available where raw data for various soil and crop performance parameters can form multiple layer maps and data sets which can help feed into decision making for sodic soil management. These new technologies and tools are secondary and supportive to the farmers knowledge and intuition developed from many years of understanding the soil, crops, pasture and climate.

Sodic and dispersive soils have certain chemical and physical characteristics such as topography, electrical conductivity (potentially sand, silt, clay, rock makeup or salt levels), soil water dynamics, flow models, soil bulk density, SAR, ESP which can now be mapped and aid in management. Other means of observing soil dispersion are visual perched water tables and waterlogging, visual crop stress, NDVI and NDVI changes relating to potential crop stressors.

The future of analysing soil for degree of dispersion and the associated plant stressors will be a combination of many of the above plus other not mentioned.

Case study 2: Geoprospectors Traiskirchen, Austria. Producer of cutting-edge soil sensor technology able to characterise sodic soils

The use of soil characterization tools such as electromagnetic sensors such as EM38-MK2 are advancing rapidly and Austrian based Geoprospectors have taken this technology forward with a highly useable and effective tool the Top Soil Mapper TSM (Figure 11). TSM is designed primarily for real time variable depth tillage in a European environment, yet the volume of data extracted from the TSM allows for a suite of soil geophysical characteristics to be measured and fed into analytic systems for use as visual maps and data sets which can be useable directly or as a tool to inform where grid sapling can be undertaken. The system is designed to mount on a tractor or utility vehicle and performed as a part of routine tillage or spraying pass etc or as a specific pass to determine the soil information required. The information can analyse EC, soil type, water saturation and compaction layers and potentially green water caused by hostile sodic layers.

The TSM technology is being adapted within Australia and there are companies such as Agree Decision Ag by Emmett's and Landmark who have vehicles with TSM's fitted to them as well as soil sampling capabilities to take samples for further chemical analysis to support the TSM information. The uptake of this technology by these companies provides a far greater depth of agronomic consultancy advice which supports traditional agronomy and can make decision making based on a breadth of information not seen before.

Figure 11: An example of the Top Soil Mapper mounted on a tractor Source: http://www.geoprospectors.com/gb/products-services/agriculture/

3.1 Information integration

Data and maps from TSM or similar technologies can then be used in conjunction with soil sample analysis, ground truthing, yield maps from harvest and NDVI information from companies such as Farmers Edge. The use of the Farmers Edge products provides the ability to use crop health history to track potential plant stress periods alongside soil moisture levels and rainfall to better understand waterlogging. Farmers edge software includes information collected from harvester yield monitors which is overlayed with NDVI information, soil characterisations, soil chemical analysis and ground truthing to better understand the impact which dispersive soils are having on medium term productivity and crop performance.

3.2 Making Informed decisions

The data sets now collated and put into useable format can then feed into management decisions for the future. Farmers can create their own decision-making tools about the economics and potential benefits for different courses of action. The various decisions would be around the potential for amelioration (gypsum vs deep ripping vs subsoil manuring vs perennial pastures etc) or modification of crop rotation management or the enterprise mix change such as increasing the ratio of grazing vs cropping. The use of risk analysis tools such as the @RISK program created as a part of the Grain and Graze program can help analyse the risks and profitability of any soil amelioration management changes. @RISK can model the impact on the overall farm performance under various changes and what this may do to profitability and the risk profile of the overall operation.

Chapter 4. Phytoremediation and Modified Management

Medium and high rainfall zones in Victoria have seen a move towards a higher ratio of cropping versus livestock since the 1990's helped by the introduction of management systems such as raised beds. The potential for high yielding cereals and oil seeds has seen more arable production with potentially high returning cropping systems as opposed to the historically lower gross margin pasture and livestock systems. As many farmers are aware cropping after long term pasture can be very successful and a high level of productivity can be achieved, yet as farmers move further into the continuous cropping cycles the yields and returns can become more challenging. The need for tillage, summer fallow, biological break periods, monocultures and synthetic inputs in continuous cropping systems provide challenges in maintaining a functioning, self-sustaining, productive soil. Soil organic carbon levels have been shown to be massively reduced under continuous cropping systems and this comes with a whole suite of soil function repercussions.

4.1 Increasing perennial pastures and livestock

With soil structural instability being a major symptom of sodic and dispersive soils, there is a strong soil health, farm risk profile, profitability and long-term sustainability argument for increasing the perennial pastures, fodder crops and livestock in high rainfall operations in south-eastern Australia. The objective in introducing these pasture-based systems is to increase soil root mass, living roots, microbiological cycling, plant residue and animal manure additions back into the soil and improving soil aggregate stability to reduce the impacts of sodicity and dispersion.

4.2 Phytoremediation

Utilising strategic crop and pasture rotations is a cost effective and sustainable means for long term amelioration of sodic, dispersive soils this is a technique known as phytoremediation. *"Scientific research and farmers' feedback have demonstrated that sodic soils can be brought back to a highly productive state through a plant assisted approach generically termed "phytoremediation"."*
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.568.2469&rep=rep1&type=pdf

They go on to show that sodic soil remediation occurs through the plants root's ability to "increase the dissolution rate of calcite, thereby resulting in enhanced levels of $Ca2+$ in soil solution to effectively replace $Na+$ from the cation exchange complex.

Phytoremediation has the benefits as stated in Qatar et al* "(1) no financial outlay to purchase chemical amendments, (2) accrued financial or other benefits from crops grown during amelioration, (3) promotion of soil-aggregate stability and creation of macropores that improve soil hydraulic properties and root proliferation, (4) greater plant-nutrient availability in soil after phytoremediation, (5) more uniform and greater zone of amelioration in terms of soil depth, and (6) environmental considerations in terms of carbon sequestration in the post amelioration soil."

https://www.researchgate.net/publication/254328988_Phytoremediation_of_Sodic_and_Saline-Sodic_Soils

There are many means of using modified management with pasture or crop species on sodic, dispersive soils. There are five principles for soil health, which was born in the Mid-West and great plains of the USA, which guide the conservation agriculture movement which is spreading globally:

1. Maintain soil cover
2. Minimise soil disturbance
3. Diversity of plant species
4. Continual live plant/root
5. Livestock integration.

While these principles are designed for general soil health there are common threads which relate to minimising the impacts of dispersive soils. Within south-east Australia and south-west Western Australia – where there is predominantly temperate environment with winter dominant rainfall – there is a tendency towards growing cool season annual crops. There is an argument for the addition of strategic spring sown warm season forage crops. The use of perennials such as phalaris or lucerne have clear soil aggregate stability benefits and there are also options for innovative pasture management such as pasture cropping which is the use of annual varieties sown into perennial pastures either for forage or cash crops.

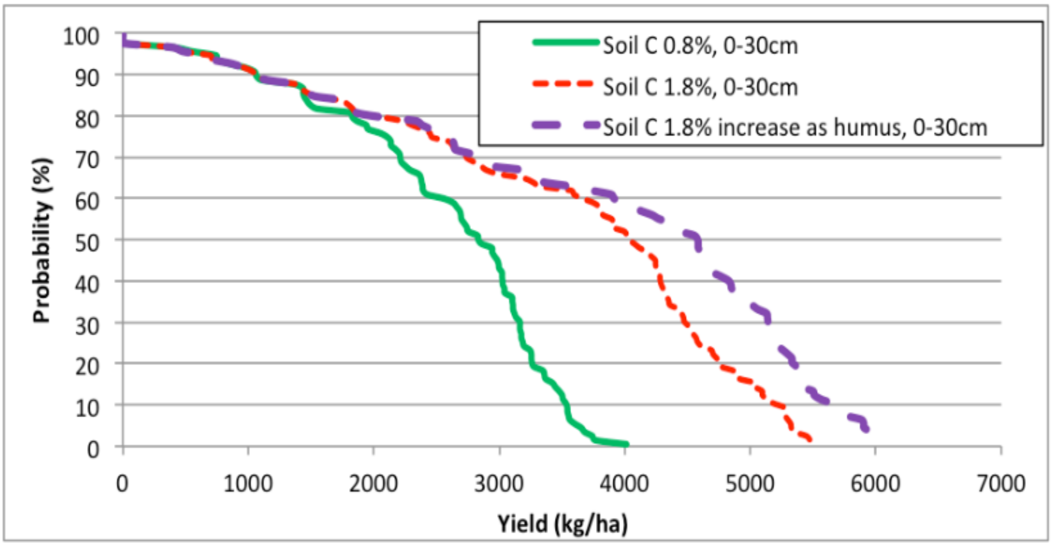


Figure 12: Represents a model for probabilities for yield potential at variable soil carbon levels Source: (Van Rees, 2014) https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2014/08/soil-organic-matter

Case Study 3: Beiber Farms, Rick Beiber, South Dakota. Mixed cropping and livestock. No-Till, Cover crops, minimum inputs, perennial pastures

Rick Beiber has a means of welcoming you to his family farm which shows the depth of his character and connection to his land, soil and environment around him. Rick is a self-professed "soil custodian" who practices farming with the intent on the farm being handed on more productive and sustainable than when he received it. The Beiber property is on a large scale with some 25,000 acres yet still achieves a degree of soil health and function which is often said to be only achievable on small operations. Over the past 30 years the Beibers have been refining a soil health approach to farming which includes using deep rooted crops and pastures to improve soil health while increasing profitability. The Beiber's use diverse rotations with cropping and cover cropping to achieve the five-soil health principles stated above trying to achieve "four of the five principles at all times". The Beiber's have put certain areas of their property back to perennial pastures with managed grazing that simulate the grazing of natural Bison with high intensity short graze times with long rest periods. The Beiber's have managed their grazing to encourage native grass species to return and believe they are building their soil health and productivity accordingly. The Beibers are constantly innovating and their practices are building their resilience as a farm as the extremely dry spring had their neighbours' crops dying of drought stress and Ricks were healthy and strong. They believe their soil health is now at a point where they are trialling cutting any nitrogenous fertiliser inputs and the 50-50 crop trial showed minimal visual difference no-fertiliser-fertiliser treatments. In a soil pit in one of Ricks paddocks the soil structure and rooting depth with many corn roots were down to 1.5m and earth worm tracks to significant depth. The Beibers have areas of sodic, saline seeps and have successfully managed these areas with growing Lucerne for hay and adding some cool season grasses.

Figure 13: A group of photos from The Beiber Farms (including Rick Bieber) in Western South Dakota whom have been using "soil health" practices for 30 years with significant productivity benefits above district averages. They manage sodic soils with deep rooted annuals. Source: Author

4.3 Increased livestock integration to reduce impact of dispersive soils

There is a case to be made that including well managed livestock in a mixed livestock/cropping operation can improve the risk profile, reduce the impact of waterlogging and hard setting sodic soils, increase rainfall capture, biomass production and farm resilience. Through increasing the number of perennial pastures and fodder cropping farmers in south-east and south-west Australia's medium/high rainfall zones can increase productivity through capitalising on rainfall 12 months of the year and increasing the versatility by being able to harvest or graze certain crops. The soil health and sustainability component mean that the integration of more perennial pastures and fodder cropping with increased manure additions to the soil and greater diversity in root types and sizes provide the basis for improved soil health which will be functioning and productive for the long term.

4.4 Risk

As all farmers understand risk is a part of the agriculture business. Yet for value of output, Australian agriculture is very volatile and one of the most volatile sectors in the Australian economy. Greater livestock numbers can level the risk profile of an operation. GRDC launched *The Grain and Graze* program developed for south-east and south-west Australian mixed farming operations since 2003 has "conducted research, development and extension activities to enhance the profitability and sustainability of farm businesses". This program, and greater work by Cam Nicholson (and others) from Victoria, have developed a method for better understanding risk within farming operations. As concluded by a GRDC report "enterprise diversity usually decreases risk" and there is a far reduced year-year fluctuation in returns for livestock operations compared to cropping in south-west Victoria.

Case Study 4: Kenny and Bonnie Miller, Bismark – North Dakota. Formerly Cropping and Livestock converted to almost fully pasture-based livestock

- **2017 Leopold Award Winner for Conservation Agriculture**

Kenny has a passion and enthusiasm for farming and sharing his ideas like few others the author has met. Kenny takes a holistic approach to farming and always has the animal and soil health in mind when planning and implementing changes on their property and also balance their ecological, social and economic resources. The Millers were operating a mixed operation with irrigated and dryland crops yet made the decision that there were greater long-term economic returns and soil health benefits to pasture-based livestock systems. They farm with high intensity short grazing periods and long rest periods to help the soil and plant health. They are moving more and more land back into perennial pastures by using fodder crops to build the soil up to the point where they then sow in a mix of mainly native warm season perennial pastures. The Millers have different fodder cover crops and are constantly seeking innovation and undertook formal trials to assess the benefits of “bale grazing” and found a four-fold increase in pasture production in these areas. The millers through the modified management have been able to triple their carrying capacity as well as the resilience of the farm.

Figure 14: A group of photos from the Millers properties who practice “soil conservation” practices including perennial pastures, cover cropping, mob grazing and bale grazing. Source: Author

Chapter 5. Soil Amelioration

Soils are highly variable across the globe, and it must be understood that each production area has its own soil strengths and weaknesses. Sodic soil amelioration can occur at a physical, chemical, and biological level and holistic soil function should be kept in mind when sodic soil amelioration strategies are being formed. Traditionally the use of calcium carbonate (lime) and calcium sulphate (gypsum) is a cost effective means of reducing the impact of dispersion by substituting the monovalent na+ with the divalent Ca2+ within the clay particles * http://extension.colostate.edu/docs/pubs/crops/00504.pdf. The limitation of calcium-based ameliorants in an Australian setting can be dense subsoils and low rainfall (and associated slow leeching) preventing the removal of substituted Na+ from the root zone creating the need for a frequent (1–3-year gypsum or lime application).

Physical deep tillage alone has been another method to improve drainage and reduce physical resistance to root penetration, a process which is also limited in its benefit beyond one seasonal wetting and drying cycle due to chemical environment causing the structure to disperse when wet and reform the highly uniform and dense structure when dry. Various trials have been undertaken with deep tillage in combination with the deep placement of ameliorants such as lime and gypsum or recently organic material (chicken litter or compost) in a process termed sub-soil manuring. Sub-soil manuring is performed with the intention of improving the soils physical, chemical and biological characteristics of through physical deep tillage, the placement of organic material at depth increasing microbial activity which in combination of phytoremediation with plant roots improves the soil porosity through increased clay aggregation. Sub soil manuring trials have shown great promise in improving crop and pasture performance and long-term improvements in soil structure there has been a major limitation in access to machinery to perform this task. A major focus of the authors international research was to investigate machinery with the objective to designing and building a machine for Australian conditions.

5.1 Global Subsoil Amelioration

Case Study 5: Radium Engineering, Northwest Province, South Africa

- Soil Constraint: Variable including hostile sodic clay subsoils
- Ameliorant: Varied, composted materials, fertilisers, Lime, Gypsum or blends
- Machine: Chain floor hopper, material fed into soil opening created by ripping shank
- Acknowledgements to Compost Matters for access to their machine

South Africa and Australia share similar climate and agricultural production systems and face many similar challenges therefore it would make sense that a machine designed and built in South Africa would have application in Australia.

The Radium Engineering machine utilises a fertiliser type chain floor bin built on top of a deep ripping frame with tines that create an opening for the material to fall to the bottom of the rip zone. This type of machine when performed at the right time of the year provides the ability to fracture the dense clay subsoil creating a more root friendly subsoil as well as allowing the ability for topsoil to fall into the newly formed cracks etc. The placement of the compost at the bottom of the rip zone provides a reason for plant roots to go to depth while root exudates and the associated microbial activity aids in the aggregation of clay particles. The fracturing and deep penetration of the tines also allows top-soil to filter into the fractured soil creating a physical V. This newly slotted top soil allows improved water infiltration allowing for greater plant available water along with better nutrient efficiency with greater nutrient cycling within this zone. The machine has the capacity to handle a variety of ameliorants at variable depths and tonnage application per hectare.

Figure 15: A group of photos of Radium Engineering subsoil manuring machine owned by Compost Matters, this design has strong potential for improving sodic, dispersive soils. Source: Author

Case Study 6: Phillips Macerator Injector, South Africa/Australia

- Soil Constraint: Variable soils, hostile sodic clay subsoils
- Ameliorant: Varied, ability to handle a wide range of materials and turn them into a uniform biosolid
- Machine: Open hopper with a macerator auger in the base with an extrusion pump to move the newly formed bio-solid to the bottom of ripping tine.

The Wayne Phillips subsoil manuring machine is unique with significant potential for soil amelioration in Australia and around the world. This machine has the capacity to handle raw non-uniform materials by mixing the raw material with water in the hopper turning these non-uniform materials into a uniform and flowable paste which travels through a hose into a ripping tine at the rear of the machine. The capacity to handle a wide range of raw materials and change the ratio of different additives if desired will make this machine valuable to a wide range of farmers who have different raw materials. Raw materials such as straw which are readily available to most arable farmers with added nutrients required to ameliorate the specific farmers soil could be incredibly valuable and help reduce the cost of amelioration.

Figure 16: South African designed subsoil amelioration machine has the capacity to handle a variety of raw materials with different consistency Source: Author

Case Study 7: Flex Fertiliser Systems, Flyn, Denmark

- Localised/On Farm Liquid Nutrient Blending
- Ameliorant: Custom blend liquid for soil requirements
- Machine: Sophisticated plant and storage for mixing nutrients

As research reveals a greater understanding of soil constraints and the types of amelioration techniques required to overcome these constraints, better targeting of the optimum ameliorant to the right soil can occur. If physical amelioration is required and either with or without the addition of organic (compost/manure/straw) or calcium (gypsum or lime) material, there will most likely be the need to compliment these processes with other micro or macro nutrients. An extremely efficient mechanism for adding these extra ameliorants is through liquid fertiliser added via a liquid line behind the ripping tine. Flex fertiliser systems have a system which allows a farmer or group of farmers to build a small plant in an area and create custom liquid fertiliser blends according to need. Soil amelioration liquids could be a fantastic compliment to a wider liquid fertiliser program for a large farm or group of farmers.

Figure 17: Danish liquid nutrient company and plant which is available to farmers globally who intend on using liquid fertilisers as apart of their system and has application for soil amelioration. Source: Author

Case Study 8: Dr. Len Leskiw – Industrial land reclamation, Edmonton, Alberta, Canada

- Soil Constraint: Compacted Clay Subsoils due to heavy machinery
- Ameliorant: Pelletised Compost
- Machine: Small hopper with small transfer auger and gravity injection over a three-point linkage dual tine ripper with curved shanks

Canada is a resource rich country with large volumes of crude oil extracted for domestic and export markets. Travelling across the rural areas of Canada it wouldn't be unusual to see pumpjacks drawing oil from the underground reserves. When these bores become uneconomic the hardware is removed and topsoil added back to the sites, due to significant subsoil compaction, returning this land to agricultural production can be challenging. Len created a company which consults on reclamation and assists in the regeneration of land for resource companies. Len had major challenges with regenerating these damaged soils and had the idea of sub-soil manuring when he was considering similar principles done in gardening. Many years later and with over a hundred sites regenerated Len has built a subsoil manuring machine for the deep placement of pelletised compost. While the machine has a small capacity, its design foundations are strong and it has a very novel idea of a large curved shank an attempt at increasing the soil de-compaction. The machine as shown in the photo has a flexible gravity feed tube behind the curved tine. The material is transferred in a small auger from the base of the hopper to the pipe above the ripping tine.

Figure 18: Dr Len Leskiw shown with the subsoil manuring machine he has design and had built for the reclamation of industrial land Source: Author

Case Study 9: Prairie Agricultural Machinery Institute (PAMI) – University Saskatchewan

- Dr. Hubert Landry, Humboldt, Saskatchewan
- Soil Constraint: No constraint, machine designed for better management of manures and environment
- Ameliorant: Swine, beef feedlot manure, poultry manure or digester effluent
- Machine: Shallow incorporation system, auger floor hopper with multiple auger distribution out to a disk opener

Canada has significant volumes of indoor and outdoor intensive animal production and a visit to Lethbridge (locally known as Feedlot Alley) in Alberta shows the extent of these industries. The manure produced in these feedlots commonly gets spread on the farms closest to the feedlots for economic and logistics reasons. This often creates a zone close to these facilities which can be heavily treated with animal manures creating environmental issues with the build-up of certain nutrients and runoff into waterways. PAMI were contracted to build this subsoil injection machine to improve the uniformity of application of solid manures with the ability for shallow or deeper injection at a wide range of injection rates. This machine utilises a reasonable size bin with an auger floor. The machine moves the manure to another smaller hopper at the rear of the machine which uses a series of augers to get the manure into centreless auger which distribute the material to disk openers on a frame attached to the bin. This is a novel design with augers for moving solid material with some allowance for variable uniformity of material. The system also allows for scaling up the machines width as the centreless augers which can distribute out in different directions. The system does have a large degree of complexity and requires significant horsepower to run which may impact on it from a construction and operating cost perspective.

Figure 19: The PAMI solid manure injector system from its operating period Source: PAMI <u>http://pami.ca/crops/agronomy/manure-research/</u>

Figure 20: A group of photos of the PAMI solid compost injector including the auger components Source: Author

Case Study 10: Husky Farm Machinery – Bio-Solid Injector, Ontario, Canada

- Soil Constraint: No constraint, machine designed for the improved management of town waste and the reduced odour and runoff of these ameliorants
- Ameliorant: Treated town wasted in a bio-soiled form
- Machine: Shallow incorporation tine system with vacuum unit rotary pumping system

The team at Husky Manufacturing have come up with a commercially available bio-solid injection system which could be easily modified to inject organic by-products into the hostile Australian subsoils. The system is a unique combination of different technologies to form a machine which can apply organic material to agricultural soil while reducing odour levels, runoff of nutrient into water ways and reducing oxidative loss of nutrient to the atmosphere. This machine has fantastic potential to farmers who have a semi-liquid material from piggeries or dairies or able to economically liquify solid products. The commercial availability of this machine is advantageous and reduces the uncertainties with designing and custom building a machine.

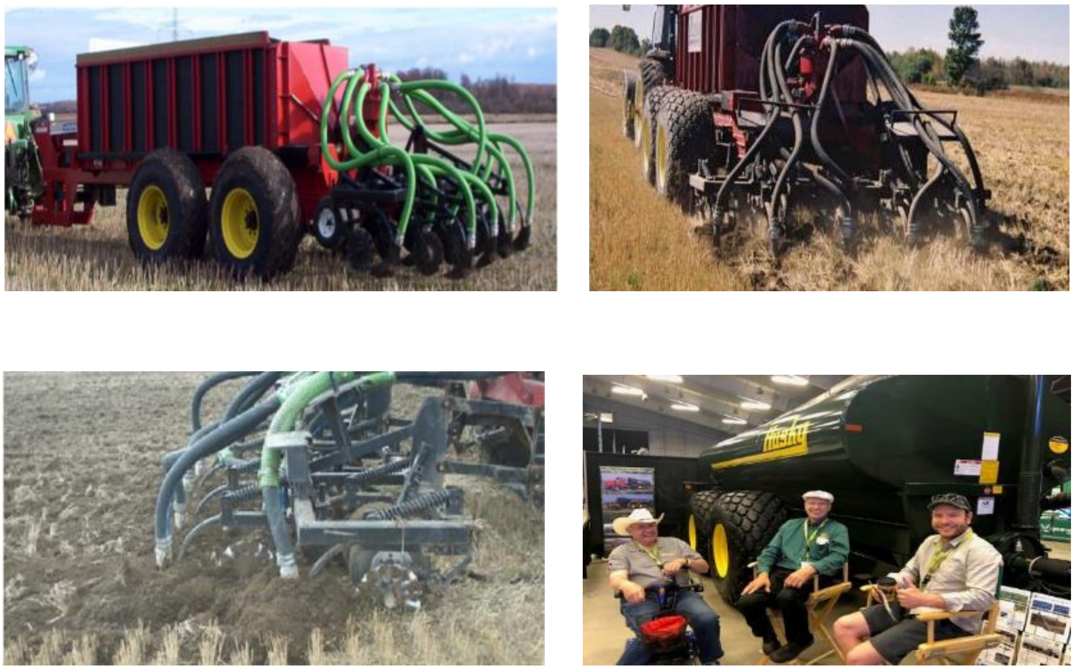


Figure 21: A group of photos of the Husky engineering staff and machine built for the injection of bio-solids Source: Husky Canada and Author

https://embrofarm.com/helper/viewpdf/tar/aHR0cHM6Ly9lcXVpcG1lbnRzZWFyY2guY29tL3VwbG9hZGVkaW1hZ2VzLzgzMzkvYmlvX2luai5wZGY=

Case Study 11: Veenhuis Machines, Raalte, Netherlands

- Soil Constraint: No constraint, machine designed for the improved management of liquid manures in agriculture
- Ameliorant: Slurry, liquid animal manures
- Machine: Shallow incorporation disk and tine machines

Europe has a large volume of housed intensive animal production and has strict regulation about the timing, method and rate of manure application. Most of this manure is liquid and there is a large market for liquid manure injectors/applicators through Europe, Veenhuis is a large supplier of these types of machines. They are highly sophisticated, and designs built for high speed application. Veeinhus have an extremely forward-thinking ideology and their company moto is they contribute to “nourishing soil, plants animals and humans. A sustainable agriculture sector and food chain is a worldwide goal. We believe in a closed cycle of natural manure and thus the optimal use utilization of nutrients”. Australian operators who have access to slurry products could easily modify the applicator design of a Veenhuis or similar machine to apply slurry or other liquid products at depth into clay sub soils.

Chapter 6: Australian Sodic Soil Picture

Australia has its own unique climate and soils with a high proportion of sodic soils relative to most other countries around the globe, so it is important to make reference to some of the work being undertaken locally to overcome sodic, dispersive soils here in Australia.

Many universities and research bodies are currently undertaking research for the best management of sodic dispersive soils, building upon a catalogue of research from previous years. The GRDC have been a strong supporter of the work into sodic dispersive soils and have a significant number of reports into this research. Currently there is a project led by Dr. Fiona Robertson and assisted by Jim Zwar investigating the impact of waterlogging and have some early findings suggesting the potential for new genetics in waterlogging tolerant barley and the potential for phytoremediation using deep rooted crops such as Lucerne to improve clay aggregation.

GRDC are supporting a significant series of research trials across four south-eastern Australian states led by Dr. Roger Armstrong investigating the impact of a variety of soil ameliorants on sodic, dispersive soils. The short- and medium-term soil amelioration will be heavily supported by the findings of this current series of research trials and the significance should not be understated. The understanding of the impact of specific ameliorants in certain soil types under different seasonal years will support the information feeding into the modelling which farmers can apply to their own situation.

6.1 Sustainability Victoria, James Hawkins and Tilco Engineering Project

As a result of Nuffield research, which has built upon earlier work, there has been a project born for the construction of a commercial scale Australian built subsoil manuring machine. Sustainability Victoria have a desire to reduce the volume of organic material from urban centres ending up in landfill. The subsurface application of recycled organics has the potential to be highly beneficial to local farmers and reduce the impact of non-hazardous contaminants which can be present within some recycled organic material. This project begins a new era for soil amelioration within Australia and has potential to expand into a significant sub-industry within agriculture.

Case Study 12: Yaloak Estate – Ballan – Victoria

- Soil Type – Mixed – Duplex with dispersive subsoils
- Rainfall zone – High

Yaloak Estate at Ballan, west of Melbourne, are unlike any other farm or business visited in Australia or around the world. Scientific inquiry and innovation are so deeply embedded into their DNA it is hard to know where research and business start and stop and they have so magnificently interwoven both that their long-term success can possibly be attributed to the marriage of these disciplines. Under the leadership of Yaloak's owner Peter Yunghanns, there has been a systematic investment in human intellectual development and the involvement both directly and indirectly of Australian agricultures great minds through research relationships. Yaloak have learnt in detail their available resources and the natural resource limitations and manage in a way that maximises the use these resources and constraints to get maximum production. Yaloak have been at the tip of the spear with moving Victoria's high rainfall zone from majority livestock in the 1980's into a far greater proportion of cropping today with the use of innovative thinking and highly calculated risk taking. Yaloak have understood the dispersive nature of the soils and the limits which the waterlogging/hard setting soils were putting upon them and have teamed up with soil scientists such as Peter Sale from La Trobe University to better understand these soils and develop strategies to overcome them.

Conclusion

A holistic approach to management including crop and pasture rotations, livestock and cropping integration, soil health, productivity, economics and a long-term focus can help farmers manage their sodic dispersive soils and the associated constraints.

Farming is about employing available resources in the most effective manner which creates value for the organisation and people involved with that farm. Productivity is one of three (productivity, price, costs) pillars which contribute to the profitability and longevity of agricultural enterprises and ensuring the land is functioning correctly is essential to the longevity of the business.

Moving the mindset

Farmers have a unique connection and understanding of their land and how it performs under different crops and fodder varieties during varying seasonal conditions. These intuitions can now be supported by readily available and cost-effective sensor and software technologies which can be integrated into a farms normal operation and provide empirical data which can feed into decision making to improve the productivity and profitability of a farm. Farmers can use the new technologies and algorithm-based software programs to understand their land, how it functions and financially compare different options for ameliorating constrained soils.

Soil categorisation and technology integration

Soils including sodic, dispersive soils can be geo-physically categorised, mapped through Top Soil Mapping (TSM) technology to better understand the physical and chemical properties of these soils. This information can be supported by chemical and physical analysis through grid sampling and coring to understand the factors which may be restricting function such as sodium, magnesium, aluminium, organic matter, pH, bulk density. Crop health information such as satellite or drone style NDVI data can provide crop health information throughout the year and overlayed with rainfall levels to better understand if areas are becoming waterlogged. The use of yield monitoring technology is standard on all combine harvesters built today which reveals the yield performance of the crop. These different data “layers” can help farmers analyse the performance of different areas of the farm and feed into management decision making about potential amelioration which can be support with analytic information such as @RISK.

Pasture and livestock for business diversity and soil amelioration

Integrating livestock, greater pasture phases into rotations and perennial pastures into a cropping property can be a risk management strategy, build resilience, increase solar and rainfall capture while reducing the constraints associated with sodic dispersive soils. When considering the impacts of management decisions, the five pillars to healthy soils are a great guideline and include soil cover, livestock integration, living root in soil as much of year as possible, minimal soil disturbance, diversity of plant and animal species. These principles are all relevant to sodic, dispersive soils and reducing their impact.

Soil amelioration

Well managed crop and pasture rotations, including the use of perennial pastures, are a great low risk strategy to improve soil health and reduce the impact of sodic, dispersive soils. Once soils are categorised and the decision to ameliorate an area has been made there are many options including any combinations of physical, chemical, phytological and biological amelioration which should be supported with good rotation management and agronomy for the years following treatment to improve and prolong the benefits of treatment. The process of subsoil amelioration such as subsoil manuring can help overcome sodic, dispersive soil constraints through promoting clay aggregation, increased microbial activity, nutrient cycling, improved soil water dynamics. The key to successful subsoil amelioration is getting the correct amendment at the right levels into the soil, research conducted by GRDC in their project DAV00149 headed up by Professor Roger Armstrong will be incredibly informative about responses to different amendments.

Amelioration machinery

Commercial machinery at time of writing is extremely limited yet there is a great deal of interest in this space as outlined in this report. As a result of this research and previous work, the author has entered into a project with *Sustainability Victoria* to build a commercial scale subsoil manuring machine. This will be the first commercial subsoil manuring machine available for hire in Australia and will mark the beginning of a new era for sodic soil management in Australia.

Recommendations

- Create a mechanism for understanding farm performance.
- Ensure agronomic management is at a high level to hit peak performance as much as possible.
- Identify specific constraints on productivity.
- Integrate available technologies to continually feed in information about performance to improve the potential for successful strategic decision making.
- Use sensor technology to categorise soils.
- Support soil mapping with soil sampling and coring to understand chemical and physical properties of the soil.
- Use crop health sensor information such as NDVI data overlayed with rainfall records and soil moisture data to assess the impact of waterlogging from sodic, dispersive soils.
- Create a strategy to improve performance by methodically modelling any soil amelioration strategies with the help of tools such as @RISK.
- Use management strategies such as rotations including phytoremediation by means of increased pasture phases, perennial pastures, cover cropping, pasture cropping etc.
- Use modelling tools to analyse the potential for subsoil amelioration and target soil types which will respond best to amelioration.
- Analyse the most appropriate ameliorant for certain areas and modify both depth, rate and type of ameliorant to the specific soil type.
- Create support networks with farmers and researchers to enhance knowledge.
- Finally, have a mindset which continues to improve productivity and reduce crop/pasture performance.

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Plain English Compendium Summary

Project Title:	Sodic Soil Management Increasing profitability in SE Australian farms
Nuffield Australia Project No.:	1803
Scholar:	James Hawkins
Organisation:	Partners in Growing Sustainably P.I.G.S Brippick Road Neaurpurr VIC 3413
Phone:	0419446058
Email:	jmhawk@outlook.com
Objectives	Develop a strategy for farmers to manage soil constraints through soil amelioration and management modification. Including framing the issues with soil constraints. The means on identifying soil constraints. Develop management strategies for combating soil constraints. Outline the soil amelioration options for farmers. Outline some the potential ameliorants for soil amelioration and create potential design options for the construction of a soil amelioration machine.
Background	James Hawkins and the wider Hawkins family have been looking to improve productivity and profitability by overcoming yield limiting sodic, dispersive soil constraints. James has undertaken on-farm trials investigating subsoil manuring since 2016 and also has written a paper on the potential for subsoil manuring under irrigation during a masters of agribusiness with Marcus Oldham College.
Research	The Nuffield 2018 project was a wide ranging 12 country investigation into soil constraints, soil categorisation technology, risk analysis and modelling, farm management, soil amelioration and amelioration technology.
Outcomes	A widely researched set of recommendations for a holistic approach to managing and overcoming sodic, dispersive soil constraints. A series of machinery options for the amelioration of sodic, dispersive soil and a machine to be built in Australia for the author available for use by the Australian farming community for the deep application of ameliorants into subsoils.
Implications	Provides value to farmers for the best way to manage soil constraints for the medium to long term. Provides the industry for a much-needed machine for the application of ameliorants on a commercial scale.
Publications	Nuffield Australia National Conference, Brisbane, Qld, September 2019