Soil constraints and management strategies for increasing soil carbon

Soil constraints refer to various factors in the soil that can limit or inhibit root growth and development. These constraints can have a significant impact on plant growth, productivity and ultimately soil carbon sequestration. Soil carbon is predominantly a function of plant production and microbial activity which is largely constrained by the soil type, rainfall and temperature limitations that are present at any location. Increasing plant production in either a livestock or cropping system will have a positive impact on the operation along with benefits to soil carbon sequestration.

Soil carbon has a direct link to productivity playing a significant role in supporting plant growth, nutrient cycling and overall ecosystem function. Improving soil carbon has flow on effects by improving nutrient availability, water retention and moisture regulation, microbial activity, pH buffering and support biodiversity. While there is a lot of hype around improving soil carbon for carbon projects it is important to remember that there are also considerable production benefits through improving soil carbon.

Some common soil constraints that can affect productivity and/or root growth are listed below, however there are many others.

- **Compaction:** Soil compaction occurs when soil particles are pressed tightly together, reducing pore spaces, and limiting root penetration and movement. Compacted soil restricts the availability of air, water, and nutrients to the roots.
- **Poor soil structure:** Soil with a poor structure, such as heavy clay soils, can have small particles that easily compact and become waterlogged. This restricts root growth and limits the movement of water, air, and nutrients within the soil.
- **Soil acidity or alkalinity:** Extreme pH levels can be detrimental to root growth. Highly acidic (low pH) or highly alkaline (high pH) soils can hinder nutrient availability and disrupt root function.
- **Nutrient deficiencies or toxicities:** Imbalances or deficiencies in essential nutrients like nitrogen, phosphorus, potassium, and micronutrients can limit root growth. Similarly, excessive levels of certain nutrients can be toxic to roots.
- **Non-wetting:** A water-repellent soil (or hydrophobic soil), will repel moisture instead of absorbing it. The soil does not wet up spontaneously when a drop of water is placed upon the surface. It is common to see water pooling on the surface of dry soil rather than absorbing. Non-wetting soils will generally result in reduced infiltration, have low water holding capacity and subsequently low plant growth and root growth.
- **Clay Content:** While there is no 'one size fits all' ideal clay content for sequestering carbon, soils with a clay content in the range of 20% to 30% or more are often considered favourable for carbon sequestration. Western Australian soils, which can have a low clay content, can still sequester carbon but may do so at a lower rate or with certain limitations compared to soils with a higher clay content. This is due to clay improving absorption and protection of organic matter plus slowing decomposition. Clay content also improves soil aggregation, creating stable soil structures that also protects organic matter. Without clay particles organic matter/carbon can be subject to faster decomposition, erosion and leaching.

It's important to note that different plant species have varying tolerances to these soil constraints. Understanding the specific soil conditions and their effects on root growth is crucial for successful plant cultivation. Soil testing, appropriate soil management practices, and suitable plant variety selection can help mitigate these constraints and promote healthy root development.

Soil acidity and alkalinity

To improve soil carbon levels, it's essential to manage the soil's pH effectively (acidity or alkalinity). Soil pH directly influences nutrient availability, the activity of soil microorganisms and affects the decomposition of organic matter, which ultimately impacts soil carbon levels. Managing soil pH is part of the integrated overall soil management plan, with the points below s specifically identified for soil pH:

- Soil testing: Begin with a comprehensive soil test to determine the current pH level and identify any nutrient deficiencies or excesses. A soil test will guide you in making informed decisions about pH management.
- Lime application: If the soil pH is too acidic (pH below 6), apply agricultural lime or dolomitic lime to raise the pH level. Liming increases the availability of nutrients and enhances microbial activity, which can lead to better decomposition of organic matter and increased carbon sequestration. Chart 1 demonstrates nutrient availability according to soil pH levels.
- Avoid over-application of acidic fertilizers: Some fertilisers, like ammonium-based fertilisers, can lower soil pH when used excessively. Use fertilizers judiciously and consider using balanced fertilizers or slow-release fertilizers to reduce the risk of soil acidification.
- Crop rotation: Implement diverse crop rotations, including deep-rooted plants and cover crops, to maintain a balanced soil ecosystem and improve soil carbon sequestration.

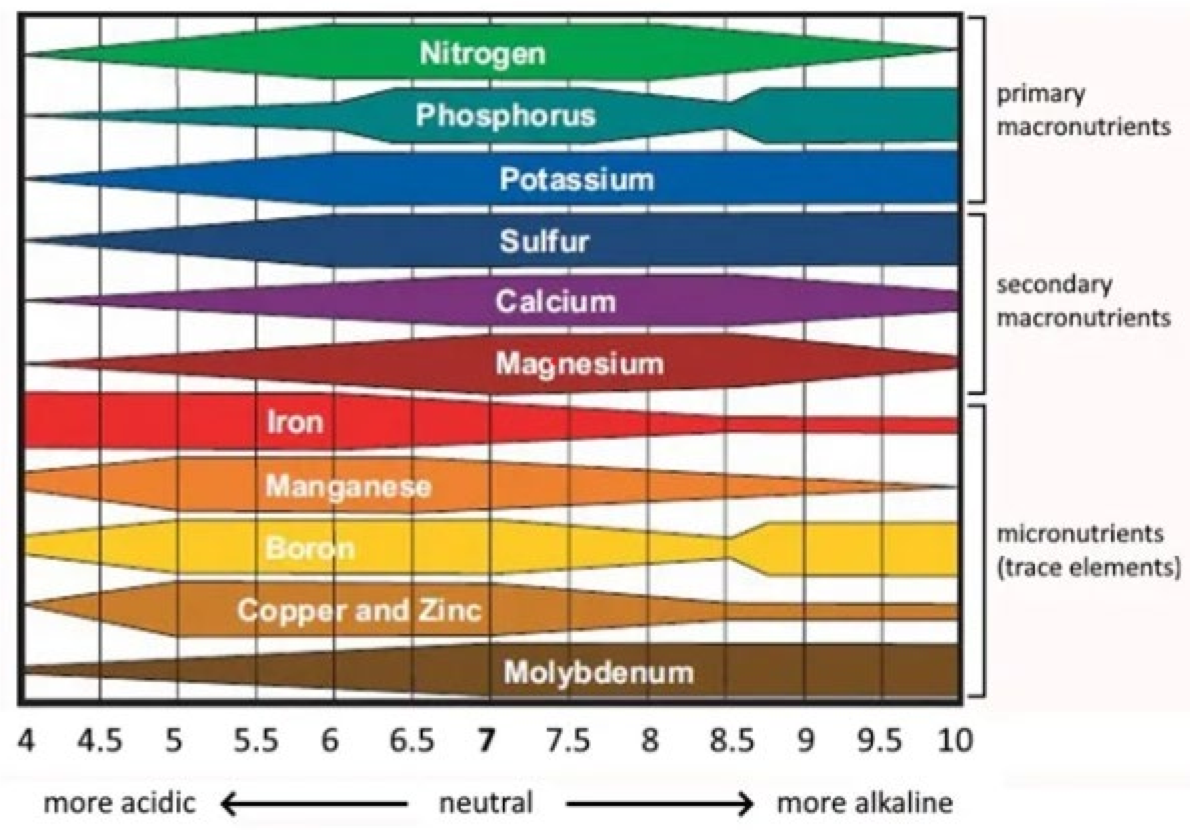

Chart 1: Plant nutrient availability according to soil pH

Nutrient toxicities

Nutrient toxicities in soils can have a significant impact on root growth and overall plant health. While plants require essential nutrients for their growth and development, excessive concentrations of certain nutrients can become toxic and hinder root function. This can be a particular issue at depth, and is the most common source of toxicity in Western Australia from heavy metals such as iron, boron and aluminium.

Managing nutrient toxicity deep in soils can be challenging, as it involves addressing the accumulation of excessive nutrients in the lower soil layers. Here are some management options to consider:

- Soil testing and nutrient management: Conduct soil testing to determine the nutrient levels in the deeper soil layers. This will help identify the specific nutrients that are causing toxicity. Adjust nutrient management practices based on the test results to avoid overapplication of fertilizers or amendments.
- Crop selection and rotation: Select plant species or crop varieties that are less prone to nutrient toxicity or have a higher tolerance for excessive nutrient levels. Rotating crops can also help prevent further nutrient buildup.
- Deep-rooted cover crops: Introduce deep-rooted cover crops that can absorb excess nutrients from the deeper soil layers. These cover crops can help extract and immobilise nutrients, reducing their availability in the root zone.
- Soil amendments: In some cases, soil amendments can be used to modify nutrient availability and reduce toxicity. For example, adding organic matter or amendments like gypsum or lime can help improve correct toxicities by reducing availability of key nutrients or facilitating the leaching of these nutrients from the root zone.
- Monitoring and adjustment: Regular monitoring of soil nutrient levels is important to track the effectiveness of management practices. Adjust management strategies based on monitoring results to ensure long-term nutrient balance and prevent further nutrient toxicity.

Example - Aluminium toxicity: Plant available aluminium is influenced by the pH of the soil. At lower pH's excessive aluminium can be released into a plant available form creating a toxic environment for root growth. By increasing the pH, aluminium is tied up (Chart 1), and toxicity is reduced to allow for improved root growth at depth.

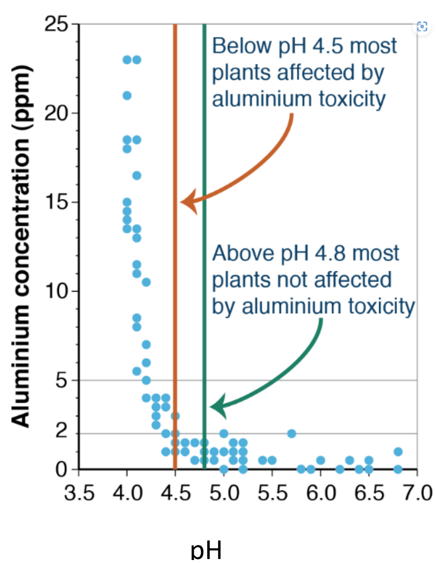

Chart 1: Aluminium concentrations in soils at different pH's.

Addressing soil acidity through the use of soil ameliorants like lime is a key strategy to address soil constraints on multiple levels. By addressing acidity nutrient availability limitations and toxicities can be brought back into balance and will enable improved biomass and root growth and in turn soil carbon.

Compaction and soil structure

Soil compaction can be of significant concern for root growth and can inhibit a plant's ability to sequester soil carbon. It occurs when soil particles are pressed together, reducing pore space and limiting the movement of air, water, and nutrients. This compression leads to reduced plant growth, increased erosion, and decreased soil fertility. Poor soil structure is often characterised by compaction, low organic matter content, and limited pore space, which hinder the movement of water, air, and nutrients in the soil.

Prevention of soil compaction is often more effective and cost-efficient than trying to remediate already compacted soils. To address soil compaction and soil structure effectively, consider the following management strategies:

- Minimise or reduce heavy machinery usage and utilise controlled traffic where possible: Designate specific pathways or controlled traffic lanes for machinery movement to concentrate compaction in selected areas and preserve the rest of the field.
- Increased fodder production/green material: Maximise plant production throughout the year like cover crops during off-seasons or between main crops. Plant growth helps improve soil structure and reduce compaction by creating root channels and increasing organic matter content.
- Add organic matter: Incorporate organic matter such as compost, manure, or crop residues into the soil. This improves soil structure, porosity, and water-holding capacity, reducing the risk of compaction.
- Reduce tillage: Adopt conservation tillage practices, such as no-till or reduced tillage, which disturb the soil less and minimise compaction risks.
- Timely deep ripping: In severe cases of compaction or hard pans, deep ripping can help break up compacted layers in the soil profile, allowing for better root penetration and water infiltration.
- Improve drainage: Proper drainage systems can prevent waterlogging, which contributes to soil compaction. Well-drained soils are less susceptible to compaction. Compaction and waterlogging are two related but distinct problems which do influence each other.
- Manage livestock grazing: provide sufficient rest to maintain groundcover and maximise actively growing roots within the soil.
- Use deep-rooted plants: Incorporate deep-rooted plant species such as perennials to increase root growth and roots at depth. These plants can help break up compacted layers and improve soil structure over time.
- Soil aeration: Use mechanical aerators or deep-rooted plants to aerate compacted soils. Aeration helps create pathways for air and water movement in the soil, promoting a more favorable environment for soil organisms and root growth.
- Soil amendments: Apply soil conditioners like gypsum to improve soil structure and reduce compaction in certain soil types. Gypsum can enhance the aggregation of clay particles and improve water infiltration.

Non-wetting soils

Increasing soil carbon in non-wetting soils can be challenging due to their inherent properties that prevent water infiltration and retention, as well as their tendency to have a low clay content. However, there are several management strategies that can be implemented to improve soil carbon levels in such soils:

- Increased soil microbial activity: Increasing organic matter or ground cover provides a source of carbon for soil microbes, enhancing their activity and facilitating the formation of stable carbon compounds in the soil, which improves the water holding capacity of soils and keeps soils cooler.

- Cover cropping: Plant cover crops that have deep root systems and can thrive in non-wetting soils. Cover crops help break up compacted soil, improve soil structure, and increase organic matter inputs when they are incorporated into the soil.
- Reduced tillage: Adopt minimum tillage or no-till practices to minimise soil disturbance. Tilling can lead to the breakdown of organic matter and increase soil erosion in non-wetting soils. Reduced tillage helps maintain soil structure and preserves organic matter content.
- Targeted tillage: such as deep ripping, delving, mould board ploughing or spading can all be utilised as strategies to manage non-wetting soils as they shift or blend the non-wetting component with soil that has good wettability.
- Soil surfactants: Apply soil surfactants that can improve water penetration into the soil. These products help to break down water-repellent coatings on soil particles and enhance water movement through the soil profile.
- Clay spreading: Spreading clay is a proven strategy to assist in reducing non-wetting as the clay content acts to bind the water in the top soil where it has been blended through.

By implementing the above strategies which help address the soil's water repellence, the resulting improvement in plant growth, establishment and ground cover will also contribute to reduce the soil's non-wetting constraints. As productivity improves, soil biology and organic matter will also improve and work together to increase production and organic carbon.

Improving topsoil's clay content

Increasing the topsoil's clay content - even by only small amounts - to improve production and increase soil carbon sequestration can be a beneficial strategy, as clay soils have a higher capacity to retain organic matter and nutrients. There are several mechanical strategies that can be implemented to increase the clay content in soils:

- Spreading Clay – Spreading clay on sandy soils, particularly with non-wetting issues, has been a popular strategy in assisting in overcoming non-wetting concerns; however it has the added advantage of improving a soil's clay content.
- Delving – Acts to lift soil (which can be higher in clay content), from deeper in the soil profile to the topsoil,can add minor improvements to the topsoil's clay content. Delving can lift soil from indicatively 700mm deep and is a method of covering larger areas at reasonable costs.
- Mould board ploughing - Inverts the soil profile from a depth of roughly 300mm, placing the soil from 300mm below, to become the new topsoil, which can often be higher in clay content.

Understanding each farm or paddock's soil profile is essential to select the appropriate mechanical option to improve the topsoil's clay content and determine whether an improvement is even possible. However, it is worth noting that if an increase in a soil clay content can be economically achieved the resulting improvement in production and carbon sequestration should be significant.

The potential of biomineral fertilisers to increase soil carbon sequestration

Pedaga Investments and the MLA Donor Company are midway through a project aiming to assess the ability of Troforte Cropping Plus (biomineral fertiliser), to increase soil carbon sequestration, while at least maintaining productivity and profitability in relation to best practice conventional fertiliser use. It is being explored through an Integrated R&D PDS model and is relevant to all livestock producers currently implementing a fertiliser regime.

Baseline soil testing across the different trial sites was completed in March and April 2022. The main trial site for the project recorded the below soil testing results:

Soil depth (cm)	Al	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn
0-10	1246	0.79	2028	0.60	147	146	355	17	274	37	33	2.37
10-20'	1377	0.27	681	0.28	106	63	143	11	111	13	16	1.06
20-30'	1168	0.20	389	0.16	105	39	119	8	75	8	12	0.40
30-40	1019	0.18	315	0.12	67	27	117	7	71	6	10	0.37
40-50	930	0.20	239	0.10	58	20	114	8	68	5	10	0.35

Table 1: Baseline Mehlich soil test results for nutrient levels

Soil depth (cm)	EC (µS/cm)	pH (CaCl2)
0-10	280	5.55
10-30	107	5.26
30-50	64	5.26
30-40	55	5.30
40-50	61	5.36

Table 2: Baseline salinity and pH soil test results

Soil depth (cm)	MBC (mg/kg)	MBN (mg/kg)	DOC (mg/kg)
0-10	787	49.58	72
10-20	159	11.33	44
20-30	75	5.33	32

Table 3: Baseline soil health test results measured as (MBC microbial biomass carbon, MBN: microbial biomass nitrogen, DOC: dissolved organic carbon)

MTS	%Sand	%Silt	%Clay
0-10	92	5.55	2
10-30'	91	6.22	2
30-50'	91	5.93	3

Table 4: Baseline soil texture results

The main trial site in Bridgetown is a 40-year-old stand of Kykuya that is surface irrigated and has been predominantly fertilised with synthetic fertiliser super potash and urea. The results from the above tables show the typical nutrient status of a soil that has been spread with synthetic fertilisers for the past 40 plus years, with the majority of the nutrition held in the top 10cm.

The results from the completed testing shows there are limited soil constraints within the main trial site which would restrict soil carbon sequestration. The use of the biomineral fertiliser is hypothesised to increase soil health through improved soil microbial activity to increase nutrient availability and drawing greater levels of carbon from plant roots, which are growing deeper into the profile.

The next soil testing for the project is scheduled to occur in March 2024 with the final testing to be completed in March 2025. This will determine any changes that result from the change in fertilizer regime in soil carbon throughout the soil profile to 50cm along with soil health, nutrient status, and pH and salinity.

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