Addressing our sub-soil yield limitations by digging up the answers of localized soil constraints

A farmer friendly guide to sub-soil management across the Upper North

UNFS
Upper North Farming Systems

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This literature review has been compiled as part of the National Landcare Program: Smart Farms Small Grants Round 4 project 'Building soil knowledge and capacity to implement change in the farmers of the Upper North Agricultural zone of South Australia. Improving soil structure and function to improve plant health, landscape function and farming system resilience'

CONTENTS

INTRODUCTION

This review aims to analyse available literature regarding sub-soil constraints relevant to South Australia's Upper North growing region and farming systems. These constraints were identified through a region wide survey directed at growers and agronomists in collaboration with localized soil science knowledge. It is written as part of a project funded by Smart Farms Small Grants Round 4 and will summarize some of the questions around yield limiting sub-soil constraints leading to loss of soil structure, function and management. This literature review will provide Upper North (UN of SA) farmers tools to help identify potential constraints paired with local examples of practical and cost effective soil remediation activities & best practice soil management.

What to expect from this review

01. An overview of the project and our localized soil type.

02. A review of results gained from a region wide survey. This was taken with the aim of baselining current knowledge, uptake of soil amelioration techniques and knowledge gaps that this project work aims to address.

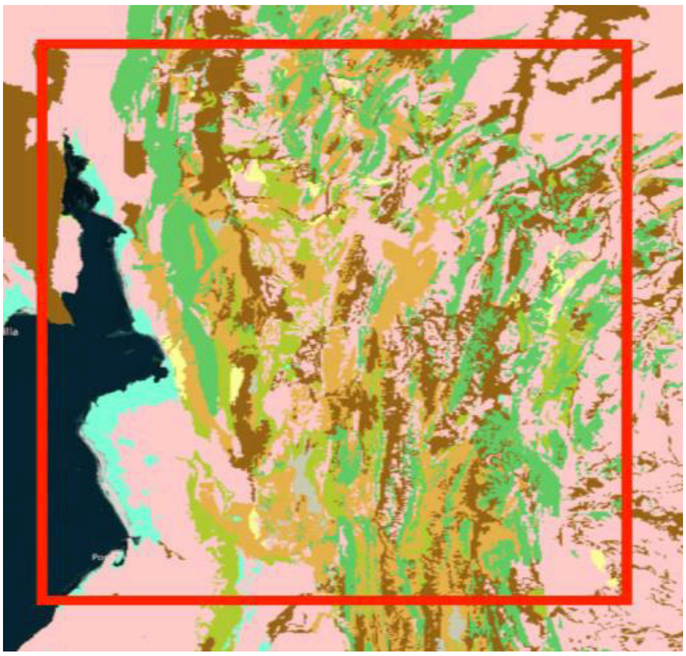
03. The review will then break down sub-soil constraints experienced across our growing region into a series of fact sheets, summarizing what the constraint is, how to identify such constraints and discussion around common amelioration techniques.

SOILS IN THE UPPER NORTH

This project aims to close the knowledge and language gap between farmers of the Upper North and the soil science community. Consequently, we aim to help growers identify and match yield limiting soil constraints with best practise soil amelioration techniques to ultimately achieve sustainable soil management. There are varying soil types spanning across our region, ranging from sand over sodic clay soils to hard setting red clays with limestone parent material. Soil types can change abruptly with topography and landscape, meaning farmers need an understanding of numerous soil types and how they change across our growing farm sizes. This can increase complexity of soil management, with site specific management (SSM) of soils both between and within paddocks being a good option to help match management and inputs with soil type. This project aims to consider management of both cropping and pasture soils in line with our dominant mixed-farming systems utilised across the region.

Under long term farmer management, a shift in localised soil properties has been observed. This includes changes to pH, organic carbon (OC), electrical conductivity (EC) and nutrition. Historically described as an alkaline landscape, the district is now known to have all pH combinations, with a trend toward acidification in some soil types. Organic carbon has also fluxed throughout management history, now typically stabilised or trending upward, resulting in the slow improvement of soil structure. Some management practises accelerate this positive change which will be investigated throughout this project. Lastly, sodicity and salinity is also a dynamic factor in the landscape with areas experiencing dryland salinity, dependant on growing region and rainfall. These factors and the influence each has on crop and biomass yield will be discussed in this paper and explored throughout the lifespan of this project, assessing the viability of common and novel soil amelioration techniques available to Upper North growers.

Dominant soil types identified throughout the Upper Mid North growing region include chromosols and sodosols, with calcarosols and tenosols also identified to a lesser extent (figure 1). These soil types have an overarching influence on yield potential and productivity.



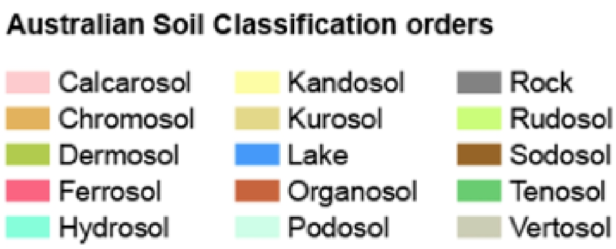


Figure 1: A map of South Australia's Upper North region, showing the areas of different soil orders (CSIRO SoilMap 2018).

Chromosols:

Brown and red Chromosols, such as those found in the Upper North, are typically found in well-drained areas with annual rainfall between 350 and 600 mm. Chromosols tend to have moderate chemical fertility and water-holding capacity, giving them moderate agricultural potential. Chromosols can be susceptible to soil acidification and structural degradation. The defining characteristic of a chromosol is a texture contrast soil that is not acidic or sodic in the B horizon and are rich in iron giving a red or dark brown colour

Sodosols:

This order is characterised by a highly sodic sub-soil but is not highly acidic (pH >5.5). Sodosols are only found in poorly drained sites, either due to low rainfall or compaction layers leading to reduced infiltration. They generally have very low agricultural potential due to their high sodicity, poor structure, high erosion risk, low permeability and low to moderate chemical fertility. Sodosols can also have problems with salinity. Sodosols are classified when the B horizon has an exchangeable sodium percentage greater than 6%. Sodosols are often

Calcarosols:

Characterised by their calcium carbonate content, typically concentrated to the sub-soil layers. Carbonate is a type of free-lime, originating from parent material in-situ or aeolian (wind) deposition which has accumulated in the profile. Carbonate influences the ability of plants to access a range of macro and micro-nutrients. Calcarosols are found in either imperfectly drained sites where annual rainfall is up to 400 mm, or in well-drained sites where annual rainfall is between 250 and 500 mm. Calcarosols typically have low to moderate agricultural

Tenosols:

Typically, tenosols are very sandy and without clear horizons, defined as a weakly developed profile. Tenosols generally also have little structure, with high sand concentration. Typically, tenosols have lower agricultural potential due to their low chemical fertility and poor water holding capacity as a result of the high sand content. However, in marginal rainfall years, they can produce productive crops and pastures due to lower water retention which increases plant available water in low moisture environments. These soil types can

SUBSOIL CONSTRAINTS OF THE UPPER NORTH REGION

The subsoil is defined as the underlying layers of soil beneath the topsoil that often contain less organic matter and more characteristics of the soil's parent material. This is typically less weathered in comparison to the topsoils and is generally below 300 mm from the soils surface. However, the depth can vary depending on soil formation and erosional processes. Subsoil constraints are often the elephant in the room when it comes to improving land management. Soil management is often focussed on the topsoil as this layer has greatest impact on crop and pasture establishment however in marginal rainfall environments access to subsoils and its associated moisture is a critical piece in the land management strategy. Not only do subsoil constraints such as sodicity, salinity, acidity, alkalinity, and compaction have negative impacts on crop production, but also have on going environmental impacts that influence at a landscape level. Subsoils are a major driver for overall landscape productivity, with majority of the resources required by plants concentrated to the 300-900 mm fraction of soil. Additionally, when subsoils are compromised, topsoils are of greater risk of degradation with decreased capacity to grow biomass, leading to reduced ground cover. This increases risk of erosion which can lead to the loss of the most fertile fraction of a soil profile. In soils that are less hostile, effects can sometimes go under the radar, but still significantly reduce yield potential.

The main sub-soil limitations in the Upper North growing region, as identified by a grower and agronomist survey, are listed below.

Each of these constraints will be explored in detail, in the form of a fact sheet, discussing associated production limitations and how to best identify and ameliorate the relevant constraint.

Soil pH imbalances
- Acidity (low pH)
- Alkalinity (high pH)
- Macro and micro-nutrient deficiency including, but not limited to, nitrogen (N), phosphorus (P), potassium (K), sulphur (S) and calcium (Ca), zinc (Zn), copper (Cu), magnesium (Mg), manganese (Mn), molybdenum (Mo) and iron (Fe)
- Nutrient toxicity including, but not limited to, boron (B) and aluminium (Al)

Soil sodicity (high in sodium) and salinity (high in salts)

Compaction
- Low organic carbon and its impact on soil structure and structural stability
- Reduced porosity leading to lesser plant available water (PAW)

Non-wetting soil

Historically eroded soils leaving exposed sub-soil, commonly either gravel based or chemically imbalanced

Soil stratification
- A large difference in soil physical or chemical characteristics between top and sub-soil layers

From the above constraints, seven case studies have been formed to help identify the best practice management for each.
This is summarized below.

Table 1. Summary table for case studies that will be completed as part of this project.

	Case study title	**Description**
Case study 1	Pastures erosion on arable land	This project aims to match crop type and grazing technique, to impacts on soil erosion. This will focus mainly on soil erosion over the summer fallow period and the impacts this has on the overall soil health and function of the farming system. The expected outcome from this project is to produce a ranking system of management styles around the pasture rotation.
Case study 2 / 3	Improving soil structure and structural stability using a change to management	This project will be a two part study which aims to compare various management techniques commonly used to improve soil structure and structural stability. These include controlled traffic, use of a stripper front and full stubble retention and the incorporation of deep-rooted crop species.
Case study 4	Amending sub-soil constraints including acidity, sodicity and compaction layers	A deep ripping trial, aiming to move soil ameliorates into the sub-soil resource and hence correct issues found at depth. This will be a trial site using replicated treatments to identify the use of ripping as a tool to correct hostile sub soil conditions in a clay based soil type. The project will run over two growing season, established at the start of the 2022 growing season.
Case study 5	Use of precision agriculture mapping to identify and ameliorate constrains	A case study looking at high resolution soil map layers and how soil variation has changes over time with site specific management.

SOIL PH

What is soil pH?

pH is the measurement of hydrogen ions within the soil solution and can have a large impact on the availability of nutrients to plants (figure 2). The scale begins at zero, moving up to fourteen, with a value of seven being considered neural. Anything below seven is acidic and anything above, alkaline. Ideally, productive agricultural soils should be between a pH of six to eight and ideally six and a half, as this is where nutrients are most available to plants. Soils outside this range will show nutritional deficiencies and toxicities (figure 1). pH is on a logarithmic scale, meaning moving one pH unit has a tenfold change to the amount of acidity or alkalinity.

How are pH imbalances identified?

Typically, pH is measured in a laboratory using either a calcium chloride ($CaCl_2$) or water (H_2O) extraction. Typically, pH measured with $CaCl_2$ is used as this best represents what roots would experience more closely when compared to the water extraction method. pH needs to be considered through the profile and across the landscape as it can change quickly, altering management decisions. pH mapping is a great tool, available in our region, to identify such changes. Alternatively, zoned aggregate sampling and stratified layer sampling are further options.

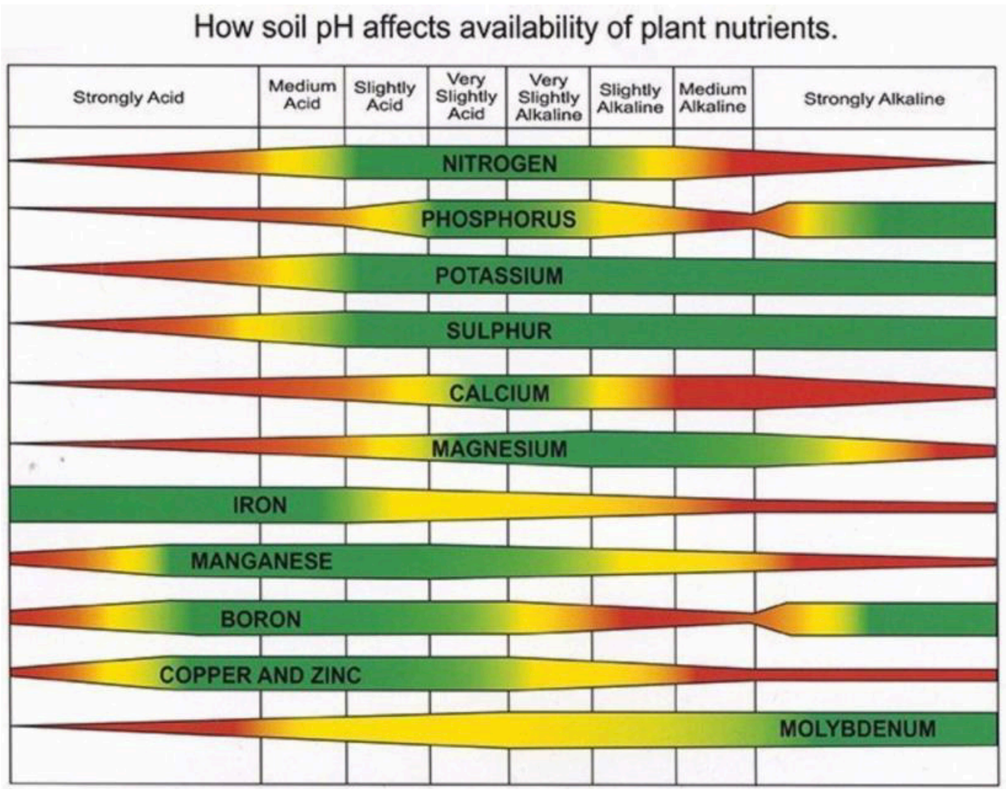


Figure 2. pH scale showing the availability of nutrients required for plant growth (AgroBest, 2017).

Current amelioration techniques / management

Soil Acidity:

For acidic soil resources, the addition of either calcium carbonate, (lime), or magnesium carbonate (dolomite) can help correct topsoil acidity. pH corrections become more complex moving into subsoil layers as lime applications can take time to move through the profile due to low solubility and is dependent on degree of soil incorporation and rainfall. Lime rates are calculated on the desired change to pH, soil texture and quality of the lime resource. When considering quality of lime, two factors; particle size and neutralizing value, are considered. Finer sources are better when attempting to ameliorate a subsoil constraint as they have greater solubility and capacity to move through the profile. Modern land use practices are naturally acidifying our soil resources and therefore maintenance lime is now becoming necessary across more areas. This is as a result of fertiliser use, export of nutrients in the form of harvest products, incorporation of legumes into our cropping rotation (which excrete acid from roots in an attempt to increase phosphorous availability) and natural leaching of cations down the soil profile with water movement. Maintenance applications of a neutralizing product is therefore becoming increasingly important. Some growers turn to lower quality lime and dolomite sources, as these typically are lower in solubility and hence are 'slow release'. Alternatively, novel research is considering the application of bio-solids to help maintain pH, with the added benefits of micronutrients and organic carbon to the soil at the same time.

Due to our mosaic of soil types, pH within paddocks often move from acid to alkaline conditions abruptly. This can be attributed largely to the presence of carbonate out-crops/limestone parent material, typically seen in rising ground. Therefore, whole paddock aggregated sampling paired with blanket lime applications are not well suited to our area. By surveying pH change across paddocks and targeting lime application to the acid areas of the paddock, growers are better able to avoid further increasing the pH of alkaline areas in paddocks. This leaves more lime / dolomite to target acid areas of the paddock enabling the speed at which these areas are raised to a pH of 6.5 ($CaCl_2$).
The decision between lime and dolomite is based mainly on the requirement of magnesium within the soil resource. Dolomite is generally more expensive compared to lime and so if magnesium is not required, lime is typically preferred.

Soil Alkalinity:

Soil alkalinity cannot be as cost effectively managed with a soil amendment compared to acidic soils, but is typically managed using strategic land management decisions. In alkaline soils, plant accessibility to nutrients is significantly reduced (figure 2). This is particularly true for phosphorous, iron, copper, zinc, manganese, and nitrogen. Therefore, increased phosphorous rates resulting from the tie up of phosphorus may be required, depending on parent material of the soil. Additionally, the foliar application of nutrients in-season may address annual nutrient deficiencies. This essentially by-passes the soil to prevent tie up and loss of nutrients through entering the plant from above ground biomass. Areas of high alkalinity will also have a negative impact on herbicide efficiency, crop safety and break-down of certain applied agrochemicals which should also be considered.
Typically, alkalinity in our area is caused by carbonate or free lime within the soil resource, as mentioned above. Many of these soils are in medium to low rainfall areas, further inhibiting the use of increased fertilizers to address the increased tie up of P.

Table 2. Neutralizing resources available to growers throughout the Upper North growing region, as identified by project work completed by Brian Hughes and Andrew Harding

Source	Product
Tantanoola	Dolomite
Coffin Bay	Lime Sand
GEM Telfords	Limestone
Rapid Bay	Lime Sand
Southern Quarries (Sellicks Beach)	Limestone
Henschke (Naracoorte)	Limestone
Penrice Quarries (Penrice)	Limestone

SOIL SODICITY AND SALINITY

What is Soil Sodicity and Salinity?

Soil salinity considers the salt content of the soil; with soils high in salts severely limiting plant growth due to the reduced ability of plants to access water (osmotic potential) and nutrients (ionic potential). A vast majority of Australian cropping land is at risk of salinity due to rainfall containing small concentrations of salt, parent material introducing salts and the rising of saline water tables as a result of increased deep drainage as a result from reduced deep-rooted perennials used in our growing systems (Price 2006). In-season rainfall will have an impact on the severity of symptoms. In drier years salts are less diluted due to limited moisture within the soil profile. This makes symptoms much worse in drier years. Alternatively, wet years help salts to leach beyond the plant root zone and have a higher dilution effect, lessening symptoms. A good analogy to help explain this is a glass of cordial. In dry years, the glass has less water to help dilute the cordial and so it is stronger. However, in a wetter year, there is more water resulting in a higher dilution of the cordial.

Sodicity refers to the excessive content of sodium (Na) relative to the other cations (calcium, magnesium, potassium) on the soil exchange sites and in soil solution. Whereas salinity refers to the presence of salts (both cation (positively charged) and an anion (negatively charged)), commonly sodium chloride (NaCl), within the soil solution. A soil is classified as sodic when the exchangeable sodium percentage is greater than 6%. Soil sodicity can occur solely or in conjunction with salinity. Soil sodicity results in poorly structured soils with slow infiltration rates and poor plant available water capacity.

Figure 3. image showing the impacts of dispersion, caused by sodicity, which limits plant establishment due to the formation of a hardpan within the top layers of soli (Tullberg et al 2007).

How is soil sodicity & salinity identified?

Growers can identify sodicity via a simple in-field dispersion test, where aggregates of soil are placed in a plate with water. If the soil disperses, turning the water milky, then it is reasonable to conclude the soil is sodic. However, in order to quantify the exact level of sodicity, growers are required to send soil samples away for analysis. A comprehensive soil analysis will report the exchangeable sodium percentage (ESP). This measurement will consider the sodium content in relation to the texture (cation exchange capacity) of the soil. When the ESP is greater than 6% the soil is classified as sodic.

Typically, the salts in a saline soil are introduced from the water table rising due to dryland salinity. Salts can be measured using a laboratory test, giving a reading of electrical conductivity (EC) and concentration of individual salts. Often two readings are reported, EC1:5 extract and ECe. ECe is a calculated EC that accounts for the soil texture making the EC reading easier to interpret when comparing soils of varying texture. Each of these have associated thresholds, matched with farming systems and species. Thresholds are different dependent on crop type. Barley, canola and rye grass are considered highly tolerant to salinity and sodicity compared to wheat, lucerne and peas which are moderately tolerant, and clover or medic considered low in tolerance.

Figure 4. Example of simple dispersion test, with the sample to the left extremely dispersed and the sample to the right only moderately dispersed (Beth Sleep, 2021).

Current amelioration techniques /management changes

Sodicity

Sodium can easily become bound to the cation exchange sites (CEC) of a soil, meaning ions are held in the plant root zone. If sodium is bound, then the application of gypsum (calcium sulfate), which replaces the sodium on the CEC of the soil with calcium, will allow the sodium salts to leach beyond the plant root zone. In some scenarios, where subsoil layers are sodic, then deep ripping in combination with deep placement of gypsum maybe required to help leach salts.

Table 3. Gypsum products available to the Upper North growing region, as identified by the agronomist survey completed as part of this project.

Gypsum sources nearby;
Penrice
Morgan (subject to licensing)
Blyth

Salinity

Salinity cannot be easily managed with a soil amendment, but rather managed with altered land care. Salts can be removed from the plant root zone via careful leaching, while water tables can be managed by increased water use efficiency (WUE) and the adoption of deep-rooted plant species into the system. In drier years, salts do not leach as much, meaning saline symptoms will be more prevalent. Crop type should be considered in these years, matching tolerance to salinity levels. Infiltration of the soil plays a big part in the leaching of salts, with compacted soils being linked to reduced water movement down the profile. Improving soil cover and reducing bare soil exposure will reduce the movement of saline water toward the soils surface from underlying layers.

ERODED SOILS

What are eroded soils?

Localised soils can exhibit areas of erosion, commonly concentrated to hill tops, where bare gravel rises, containing little to no topsoil (figure 6). Topsoil is typically eroded as a result of both previous land management and local hilly terrain. Repeated cultivation of these soils throughout early cropping years soils left exposed and depleted of structure. The topsoil in these areas moved to lower lying areas of the paddock, meaning depressions are generally more fertile with a thicker, productive topsoil and hill tops are shallower and often with exposed sub-soil at the surface. These are now typically found as our alkaline hill tops where free lime /carbonate has been exposed, typically lower in productivity.

Alternatively, modern day erosion is typically associated with vetch pastures or legume stubbles, where livestock are left to graze paddocks over summer. The legume residue is often not thick enough to provide adequate cover to hold together soil structure and reduce wind velocity over summer, in combination with livestock moving across the paddock.

Current amelioration techniques /management changes

Due to significant soil loss, eroded hill tops generally require longer term amelioration strategies. These areas are essentially functioning with a pseudo-topsoil comprising of the exposed subsoil material, which takes decades to function as a more typical topsoil. The addition of organic amendments to these areas can help to accelerate the process of building structure, function and promoting biological activity. These hilltops are often alkaline in nature, resulting in nutrient availability and agrochemical safety should be considered, as mentioned in the pH section of this review.

Legume based pastures such as vetch, are often utilized as a cereal root-disease break crop. Therefore, growers are often hesitant to add a cereal or brassica species to the diversify the mix due to complexity in weed and pasture management. Where this is an option, the addition of another species can help to hold the soil resource together over summer. However, where this is not an option, rotational grazing may be a better fit. This increases the ability to control how the paddock is being grazed and can help to maintain reasonable levels of ground cover over the summer period.

Figure 5. A soil core collected on an eroded hill top, highlighting the missing fertile top soil layer reducing in delayed and patchy crop emergence which limits yield potential.
Photo source, Beth Sleep

COMPACTION

What is compaction?

Soil compaction is defined as an increase in soil bulk density. Soil compaction is a physical constraint that induces a variety of issues such as reduced water and nutrient holding capacity, reduction of porosity which impacts water and root movement and suppresses microbial activity. One major factor contributing to a lack of soil structure is a deficiency in soil organic matter which acts as a glue, holding together primary particles to form the primary structure of a soil. Sandy soils are more prone to soil compaction; however, compaction is observed right across our growing region. Compaction is also associated with various other negative implications such as soil erosion or the occurrence of dispersion and can be linked with sodicity.

How is compaction identified?

Soil compaction can be identified using a hand penetrometer, which show the force required to insert a probe into the soil resource. This should be completed only when the soil has reached 'field capacity', or in other word, is at peak water retention. UNFS has access to one, should you be interested in measuring compaction on your farm. Alternatively, soil pit analysis, and considering soil structure and rooting depth can inform the level of compaction in a given soil. Lastly, the ability of a soil to infiltrate water can help identify how good soil structure is.

Current amelioration techniques /management changes

There are various methods growers can employ to reduce the effects of compaction. Among these include increasing organic carbon levels within the soil. This may include reduced soil disturbance associated with seeding practices, the use of stripper fronts or increased stubble retention. The reduced disturbance of soil with seeding operations reduces the loss of carbon into the atmosphere with the introduction of oxygen into the top-soil layers. Alternatively, stubble retention or the use of stripper fronts acts to increase the amount of carbon cycling, sequestrating carbon into the soil resource. Other more novel methods used to increase carbon content of a soil include spreading carbon rich products such as bio-solids and animal manures or growing green/brown manure crops. The continual incorporation of organic matter acts to hold aggregates together, forming a primary level of structure within the soil. Some soil types will require physical intervention such as ripping or delving to alleviate the soil compaction, then best management practice for soil cover and reduced disturbance are employed post strategic physical soil intervention.

Tap rooted species, such as canola, can be used to create 'bio-pores' within a compacted soil. These species can exert a greater pressure, in contrast to cereals, to push through compaction layers, leaving channels for following crops to then utilize and build on. This can expose soil layers that were previously inaccessible to plants, increasing plant access to moisture and nutrients.

In addition to the above, the use of controlled traffic farming can help to concentrate compaction within paddocks, with traffic being identified as a primary cause of compaction.

The trafficability of a soil resource should be considered before driving over a paddock. With increased water content, the soil becomes more susceptible to compaction. With the boom spray being the most common implement driving over soils throughout winter, when soils are at the highest moisture content, it may be a viable option to follow controlled traffic for the boom spray, as a minimum. This takes away the pressure of changing axle widths on all machinery, if you have not already do so. Likewise, moisture content should be considered before deep ripping a

Ripping when the soil resource is too wet can result in 'smearing', creating vertical compaction columns where ripping was attempted.

NON-WETTING SOILS

What are non-wetting soils?

A soil is considered non-wetting if it does not absorb water but actively repels (beading) water after its application to dry soil. Hydrophobic or water repellence is commonly associated with sandy textured soils. Hydrophobicity occurs when waxes from organic matter coats sand particles, significantly decreasing the ability of the soil profile to infiltrate water. This leads to irregular infiltration and reduced plant growth due to limited water availability (figure 3). With this comes increased likelihood of erosion due to limited ground cover and land becoming unproductive, with sand being highly susceptible to water erosion due to poor structure.

How are non-wetting soils identified?

Unlike many other soil constraints, non-wetting soils are easily identified without sending away any samples for laboratory analysis. If water droplets bead after being applied to the soil surface, that soil is considered non-wetting. Non-wetting sands can be easily identified indirectly using in-season NDVI maps, showing a difference in biomass and establishment, with poorer areas potentially non-wetting.

Figure 6. Non-wetting sand soil profile, using blue dye to illustrate the irregular infiltration of water down the profile (The Observer 2018).

Table 4 . A summary of symptoms that can be used to assess the severity of water repellence (Agriculture and food WA, 2018).

Severity of water repellence	Typical visual symptoms	Water droplet penetration time (seconds)
Mild	Estabishment impacts in dry seasons only and with early dry sowing. Small lengths crop row missing, typically less than 50cm of row. Water entry generally good but small dry patches can be found after small rainfall events.	10-60s
Moderate	Establishment impacts in many seasons but less pronounced or non-existent in seasons with a wet break and consistent follow-up rains. Water ponds on surface after rain for up to 5 minutes. Moderate lengths crop row missins, up to 100cm row.	60-240s
Severe	Establishment impacts in all season, very poot establishment in most seasons, large gaps in crop rows, with gaps up to 100cm or more of row common. Water ponds on the surface after rain for up to 10 minutes or more. Large patches of poor crop establishment and growth.	>240s
Very severe	Establishment very poor in all season, sparse crop establishment. Large patches of missing crop and poor emergence, very sparse crop. Water pond on the surface after rain for more than 10 minutes.	>240s

Current amelioration techniques /management changes

Remediation can include additions of clay in the form of clay spreading, delving or spading, adding wetting agents/ surfactants to the soil or additions of organic matter such as animal manures. The addition of clay and organic matter increases the overall surface area of the soil, which is then unable to become coated by the waxes. Additionally, these particles can form soil structure, a property largely lacked by sands, providing increased porosity to the soil and thus adding to the water holding capacity of the soil.

In texture contrast soils where there is a suitable source of clay in the sub-soil, this can be delved or spaded, depending on the depth of the source, to bring clay to the surface horizons. The clay source should first be tested for pH, chemical composition, salinity, and mineralogy to ensure it is suitable. The addition of unsuitable clay could lead to further constraints such as soil alkalinity or high free lime content. A technology enabling producers to identify areas where clay is present in the sub-soil is electromagnetic soil mapping (EM-38 survey). This can produce maps directing the grower to exact areas of paddocks were spading and delving are a viable option, avoiding shallow rock or areas lacking clay.

If there is an absence of clay down the profile, then clay needs to be brought in from another source and spread. Typically, this is a less economical option in contrast to delving or spading. Alternatively, manures or bio-wastes can be applied to the soils to add organic matter, contributing to soil structure. These can be sourced from animal feedlots, chicken farms or from waste treatment plants. A major consideration when spreading manures or bio-wastes is heavy metal contaminants. These can accumulate with the repeated use of these produces. Additionally, caution must be taken when applying such amendments, as they can contribute to hydrophobicity.

A cost effective annual option is the application of surfactants/ wetting agents, applied at sowing each year. These products are a temporary solution and therefore need to be re-applied each season.

SOIL CHEMICAL STRATIFICATION

Figure 7.

What is soil chemical stratification?

Stratified soils are characterized by soils which abruptly change either chemical or physical properties when moving from the topsoil into the subsoil. This can change the way in which water moves through the profile and can also 'shock' the root system of plants, resulting in the lateral growth of roots after hitting these layers. If this is occurring, all resources beyond these layers are no longer accessible to the plant and hence resulting in a limitation to yield. This is becoming more frequently observed as a result of the concentration of inputs to the upper layers of the soil resource and is observed more commonly in lower rainfall regions due to reduced water infiltration to help move resources throughout the soil profile.

An example of a change in soil chemistry, commonly observed in our area, is a change in soil pH. For example, the topsoil may be alkaline, resulting from the application of lime to the soil surface. However, when moving down the profile, it may become acidic as a result of limited downward movement of lime to these soil layers (figure 7).

Alternatively, a similar phenomenon can be observed with clay layers. Over time in some soil profiles, clay leaches down the profile and concentrates in a narrow band somewhere throughout the subsoil, resulting in a sudden change to soil texture. This layer is often a zone of accumulation which slowly 'collect' salts and other elements within the soil over time, resulting in a hostile layer that roots struggle to move past, rendering the lower soil layers inaccessible even if they are not hostile (figure 8).

How are stratification identified?

A soil pit or core can help to identify these layers. Tracking root growth throughout spring is also another way of identifying a hostile layer.

Figure 8.

Figure 7. Soil taken from an open profile with PH indicator dye applied to each sample. This shows how pH changes down the profile, with an 'acid throttle' shown at this particular site Photo source, Michael Eyres.

Figure 8. An open soil pit, showing a duplex type face. The top fraction of soil shows good porosity with texture increasing abruptly at approx. 50 cm's. This may inhibit root growth past this point.

Current amelioration techniques / management changes

Novel approaches are currently being researched, as this is a newly identified limitation in agricultural production. Many of these include strategic tillage operations such as deep ripping and mixing of the soil resource or deep placement of soil amendments. Alternatively, soil biology can become important, helping to 'mix' the soil resource, making the profile more uniform. Promoting biodiversity throughout the soil resource is achieved with increased organic carbon, the energy source utilized by soil biology. Alternatively, the use of liquid amendments may help to increase the movement throughout the profile. This will however likely come at an inflated economic cost to the grower.

CONCLUSION

Soil resources are integral to any farming system, acting as the medium for plant growth, nutrient and water holding and biological cycling. Soil resources must be managed thoughtfully, ensuring soil constraints which limit productivity are remediated. As discussed in this paper, there is an array of agricultural innovations and technologies that growers can employ which manage these constraints and correct underlying issues. These are summarized in the table shown on the right.

These management techniques will be considered in the form of case-studies by this project to help identify the most economical options available to Upper North growers. As part of these case studies, different long-term management techniques will be identified throughout our growing region and necessary soil characteristics will be measured.

Managing acidity, alkalinity, sodicity and salinity

Table 5. adapted from CRC and Land Management 2006.

Surface Soil Constraint	Sub-Soil Constraint	Management
Acidic	Acidic	Add lime
	Alkaline & Sodic	Add lime first then; Add gypsum (consider deep-ripping to incorporate gypsum)
	Saline	Add lime Maintain or add surface cover (additions of straw are beneficial to reduce surface evaporation) Plant deep rooted perennial such as lucerne Look at water table and lower if needed
Neutral	Acidic	Add lime (consider deep-ripping to incorporate lime)
	Sodic	Add gypsum (consider deep-ripping to incorporate gypsum)
	Saline	Maintain or add surface cover (additions of straw are beneficial to reduce surface evaporation) Plant deep rooted perennial such as lucerne Look at water table and lower if needed

Surface Soil Constraint	**Sub-Soil Constraint**	**Management**
Alkaline	Sodic	Grow tolerant crop Add gypsum (consider deep-ripping to incorporate gypsum)
	Acidic	Deep rip and apply lime only to sub-soil
Sodic	Sodic	Add gypsum (consider deep-ripping to incorporate gypsum)
	Saline	Add gypsum Maintain or add surface cover (additions of straw are beneficial to reduce surface evaporation) Plant deep rooted perennial such as lucerne Look at water table and lower in needed
Saline	Any other mixture of constraints	Correct salinity before adding any other amendment Maintain or add surface cover (additions of straw are beneficial to reduce surface evaporation) Plant salt tolerant plants to start building cover
Sodic & Saline	Sodic & Saline	Control salinity Control strip of gypsum
Non-wetting	Compaction	Incorporate clay or organic carbon Utilise wetting agents at sowing
	Acidic	Incorporate clay or organic amendment then; Add lime and consider deep ripping or delving Utilise wetting agents at sowing
	Sodic	Incorporate clay or organic amendment then; Utilise wetting agents at sowing Add gypsum and consider deep ripping or delving

GLOSSARY

- Acidity/ acidic: A pH below 7
- Alkalinity / alkaline: A pH above 7
- Sodicity / sodic: Excess sodium within the soil resource
- Salinity / saline: Excess salts (this could be sodium, chloride etc.) within the soil resource
- Clay: A primary particle smaller than 2 microns in size
- Loam/silt: A primary particle between 0.05 and 0.002 mm in size
- Sand: A primary particle between 2.00 and 0.05 mm in size
- Gravel: A fragment that is greater than 2 mm in size. This is not considered soil.
- Carbonate: A fragment of undissolved lime, with a pH generally ranging from 7 up to 8.5.
- Aggregate: Primary particles (clay, silt or sand) bound together to form structure
- Soil Amendment: A substance added to the soil resource to improve its physical or chemical characteristics, such as lime or gypsum
- Cation Exchange Capacity: The negative change of the soil, gained from clay and organic matter particles, allowing the soil to hold cations within the soil resource
- Organic Matter: The by-product from the breakdown of plant and animal material
- Plant available Water: Water which is available to the plant root within that particular soil fraction
- Soil Structure: This refers to the way in which primary particles are arranged within the soil resource. Generally, the more pore space between particle, the better structure is.
- Structural Stability: The ability of a particular soil to hold onto structure under various conditions such as trafficing.
- Compaction: The mechanical compression of soils from machinery or animals moving over a soil resource – a loss of soil structure
- Leaching: The movement of nutrients, salts or amendments down the soil profile with the movement of water
- Micronutrient: Nutrients that plants require in small amounts including boron, chloride, copper, iron, manganese, molybdenum and zinc.
- Macronutrient: Nutrients that plants require in large amounts including nitrogen, Sulphur, phosphorous and potassium
- Buffering capacity: The ability of a soil to buffer against change, for example a change in pH
- Soil texture: The combination of primary particles (clay, silt and sand), giving an over all soil texture
- Subsoil: The underlying layers of soil beneath the top-soil that often contain less organic matter and more characteristics of the soil's parent material. This is typically less aged in comparison to the top-soils and is generally below 300 mm from the soils surface.

Other useful resources

- Australian Soil Fertility Manual – G. Price
- UNFS Penetrometer – available to loan by Upper North growers
- Previous projects conducted by UNFS grower group;
    - Micro-nutrients in the Upper North (2017-2021)
    - Maintaining profitable farming systems with retained stubbles in upper north SA (2013-2018)
    - Application of controlled traffic farming in the lower rainfall zone (2014-2019)
    - Vetch on saline and sodic soils
    - Warm and cool season mixed cover cropping trial for sustainable farming systems in SE Australia (2019-2022)

COMMON SOIL TESTING STRATERGIES

Table 6. Soil sampling strategies than can be used to gain soil data.

Sampling Strategies	Definition
Top soil testing	A 0-10 cm core
Deep soil coring	A deep core, typically to 90 cm's, split into horizons or 0-10, 10-30, 30-90 cm increments
Transect aggregated soil sampling	A series of cores taken in a transect across a paddock, mixed to get the average of a paddock
Random aggregated soil sampling	A series a cores taken in random locations across a paddock, mixed together to gain an average of the paddock
Zoned aggregated soil sampling	A series of cores taken in a particular zone of the paddock (as determined using special maps), mixed together to gain an average of the area.
Grid mapping	Cores taken in a grid pattern (typically 100 m x100m), sampled individually and then used to generate a special map of the paddock
Soil sensing using swath widths	On-the-go technology which takes readings in swath lengths that can then be extrapolated into a map afterwards. Eg. Em38 or yield monitors

Figure 9. A soil sampling set up, used for soil survey work (photo source, Michael Zwar).

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Upper North Farming Systems

This literature review has been compiled as part of the National Landcare Program: Smart Farms Small Grants Round 4 project 'Building soil knowledge and capacity to implement change in the farmers of the Upper North Agricultural zone of South Australia. Improving soil structure and function to improve plant health, landscape function and farming system resilience'