Soil dispersion and sodicity

Dispersion is a physical occurrence where a soil separates into individual particles after wetting. In a dispersive soil, clay particles detach and repel one another and other soil particles. This produces a hostile environment for plant growth; restricting seedling emergence, root growth, and reducing aeration and water infiltration.

While this phenomenon is often associated with high levels of exchangeable sodium, measured as exchangeable sodium percentage (ESP), it can also be found in non-sodic soil. Conversely a soil can have a high ESP and NOT display any dispersion or the problems associated with dispersion.

In addition to excess sodium, the degree of clay dispersion is also strongly linked to soil properties such as: electrical conductivity (EC, salinity), soil pH and organic matter. Dispersion is aggravated by working the soil when it is too moist, e.g. tillage and/or trampling by livestock beyond the 'plastic limit' (see www.cottoninfo.com.au/publication

www.dpi.nsw.gov.au/__data/assets/pdf_file/0020/127280/Cultivation-and-soil-structure.pdf)

Soil features such as alkalinity (pH_w above 8.5) and salinity (measured as EC) interact with sodium in the soil to either amplify or dampen the effect of excess exchangeable sodium in the soil. Studies have shown that the effects of ESP on clay dispersion vary widely depending on the amount of organic matter (OM) in soil, mineralogy of clays, pH and electrolyte concentration (roughly speaking salinity) in the soil solution. High dispersivity and associated soil structural degradation will occur if sodicity is accompanied by very low concentrations of Ca^{2+} and Mg^{2+}.

Why can sodicity be a problem?

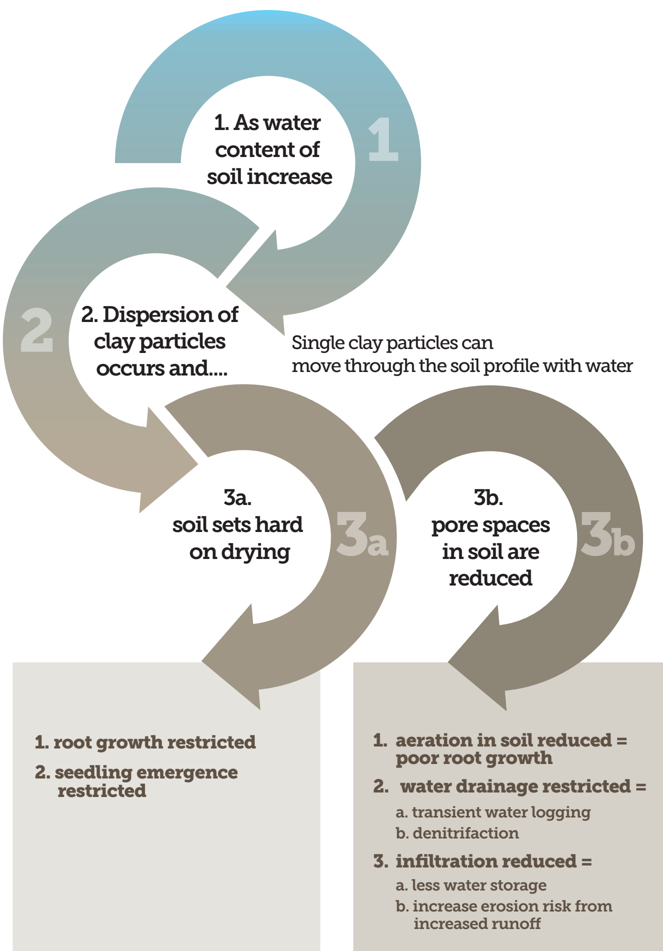


Figure 1. Process of soil structure decline and why it is a constraint

Detecting soil sodicity

Look for symptoms such as:

- Clay dispersing when wet (not to be confused with slaking – see Figure 2)
- Soil setting hard when dry
- A crust forming on the soil surface
- Waterlogging and puddling

The next step is to carry out a simple field dispersion test (a modified Emerson test). Carefully place multiple (at least four) soil aggregates (soil 'crumbs' that are 1-2 cm in size) in enough rainwater/distilled water so the aggregates are entirely submerged (a cup or jar). Observe and rank the clay concentration in suspension (cloudiness) surrounding the aggregates after a minimum of two hours. This field test is a good quick means to assess spontaneous dispersibility and can indicate the need to further investigate with a laboratory soil test. Check out this video to see how: https://youtu.be/4_6zHhlNyBU

You should follow the field identification with a laboratory test to confirm sodicity. The ratio of exchangeable sodium to the total of exchangeable cations – the exchangeable sodium percentage or ESP – is an indicator of soil structural stability. Soil testing laboratories can test for the common exchangeable cations: Na^+, K^+, Ca^{2+}, Mg^{2+}, Al^{3+}. The sum of these is the cation exchange capacity (CEC), and the ESP is calculated as:

ESP = (exchangeable Na^+ cmol (+)/kg /CEC cmol(+)/kg) x 100

The rule of thumb is that when sodicity (ESP) exceeds a certain limit, soil structure deteriorates, leading to the soil physical constraints already listed. However as mentioned, this limit depends on other soil attributes that interact with sodium levels to increase or decrease the likelihood of soil dispersion. For this reason, it is important to determine the soil salinity (EC), pH, organic carbon and texture as well. Dispersion can occur at an ESP as low as 2 with rainwater in susceptible clay soils, while sandy soils do not disperse, no matter how high the ESP, due to their low clay content.

Sodium is mobile in the soil solution, so it is important to note that sometimes soil may only be sodic at depth. Although subsoil sodicity can be harder to identify, this constraint can still have a significant impact on crop growth and yield.

Soil is at risk of dispersion due to sodicity if:

- ESP > 6 and
- ECe < 4 dS m^{-1}.

as the clay particles in soil aggregates are strongly influenced by adsorbed sodium.

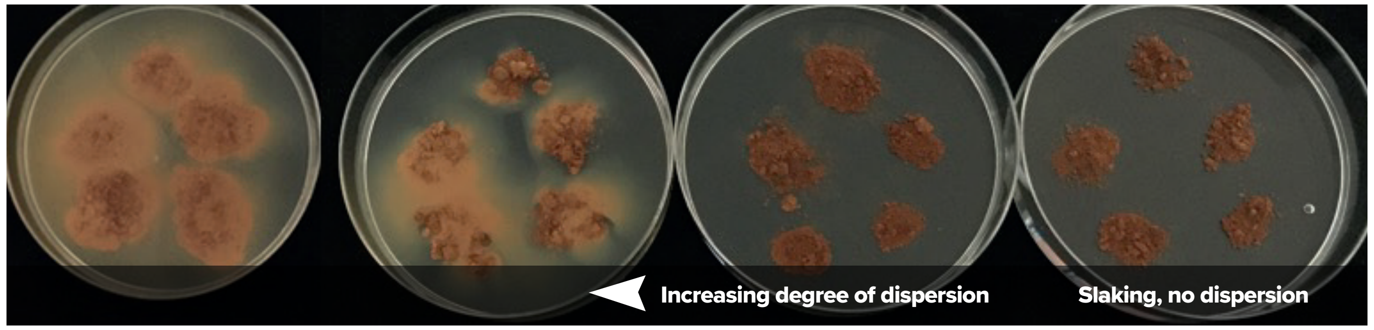


Figure 2. Dispersion due to soil sodicity. Note cloudiness will remain over time.

SOIL DISPERSION AND SODICITY – EXTENSION OF BEST PRACTICE PRINCIPLES FOR IDENTIFYING AND MANAGING SOIL LIMITATIONS IN SOUTHERN AND CENTRAL NSW

Interaction with other soil features

Alkalinity

When the pH_w of a soil is above 8.5 it amplifies the effects of excess exchangeable sodium in addition to causing nutrient deficiency and elemental toxicity. However, if calcium carbonate (often in the form of lime nodules) is present, dispersion will be suppressed. With a rise in pH, ions such as sodium (Na^+), increase in the soil solution. Added to this, alkaline soils store less organic carbon; high pH being responsible for an increase in dissolved organic carbon and reduced microbial activity.

Sodicity and alkalinity can be present in both topsoil and subsoil. However, it is more common to have subsoils with alkaline, sodic conditions.

Salinity

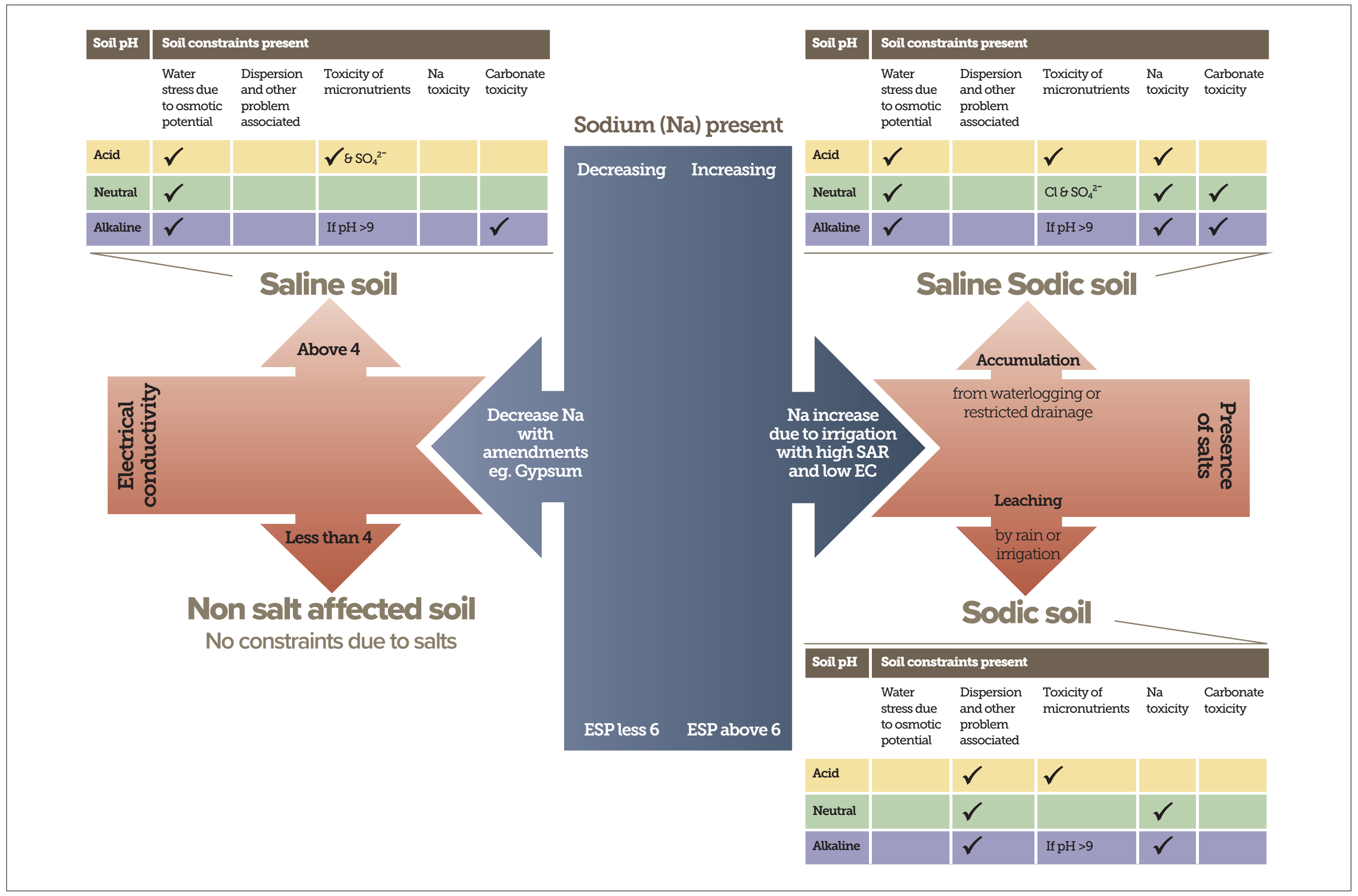
As EC increases, soil dispersion decreases, regardless of how sodic the soil is. Conversely, very low EC means that a soil may become dispersive when the ESP of the soil is as low as 2. In addition to looking at ESP, you should also measure EC values and interpret the results together.

However, although salinity greatly improves flocculation (clumping of soil particles) it makes it harder for plants to extract the water they need from the soil due to the osmotic effect. If fresh water is applied to a sodic-saline soil, dispersion will result as the flocculating influence of the salts are removed (due to salts being diluted). This can often be seen following a rainfall event, where the fresh water reduces EC in the top few centimetres of soil causing dispersion, crusting and sealing.

You can also use the Electrochemical Stability Index (ESI), which specifies the relationship between salinity and sodicity. The ESI is determined by calculating the ratio of the electrical conductivity of a one part soil to five parts soil extract ($EC_{1:5}$ dS/m) and the exchangeable sodium percentage (ESP). Topsoil ESI values less than 0.05 are often are associated with dispersion.

Low soil organic matter content

Organic matter in soil consists of microbes (including microbial glues), partially decomposed organic matter, plant roots, fungal hyphae and charcoal. All this helps to bind the sand, silt and clay particles into water stable aggregates. Increasing soil organic matter, measured as the organic carbon content (OC %) in a soil test, will assist in alleviating the symptoms of sodicity.



Saline soil:

Soil pH	Water stress due to osmotic potential	Dispersion and other problem associated	Toxicity of micronutrients	Na toxicity	Carbonate toxicity
Acid	✓		✓ & SO_4^{2-}		
Neutral	✓				
Alkaline	✓		If pH >9		✓

Saline Sodic soil:

Soil pH	Water stress due to osmotic potential	Dispersion and other problem associated	Toxicity of micronutrients	Na toxicity	Carbonate toxicity
Acid	✓		✓	✓	
Neutral	✓		Cl & SO_4^{2-}	✓	✓
Alkaline	✓		If pH >9	✓	✓

Sodic soil:

Soil pH	Water stress due to osmotic potential	Dispersion and other problem associated	Toxicity of micronutrients	Na toxicity	Carbonate toxicity
Acid		✓	✓		
Neutral		✓		✓	
Alkaline		✓	If pH >9	✓	

Figure 3. Interaction of sodicity and salinity soil constraints (after Rengasamy reference)

SOIL DISPERSION AND SODICITY – EXTENSION OF BEST PRACTICE PRINCIPLES FOR IDENTIFYING AND MANAGING SOIL LIMITATIONS IN SOUTHERN AND CENTRAL NSW

How should soil dispersion be managed?

1. Promoting soil aggregation

There are a few basic rules of thumb that are applicable to all situations.

- Avoid disturbing (cultivate, digging, stock trampling etc) the soil when it is moister than the 'plastic limit'. Disturbance will make the problems of soil structure degradation worse. Reducing ground cover and breaking up soil aggregates facilitates the breakdown of organic matter which binds soil particles together and can make the soil vulnerable to erosion. Disturbance from deep ripping associated with subsoil sodicity treatment is acceptable, provided that the subsoil is drier than the 'plastic limit' so that it shatters rather than being smeared.
- Improve the organic matter content of soil. Increasing SOM enhances soil structure and can improve the efficacy of gypsum and other soil amendments. Practices such as permanent pasture, pasture phases in crop rotations, green and brown manure crops, retaining stubble, spray fallowing and minimum/no till will all assist in building SOM with minimum soil disturbance.
- Reclaiming a dispersive sodic soil can be a slow process as soil structure takes time to rebuild. While displacement of excess sodium is being carried out it is good practice to grow tolerant crop species, retain crop residues and add additional organic matter.
- Addressing soil compaction (poor soil structural form) is a common soil constraint, particularly where the guidance of heavy farm machinery is poor. It often occurs in conjunction with dispersion. Unless both compaction and dispersion are treated simultaneously, progress with soil structure improvement will be disappointing. (see factsheet on soil structure link?)

2. Manage excess sodicity

The object of any management option for soil sodicity is to reduce soil dispersion by removing the excess exchangeable sodium and replacing it with other cations. You will need to know the current ESP of your soil to determine the rate of ameliorant required whatever method you use. The type and quantity of a soil amendment to be used for amelioration of sodic dispersive soils depends on:

- Soil properties determined by soil tests (CEC)
- Extent of structural degradation, (dry bulk density)
- Target level of soil improvement, (ESP desired)
- Location of sodicity in the profile (surface or subsoil and depth of soil to ameliorate),
- Location of sodicity within a paddock, and
- Product fineness and quality

These will also help in determining the cost effectiveness of an amendment.

Amendments

Application of an amendment to supply soluble calcium (Ca^{2+}) to replace exchangeable sodium is a common strategy. Commonly used amendments include:

- Gypsum (calcium sulfate) - the most common ameliorant recommended for the reclamation of sodic soils. Use of this calcium amendment must be coupled with the addition of good quality water to leach the displaced sodium beyond the root zone.
- Lime (calcium carbonate) is sometimes suggested but is unsuitable for alkaline soil due to it insolubility.
- Organic matter (i.e. straw, farm and green manures), coupled with natural decomposition and plant root action will improve aggregation of poorly structured soils, promoting reclamation. This is relatively a slow process on its own and using organic matter inputs in combinations with other amendments (for example, gypsum and lime) can increase effectiveness and crop yield.

Often gypsum is applied at lower rates than are required to displace all of the sodium to only alleviate dispersion at the soil surface so that crops can be established, and water can infiltrate the soil. Generally, 2.5 t/ha of gypsum can be used to prevent surface soil dispersion where up to 10mm/hr water (or rain) is also available (see more information No. 1). Where smaller rates are applied, repeated applications may be needed to maintain improvements in surface soil condition. This is partly due to the impermanence of the beneficial electrolyte (salt) effect of gypsum. Over time these repeat applications may improve subsoil sodicity.

How should soil dispersion be managed?

A higher application rate is required where coarse gypsum is used, water applied is >10mm/hr, soil is extremely sodic or where a longer-term effect is desired.

Surface application of gypsum is far more effective at treating surface sodicity. Gypsum is partially soluble and will enter the soil in infiltrating water, so it does not need to be incorporated like lime. However, the amount of gypsum needed to surface apply and then flush through the soil profile to depth can make surface application impractical for subsoil sodicity. Deep ripping coupled with amendment application can produce better results. To prolong the effects of gypsum deep placement beyond 2 years enough ameliorant to replace the excess Na here must be applied. There are calculators available online to help with this calculation

It is common for multiple subsoil constraints – including sodicity, alkalinity, nutrient deficiencies and compaction – to occur together in clay subsoils across south-eastern Australia, so multiple management methods are often required. In these cases, professional guidance from soil science specialists is recommended.

& Alkalinity

The aim of reclaiming alkaline sodic soil is to reduce BOTH soil pH and clay dispersion due to sodicity.
As stated, this requires the removal of part or most of the exchangeable sodium and replacing it with more favourable calcium ions in the root zone. However, due to soil chemistry at $pH_w > 8.5$ the addition of gypsum alone will not increase the amount of exchangeable calcium enough to reduce sodicity. Reducing the soil pHw to below 8.5 will also reduce toxicity problems and clay dispersion to some extent.

Early results from research carried out in southern NSW indicates that deep placement of both organic and inorganic amendments (that is gypsum) can improve soil properties where alkaline subsoil sodicity occurs. The combination of amendments reduced both pH and ESP and increased microbial activity which in the long-term will aid the formation of stable soil aggregates. (see more information 3,4,5)

& Salinity

Salinity can modify the effects of sodicity when the two constraints are found together. It is important to address both constraints. Leaching of salts from the profile will improve soil salinity levels but will increase the risk of soil dispersion. A dispersion test using the water that is to be applied to the soil should be carried out to determine the dispersion risk.

Applying gypsum first will keep the soil solution EC above threshold levels and thus prevent dispersion so that soil structure is optimised for the subsequent leaching excess salt from the soil profile. Leaching excess salts and maintaining a favourable salt balance remains the best strategy to prevent detrimental salt accumulation in the soil profile. This is achieved by supplying enough good quality water to leach salts below the root zone. Applying gypsum before rain (e.g. in autumn in winter rainfall zones) or irrigation will maintain flocculated soil and facilitate leaching.

Where water tables close to the soil surface expert advice should be sought regarding remediation options.

In the cotton industry, a critical ESI value if 0.05 is used to determine the economic viability of applying gypsum or lime. Above this ratio limited or no economic response to gypsum and/or lime is expected. (from: http://www.terragis.bees.unsw.edu.au/terraGIS_soil/sp_exchangeable_stability_index.html) If dispersion induced crusting or waterlogging are potential problems, then low rates of gypsum (2.5 t/ha) will aid establishment of cotton

& Acidity

It is not uncommon to have a sodic subsoil under an acidic topsoil. In this case both lime and gypsum can be used to ameliorate the soil. Lime (calcium carbonate) is far less soluble than gypsum and its use to correct sodicity is not advised unless soils are also acidic.

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More information

- **Does my soil need Gypsum (from SOILpak)**
  https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/127258/Does-my-soil-need-gypsum.pdf
- **Managing heavy clay soils**
  https://archive.dpi.nsw.gov.au/__data/assets/pdf_file/0004/79420/managing-heavy-clay-soils-bland.pdf
- **Soil amelioration – magnitude of crop productivity improvements on hostile subsoils?**
  https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2020/02/soil-amelioration-magnitude-of-crop-productivity-improvements-on-hostile-subsoils
- **Understanding the amelioration processes of the subsoil application of amendments**
  https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/02/understanding-the-amelioration-processes-of-the-subsoil-application-of-amendments
- **Amelioration for sodicity - deep ripping and soil amendment addition across NSW and Qld. Engineering challenges. Yield responses to ripping, gypsum and OM placement in constrained soils**
  https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/02/amelioration-for-sodicity-deep-ripping-and-soil-amendment-addition-across-nsw-and-qld.-engineering-challenges.-yield-responses-to-ripping,-gypsum-and-om-placement-in-constrained-soils
- **A Gypsum Requirement app can be used to determine optimum gypsum rates**
  ttps://play.google.com/store/apps/details?id=io.cordova.myappea78bc&hl=en&gl=US
- **Sodic soil amelioration using lime and gypsum – 5 years of results at Gunning Gap**
  https://www.farmtrials.com.au/trial/19779
- **How to test for dispersive soil; podcast**
  https://grdc.com.au/news-and-media/audio/podcast/how-to-test-for-dispersive-soil

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