Management of soil organic matter and gypsum for sustainable production in the Carnarvon horticultural district of Western Australia

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Management of soil organic matter and gypsum for sustainable production in the Carnarvon horticultural district of Western Australia
Management of soil organic matter and gypsum for sustainable production in the Carnarvon horticultural district of Western Australia

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Introduction

Soil quality is critically important for the long-term production of high quality and high yielding fruit and vegetable crops in the Carnarvon horticultural district of Western Australia. A stable soil structure is essential for good soil quality that will provide plants with the following requirements (Fig. 1):

- Adequate infiltration and drainage, water storage and plant water availability
- Good aeration
- Good root penetration
- Optimum soil temperature
- A ready supply of nutrients

The above factors occur when soils have a stable structure; that is one that has stable aggregates that don't collapse on wetting either from irrigation or rain.

Soil structure and aggregate stability

For a soil to have a stable structure it must consist of stable aggregates, that is, aggregates that resist break down on wetting (Fig. 2(i) and Fig. 3(i)). The components of soil aggregates are sand, silt and clay sized particles, as well as organic matter (both living and dead). The organic matter assists in binding the components into stable aggregates. The negatively charged clay particles have cations (e.g. Na+) bound to them. These cations are also known as exchangeable cations. The amount of sodium bound to the clay, expressed as a percentage of all bound cations, is termed the exchangeable sodium percentage (ESP), or sodiciry of the soil. An unstable soil aggregate can break down on wetting by two processes:

(i) Slaking

Slaking occurs when soil aggregates breakdown on immersion in water into smaller sized aggregates, known as microaggregates. Slaking usually occurs in fine textured soils that are low in organic matter and frequently cultivated. As water rushes into the aggregate, pressure builds up as the entrapped air is compressed and clay particles swell. If the aggregate hasn’t sufficient strength to withstand the build up in pressure, it breaks down into microaggregates (Fig. 2(ii) and Fig. 3(ii)). These microaggregates can undergo further break down in water due to dispersion. Note that some coarser textured soils also slake to ultimate particles (sand and silt size).

(ii) Dispersion

Dispersion may accompany slaking and occurs when the clay present in soil microaggregates breaks down by swelling into individual clay particles which diffuse out of the aggregates and cause the aggregate to have a halo of cloudiness around it (Fig. 2(iii) and Fig. 3(iii)). The sodium cations bound to the clay strongly take up water and weaken the bonds between the soil particles.
Figure 3: A schematic representation of the stages of aggregate breakdown in water (i) soil aggregate, (ii) microaggregates separated by slaking, and (iii) individual clay particles separated by swelling and dispersion.

The more sodium bound to the clay, the more likely that dispersion will occur. A soil is considered sodic when the amount of bound sodium causes structure problems such as dispersion. This is usually 5 or 6% ESP, but may vary with soil type and levels of organic matter.

When soil aggregates both slake and disperse on wetting, then the resultant breakdown products, i.e. microaggregates and individual clay particles respectively, block pores in the soil and result in sealing of the soil surface. As the soil dries out, hardsetting and crusting problems result. These changes in the soil structure reduce water/irrigation penetration, crop emergence, soil aeration and plant root growth of fruit and vegetable crops. The problems are worse in soils with higher clay contents (Greene et al. 2001). Slaking and dispersion can also lead to dense, almost impenetrable subsoils.
Effect of ESP and salinity on clay dispersion

Although raising the ESP increases the tendency of the soil to disperse, the ESP at which dispersion occurs also depends on the amount of free salts (or salinity) in the soil, as measured by its electrical conductivity (EC) (Fig. 4). Whereas the exchangeable sodium is bound to the clay, the free salts remain unbound. If sufficient amounts of free salts are present, e.g. sodium chloride (common salt) and/or calcium sulphate (gypsum), dispersion can be prevented, and the soil remains flocculated. In a flocculated soil the clay particles in the aggregates are clumped together and the clay particles don't swell and diffuse out into the surrounding water, that is, the opposite of dispersion. The solid line in Figure 4 separates stable flocculated soils (above the line) from unstable soils that swell and disperse (below the line) (Rengasamy et al. 1984). However, too much free salts present in the soil reduce the availability of water and nutrients to the plants, that is, they exert an osmotic stress that reduces plant growth (region above the dashed line Fig. 4). The preferred region in terms of salinity and sodicity levels for a soil to be is therefore above

\[
\begin{align*}
\text{Salinity (EC)} & \quad \text{Sodicity (ESP)} \\
\text{Flocculated soil} & \quad \text{Dispersed soil} \\
\text{Preferred region} & \\
\end{align*}
\]

Figure 4: The effect of ESP and salinity on dispersion of soil aggregates (the preferred region for stable aggregates is hatched). (Adapted from Rengasamy et al. 1984).
the line separating the flocculated from the dispersed regions, but towards the area of low salinity, low sodicity (hatched region in Fig. 4). As sodic soils have sodium bound to the clay, the sodium can only be removed by exchanging it with another cation, for example, by adding calcium in the form of gypsum (CaSO₄·2H₂O), or in the case of acidic, sodic soils, lime or a combination of lime and gypsum can be used (Valzano et al. 2001). However, the free salts can be removed by leaching the soil with water alone.

### Soil quality in Carnarvon

(i) Soils of the Carnarvon horticultural district

The soils of the Carnarvon horticultural district are formed on alluvium adjoining the Gascoyne River. The soils closest to the river (known as the Gascoyne Association) are generally brown, and have a uniform profile of loamy fine sand to silty loam and silty clay loam texture. Soils adjacent to the Gascoyne Association, but further from the river (known as the Coburn Association) generally have a gradational or duplex profile. In a gradational soil the clay plus silt content gradually increases with increasing depth, whilst a duplex soil has an abrupt change in texture with increasing depth, for example, a loam over a light clay. Whereas the Gascoyne Association soils are freely drained and well structured, the Coburn Association soils generally have poorer drainage and structure (Bettenay et al. 1971, Wells and Bessell-Browne 1990). Both the Gascoyne and Coburn Association soils are used for intensive irrigated cropping in the Carnarvon district.

(ii) Managing soil quality in Carnarvon

The previous sections have shown that the important components of soil structure that need to be controlled for good soil quality are the levels of organic matter and exchangeable sodium (relative to the other exchangeable cations), as well as salinity. To investigate management options for achieving good soil quality in the Carnarvon horticultural district, a collaborative project was established between Agriculture Western Australia (AGWEST), the Australian National University, Chemistry Center (WA) and the Co-operative Research Centre for Soil and Land Management.

As part of this project, an initial survey of horticultural soils from both vegetable crops and plantations in the Carnarvon District was conducted. The survey included soil samples from 14 different profiles, at depths ranging from 0-80 cm. In some profiles samples were only analysed from surface layers.

The results indicated that overall soil structure was poor, as shown by the low levels of organic matter (measured as carbon), and high exchangeable sodium levels (measured as the depth to which the profile was sodic, that is, the soil had an ESP value ≥6 (Table 1). These problems of poor soil structure occurred on soils from both the Gascoyne and Coburn Association.

(iii) Factors affecting organic carbon levels

The amount of soil organic matter is primarily determined by the climate of a region and the climate's control on vegetation. Particularly important is the amount of rainfall and the nature of its annual distribution in relation to temperature. The subsequent management of the soil is also critical in determining the levels of soil organic matter. In Carnarvon, due to the low annual rainfall (approx. 230 mm) and high summer temperatures, the native vegetation is sparse. This results in inherently low levels of organic matter (expressed as carbon). The levels are further lowered largely as a result of frequent tillage of the soil, particularly with vegetable crops. It is not uncommon for 2 to 3 vegetable crops to be grown each year in the same paddock.
Sodium in Carnarvon soils and its replacement with calcium

Most of the Carnarvon soils had a sufficiently high ESP, i.e. ≥6, that they could be classed as sodic, either throughout the entire profile, or at least in the subsoil. Sodic soils are known to disperse in water and cause poor soil structure (Isbell 1996). Greene et al. (2001) demonstrated that the sodic soils at Carnarvon had severe hardsetting problems, and this problem increased as the soils became heavier. Other studies by Lugo (1975) found that hardsetting soils decreased the establishment of plants such as cotton.

The high levels of exchangeable sodium in Carnarvon soils are probably due to salt water intrusions (largely sodium chloride (NaCl)), weathering of the parent materials and/or a build up due to irrigation with water containing sodium from the Gascoyne River. Another source may be NaCl particles blown in from the ocean.

Therefore the sodic Carnarvon soils need to be ameliorated with calcium in the form of gypsum. There are two advantages of using gypsum instead of lime to ameliorate sodic Carnarvon soils. Firstly, gypsum is more soluble than lime (approx. 170 times more so), and secondly, gypsum doesn’t increase the pH of the soil, as does lime (in fact, adding gypsum causes the soil pH to initially decrease by approx. 0.5 of a pH unit). Lime is generally not recommended for Carnarvon soils, as small amounts of free lime already occur close to the surface in most Carnarvon soils. This results in alkaline pH’s of 7-9. These high pH’s may induce deficiencies of iron, manganese and zinc (Bettenay et al. 1971).

Table 1: Survey of soils in the Carnarvon Horticultural District

<table>
<thead>
<tr>
<th>Location</th>
<th>Site Details</th>
<th>Depth of sodic soil (cm)*</th>
<th>Organic Carbon % 0-5 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fallow</td>
<td>None</td>
<td>0.50</td>
</tr>
<tr>
<td>2.</td>
<td>Fallow</td>
<td>None</td>
<td>0.94</td>
</tr>
<tr>
<td>3.</td>
<td>Vegetable/gypsum</td>
<td>&gt;25</td>
<td>0.74</td>
</tr>
<tr>
<td>4.</td>
<td>Vegetable</td>
<td>0-40</td>
<td>0.66</td>
</tr>
<tr>
<td>5.</td>
<td>Bananas</td>
<td>5-80</td>
<td>1.28</td>
</tr>
<tr>
<td>6.</td>
<td>Fallow</td>
<td>0-80</td>
<td>0.38</td>
</tr>
<tr>
<td>7.</td>
<td>Vegetable/good</td>
<td>none</td>
<td>0.46</td>
</tr>
<tr>
<td>8.</td>
<td>Vegetable/poor</td>
<td>none</td>
<td>0.25</td>
</tr>
<tr>
<td>9.</td>
<td>Bananas</td>
<td>0-80</td>
<td>0.76</td>
</tr>
<tr>
<td>10.</td>
<td>Fallow</td>
<td>0-80</td>
<td>0.59</td>
</tr>
<tr>
<td>11.</td>
<td>Vegetable</td>
<td>0-80</td>
<td>0.92</td>
</tr>
<tr>
<td>12.</td>
<td>Vegetable</td>
<td>0-40</td>
<td>0.36</td>
</tr>
<tr>
<td>13.</td>
<td>Vegetable</td>
<td>10-40</td>
<td>0.34</td>
</tr>
<tr>
<td>14.</td>
<td>Fallow</td>
<td>&gt;20</td>
<td>0.42</td>
</tr>
</tbody>
</table>

*If the soil has an ESP value ≥6 it is referred to as sodic
Field trial on organic matter and gypsum

Based on these problems, a field trial on irrigated row crops was established at AGWEST's Gascoyne Research Station (GRS), Carnarvon, and was continued over five successive crops from 1995-1997. Crops of bush beans, rockmelons, capsicums, rockmelons and tomatoes were grown successively on raised seed beds, covered with black plastic and irrigated with low-flow T-tape buried at a depth of 50-100 mm. The soil used in the trial was part of the Coburn Association. It had a gradational profile (loam surface soil grading to a clay loam subsoil), with sodic, alkaline (pH 7.5-9.0 (1:5 soil:water extract) and hardsetting properties.

The aim of the field trial was to improve soil structure by using (i) reduced tillage to conserve/increase organic matter, and (ii) gypsum addition to reduce sodicity and dispersion. To do this we measured the effects of various combinations of reduced tillage and applied gypsum (at rates of 0, 2 and 10 t/ha) to the seed bed.

The following results were obtained:

1. Reducing the amount of tillage appeared to have little effect on soil organic carbon levels, which are already low, i.e. 0.7-0.8%. In addition, as the trial only ran for about two years, significant increases in organic carbon are unlikely to be measured in this time period. Therefore there is a need to apply organic matter to these soils, e.g. as green manures, by using cover crops in the rotation. However, this will be a slow process, as previous work in other areas, using oats as a green manure cover crop, indicated that it required 13 crops, each of 6 t/ha dry matter, to increase organic carbon by 1% (Chilvers 1996).

2. Gypsum initially decreased the soil pH (approx. 0.5 of a pH unit), and decreased dispersion. This decrease in dispersion improved surface infiltration and drainage, thereby promoting better paddock access and ease of tillage. However, these effects diminished with time, as the applied gypsum was gradually dissolved and leached lower down the profile. At the 2 t/ha rate, the amount of irrigation that dissolved a tonne of gypsum was 120 mm. At the higher 10 t/ha rate, due to more contact between the gypsum particles and water, only 100 mm was required to dissolve a tonne.

Therefore the most economical way to apply gypsum is at low rates (2 t/ha) and relatively frequently, i.e. after every one to two crops. Farmers need to keep careful records of the total irrigation applied to alert them as to when re-application of gypsum is required (see section on soil testing for gypsum requirement).

3. There were no effects of any of the treatments on yields. This was due to all treatments receiving approx. the same amount of irrigation over the 5 successive crops and the beds being covered with plastic. Any improvements in soil structure (and the various soil factors needed for optimum growth) resulting from the various treatments would therefore be overridden by the fact that all treatments had adequate available plant-water. Detailed measurements of soil structure, carried out on the trial in April 1997 by Valzano (2000), demonstrated that the gypsum treatments did increase the available water holding capacity of the soils, which would improve the water-use efficiency of the soil when irrigation is restricted. Previous trials at GRS using gypsum, in combination with different levels of irrigation (Muller 1993), indicated that when
the irrigation level was low, gypsum application improved yields. Therefore, even though there were no yield differences in this trial, under more restricted irrigation regimes, gypsum is likely to increase yields. Improvement in soil structure (and hence yields) following gypsum application are also more likely to occur on the heavier duplex soil types of the Coburn association, particularly those affected by high levels of sodicity, salinity and alkalinity (Bettenay et al. 1971).

**Measurement of soil quality**

Soil testing for gypsum requirement (sodicity), salinity and pH (N.B. pH needs to be included as Carnarvon soils can suffer from high pH, causing problems with nutrient availability) is as follows. Table 2 gives some typical problems for Carnarvon soils and methods for ameliorating them.

These procedures are adopted from a field test developed by the CRC for Soil and Land Management (Rengasamy and Bourne 1997).

Use the Table in Appendix 1 to identify any major problems with surface and subsoil.

*Table 2. Controlling the problem (The following are typical combinations of surface and subsoil problems of high sodicity, high salinity and alkaline pH's existing in Carnarvon soils)*

<table>
<thead>
<tr>
<th>SURFACE</th>
<th>alkaline</th>
<th>neutral</th>
<th>sodic</th>
<th>sodic</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUBSOIL</td>
<td>sodic (alkaline)</td>
<td>sodic (alkaline)</td>
<td>sodic (alkaline)</td>
<td>saline</td>
</tr>
<tr>
<td>SOLUTION</td>
<td>grow acidifying legumes and add gypsum</td>
<td>add gypsum</td>
<td>add gypsum</td>
<td>add gypsum &amp; leach out salts (lower watertable if present)</td>
</tr>
</tbody>
</table>

To apply gypsum to the surface soil, use 2.0 t/ha; 4-5 t/ha is used for the subsoil.

Initial application

Measure sodicity using a sodicity meter* as follows (need to test both surface and sub-surface soils):

- From each surface and subsoil sample, weigh 100 g of dry soil into a clean 600 mL glass jar, and then add 500 mL rainwater or distilled water gently down the side. Apply lid.
- Gently invert the jar allowing the soil and water to be thoroughly mixed, and then wait for 4 hours before measuring sodicity. This is done by measuring the turbidity using a sodicity meter (see instructions).
- After measuring the turbidity, the jar is shaken vigorously end-over-end 15 times, allowed to stand for 15 minutes and then the electrical conductivity of the suspension is measured with a conductivity meter.
- Measure the pH of the dry soil using a Raupach soil pH kit.

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*Note: The sodicity meter (called the SASkit) is available from the following address:
PIRSA Information Services, POBox 469, Murray Bridge, SA 5253, Ph. 0885356400.
Free phone: 1800 356 446. The cost is $10 plus GST, plus postage.
When to re-apply gypsum?

The gypsum needs to be re-applied at regular intervals to the soil. To know when to re-apply gypsum, the grower needs to carefully monitor the amount of water applied, since one tonne is dissolved by approx. 120 mm of water. If 2.0 t/ha were initially applied, then this should last from one to two crops, but then another 2.0 t/ha needs to be applied for the third crop. If in doubt use the sodicity meter to test the soil for dispersion.

Acknowledgments

The authors acknowledge Mr. Bob Paulin, Mr. Malcolm Howes, Dr. Brian Murphy, Dr. Rengasamy, and Mr. Dennis van Gool, for their comments on earlier drafts and Dr. David Allen and Mr. Ivan Wilson from the Chemistry Centre (W.A.), who provided valuable assistance and advice on the soil chemical analyses conducted in this trial. Val Lyon and Clive Hilliker (ANU) are thanked for providing valuable assistance with the figures. Matt Darcy is acknowledged and thanked for initiating the project. Financial assistance for the project was provided by the Rural Industries Research and Development Corporation, the National Landcare Program, Agriculture WA and the Australian National University.

References:


APPENDIX 1: Table for diagnosis of sodicity, salinity and pH problems
(adapted from Rengasamy and Bourne 1997)
Cloudiness measures the turbidity resulting from the sodium dispersing the clay; the greater the cloudiness, the greater the sodicity.

<table>
<thead>
<tr>
<th>Cloudiness</th>
<th>Electrical Conductivity decisiemens per metre (1:5 soil suspension in water)</th>
<th>pH (1:5 soil)</th>
<th>Soil diagnosis</th>
<th>Likely most important problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>below 0.4 for sands/loams or 0.7 for clays</td>
<td>below 5.5</td>
<td>Non-sodic, non-saline, acidic.</td>
<td>Acid</td>
</tr>
<tr>
<td>0</td>
<td>below 0.4 for sands/loams or 0.7 for clays</td>
<td>5.5 – 8.5</td>
<td>Non-sodic, non-saline.</td>
<td>No problems</td>
</tr>
<tr>
<td>0</td>
<td>below 0.4 for sands/loams or 0.7 for clays</td>
<td>above 8.5</td>
<td>Unlikely to occur. High pH soils usually highly sodic and so very cloudy in water.</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.4 and above for sands/loams, or 0.7 and above for clays</td>
<td>below 5.5</td>
<td>Non-sodic, saline, acidic.</td>
<td>Acid</td>
</tr>
<tr>
<td>0</td>
<td>0.4 and above for sands/loams, or 0.7 and above for clays</td>
<td>5.5 – 8.5</td>
<td>Saline. May still be sodic as salinity can prevent cloudy reaction in water. Send sample to laboratory to test exchangeable sodium percentage.</td>
<td>Saline</td>
</tr>
<tr>
<td>0</td>
<td>0.4 and above for sands/loams, or 0.7 and above for clays</td>
<td>above 8.5</td>
<td>Saline, alkaline. May still be sodic as salinity can prevent cloudy reaction in water. Send sample to laboratory to test exchangeable sodium percentage.</td>
<td>Saline</td>
</tr>
<tr>
<td>1</td>
<td>below 0.4 for sands/loams or 0.7 for clays</td>
<td>below 5.5</td>
<td>Sodic, non-saline, acidic.</td>
<td>Acid</td>
</tr>
</tbody>
</table>

Management of Soil
<table>
<thead>
<tr>
<th>Cloudiness</th>
<th>Electrical Conductivity (decisiemens per metre) (1:5 soil suspension in water)</th>
<th>pH (1:5 soil)</th>
<th>Soil diagnosis</th>
<th>Likely most important problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>below 0.4 for sands/loams or 0.7 for clays</td>
<td>5.5 – 8.5</td>
<td>Sodic, non-saline.</td>
<td>Sodic</td>
</tr>
<tr>
<td>1</td>
<td>below 0.4 for sands/loams or 0.7 for clays</td>
<td>above 8.5</td>
<td>Unlikely to occur. High pH soils usually highly sodic and so very cloudy in water.</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.4 and above for sands/loams or 0.7 and above for clays</td>
<td>below 5.5</td>
<td>Sodic, saline, acidic. Not often found.</td>
<td>Acid</td>
</tr>
<tr>
<td>1</td>
<td>0.4 and above for sands/loams or 0.7 and above for clays</td>
<td>5.5 – 8.5</td>
<td>Sodic, saline.</td>
<td>Saline &amp; Sodic</td>
</tr>
<tr>
<td>1</td>
<td>0.4 and above for sands/loams or 0.7 and above for clays</td>
<td>above 8.5</td>
<td>Sodic, saline, alkaline.</td>
<td>Saline &amp; Sodic (alkaline)</td>
</tr>
<tr>
<td>2</td>
<td>below 0.4 for sands/loams or 0.7 for clays</td>
<td>below 5.5</td>
<td>Unlikely to occur. Low pH often prevents cloudy reaction in water.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>below 0.4 for sands/loams or 0.7 for clays</td>
<td>5.5 – 8.5</td>
<td>Highly sodic, non-saline.</td>
<td>Highly sodic.</td>
</tr>
<tr>
<td>2</td>
<td>below 0.4 for sands/loams or 0.7 for clays</td>
<td>above 8.5</td>
<td>Highly sodic, non-saline, alkaline.</td>
<td>Highly sodic. (alkaline)</td>
</tr>
<tr>
<td>2</td>
<td>0.4 and above for sands/loams or 0.7 and above for clays</td>
<td>below 5.5</td>
<td>Unlikely to occur. Salinity will prevent cloudy reaction in water.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.4 and above for sands/loams or 0.7 and above for clays</td>
<td>5.5 – 8.5</td>
<td>Unlikely to occur. Salinity will prevent cloudy reaction in water.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.4 and above for sands/loams or 0.7 and above for clays</td>
<td>above 8.5</td>
<td>Unlikely to occur. Salinity will prevent cloudy reaction in water.</td>
<td></td>
</tr>
</tbody>
</table>

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