How do we define gypsum responsive soils?

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Key messages

- Exchangeable sodium percentage (ESP) remains the most reliable measurement for predicting dispersion in loam and clay soils.
- Crop yield responses to gypsum on sodic soils were highly variable for current and historic trials. The optimum gypsum rate to ameliorate sodicity across all sites was between 2.5 and 5 t/ha.
- The soil measurements with the best ability to differentiate between gypsum responsive and unresponsive soils were ESP and Stability Index. Overlap in the data ranges of the soil chemical and physical properties defining gypsum response were found. Gypsum strip trials remain valuable in defining gypsum response.

Aims

Soil that has sodic clay layers covers more than a third of the total area of the WA wheatbelt (van Gool 2016). By definition, sodic soil has an ESP greater than 6 within the root zone. Sodicity causes soil aggregates to disperse into their sand, silt and clay fractions resulting in reduced water infiltration, water storage, seedling emergence, root growth and crop yield. Gypsum has traditionally been used to ameliorate sodicity in loam and clay textured soil. Data collected from Ravensthorpe, Lake Grace, Jerramungup, Scaddan and North Stirlings between 2009 and 2016 were used to assess (1) the effect of sodicity on crop production, (2) soil properties and indices that best predict dispersive behaviour and (3) to identify soil indices and ranges that define gypsum responsive soil.

Method

Soil and crop yield data were obtained from eight sites one of each near Ravensthorpe, North Stirlings, Jerramungup, Cascade and two near Scaddan and Lake Grace. The soil at the sites are grey or brown sodosols and have loam or clay textures to a depth of 30 cm (Table 1). Each of these sites had either a gypsum rate trial (0–10 t/ha) or a gypsum (3 t/ha) by tillage interaction trial. Based on trial yield results, the sites were defined as either gypsum responsive resulting in significant yield (grain or biomass) increases or unresponsive.

Table 1. Soil properties from the control treatments for the Ravensthorpe, Lake Grace (1,2) , Cascade, Scaddan (1,2), North Stirlings and Jerramungup sites including pH($CaCl_2$), electrical conductivity (EC dS/m), organic carbon (%), Boron (ppm) and Dispersion Index (DI). Exchangeable sodium percentage (ESP), Ca:Mg ratio and Stability Index (SI) were calculated from pre-washed cations (cmol+/kg). The sites were divided into gypsum responsive and unresponsive based on crop yield.

Site/Response	Depth	Texture*	pHca	EC	OC	B	ESP	Ca:Mg	SI	EC/ESP	DI
Gypsum Responsive											
Ravensthorpe	10	Loam	7.2	0.29	1.7	3	6	1.7	1.4	0.11	0.94
	20	Loam	7.7	0.38	0.6	7	15	1.0	-1.9	0.03	4.28
	30	LClay	8.1	0.52	0.3	11	17	1.3	-1.8	0.04	4.71
Lake Grace 1	10	SLoam	5.9	0.13	1.1	1	4	4.1	1.0	0.04	0.19
	20	Loam	6.5	0.10	0.5	7	11	1.3	-3.6	0.01	2.84
	30	Loam	7.4	0.16	0.3	14	17	0.8	-3.2	0.03	5.68
Cascade	5	LClay	5.8	0.21	1.1	2	14	0.8	-1.3	0.02	
	15	LClay	7.0	0.39	1.0	5	24	0.5	-2.1	0.01	
	25	LClay	7.9	0.70	0.9	8	31	0.4	-2.0	0.02	
North Stirlings	10	Loam	6.3	0.51	1.4	4	5	3.5	2.3	0.49	1.40
	20	LClay	7.7	1.02	0.6	16	16	2.5	-0.7	0.15	4.42
	30	LClay	8.1	1.34	0.4	24	19	1.6	-1.3	0.10	4.75

Table 1 cont.	Depth	Texture*	pHca	EC	OC	B	ESP	Ca:Mg	SI	EC/ESP	DI
Gypsum unresponsive											
Lake Grace 2	10	Clay	6.7	0.31	1.6	1	1	5.0	2.5	0.42	0.00
	20	Clay	7.6	0.22	0.9	7	2	2.4	0.8	0.31	0.30
	30	Clay	8.0	0.22	0.5	14	3	1.7	-0.2	0.14	0.53
Scaddan 1	10	Loam	7.6	0.36	1.4	3	1	5.6	2.9	0.57	0.13
	20	LClay	7.8	0.38	0.9	9	4	3.3	1.4	0.37	1.23
	30	LClay	8.2	0.47	0.5	13	5	2.6	0.4	0.30	1.15
Scaddan 2	10	Loam	6.9	0.18	1.1	1	4	6.7	1.8	0.06	0.48
	20	Loam	7.4	0.23	0.4	4	6	2.5	-0.1	0.05	5.24
	30	Loam	7.8	0.34	0.3	6	5	2.3	0.2	0.07	5.88
Jerramungup	10	SLoam	6.2	0.42	1.5	2	4	2.3	2.1	0.38	1.12
	20	SLoam	6.7	0.29	0.8	4	6	1.2	0.0	0.14	3.14
	30	SLoam	7.0	0.30	0.5	6	8	0.8	-0.9	0.08	3.76

* SLoam = sandy loam, LClay = Loamy Clay

Soil samples were collected at 10 cm intervals to 30 cm within each plot at each site. These samples were analysed for pH ($CaCl_2$), nutrients (N,P,K,S) electrical conductivity (EC dS/m), organic carbon (OC%), Boron, prewashed exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) and dispersion using a modified Emerson aggregate immersion dispersion index (DI, Loveday and Pyle 1973) (Table 1). Sulphur was not nutritionally limiting at any site. Sulfur (S) levels within the nil gypsum treatments were above 8 ppm within the 0 – 10 cm layer at all sites.

Soil stability indices which are commonly used to predict dispersive behaviour and gypsum response were calculated including ESP (Na/(Ca+Mg+K+Na)*100), EC/ESP, Ca:Mg ratio and the Stability Index (Needham 2004) = f(ESP, EC, Ca:Mg, OC%). A regression analysis (Hulugalle et al. 2003), was used to determine the strength of the relationships between DI and soil stability indices associated with dispersive behaviour. A *t*-test was used to rank soil parameters in terms of their ability to segregate gypsum responsive from unresponsive soils.

Crop yield (biomass or grain yield) was determined from the same soil sampling points at each of the sites. Crop yield was converted to relative yield (yield/potential yield x 100) and plotted against the average ESP within the 0–30 cm layer.

Data from historic gypsum trials conducted between the 1970s and early 2000s were collated into a database containing 40 trials and 113 data points. All data including the historic, gypsum responsive and unresponsive sites were used to determine the relative crop yield response to gypsum. The relative yield percentage in this case was calculated as the yield (gypsum treated) / yield (nil gypsum) x 100.

Results

Effects of sodicity on crop yield.

Relative yield declined with increasing ESP (Figure 1). For every 10% increase in ESP, crop yield was reduced by approximately 10 (Rengasamy 2002) to 20% (data presented here). The relationship from the sites in southern WA (RY% = -1.9 ESP + 100, r^2=0.09, n=107) is not strong with ESP explaining only 9% of the variation in RY%. The data from southern WA tended to fit below the line derived by Rengasamy (2002) suggesting that factors other than ESP were further reducing yields in these sodic soils. Boron toxicity and transient salinity (Table 1) are often associated with highly (ESP > 15) sodic soils and are likely to exacerbate yield declines with increasing sodicity.

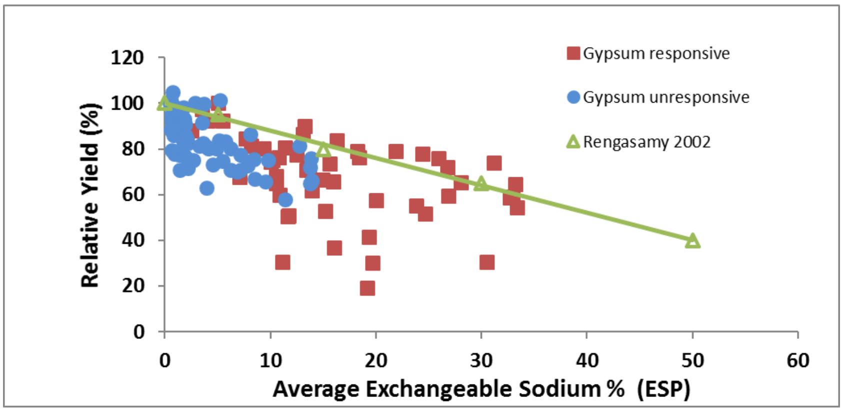

Figure 1. Relationship between relative yield and average exchangeable sodium percentage (ESP) within the 0–30 cm layer for the sites that were gypsum responsive and unresponsive. Yield and ESP relationship from other sites in Australia is represented by the (Rengasamy 2002).

Ranking soil factors that affect dispersion.

Measured soil properties related to aggregate stability were ranked in order of their ability to predict dispersion across all sites (Table 2). ESP explained more of the variation in DI than any other measured soil property. While the other measures of soil stability were statistically significant, they accounted for less than 45% of the variation in dispersion.

Across all sites, the critical levels for ESP, Ca:Mg ratio and EC/ESP above which dispersion commenced are similar to previously published levels of > 6 , <2 and <0.2 respectively (Loveday and Pyle 1973, Rengasamy et al. 1986, Hulugalle 2003). A SI of less than 0.8 was required for dispersion to occur which equates to low to moderate stability (Needham et al 2004).

Table 2. Variation in dispersion indices accounted for by related soil chemical properties (x). Dispersion Index = $a+b(c)^x$. Relationships developed from individual samples across the four sites and three sampling depths (n=294). Based on the relationships developed, the calculated critical level is defined as observed “slight dispersion” when aggregates are immersed in deionised water (DI = 2, Loveday and Pyle 1973).

Soil Properties (x)	a	b	c	Adj r^2	Prob	Critical Level
ESP	6.23	-6.46	0.92	67	*** (P<0.001)	>5
EC/ESP	-0.22	4.56	0.01	43	***	<0.13
Stability Index (SI)[#]	5.62	-2.96	1.28	40	***	<0.8
Organic carbon %	-0.86	12.74	0.15	37	***	<0.8
Ca:Mg	0.76	6.79	0.48	35	***	<2.3

[#] *Stability Index = f (ESP, OC, EC, Ca:Mg)*

Crop responses to gypsum.

Crop yield responses to gypsum from historic trials conducted in WA between 1977 and 2010 and from the gypsum responsive and unresponsive sites (Table 1) showed that much of the improvement in crop yields occured at gypsum rates between 2.5 and 5 t/ha (Figure 2). However, the results also showed a high level of variability in yield response to gypsum. Only 20 of the 52 historic trials resulted in significant yield increases in response to gypsum application.

Lemon et al. (2012) showed that profitable gypsum responses were found in only two of the six commercial gypsum strip plot trials investigated on the south coast. Given that gypsum trials are conducted on sites that have a history of dispersive behaviour, this suggests that our ability to predict soils that are likely to respond economically is poor.

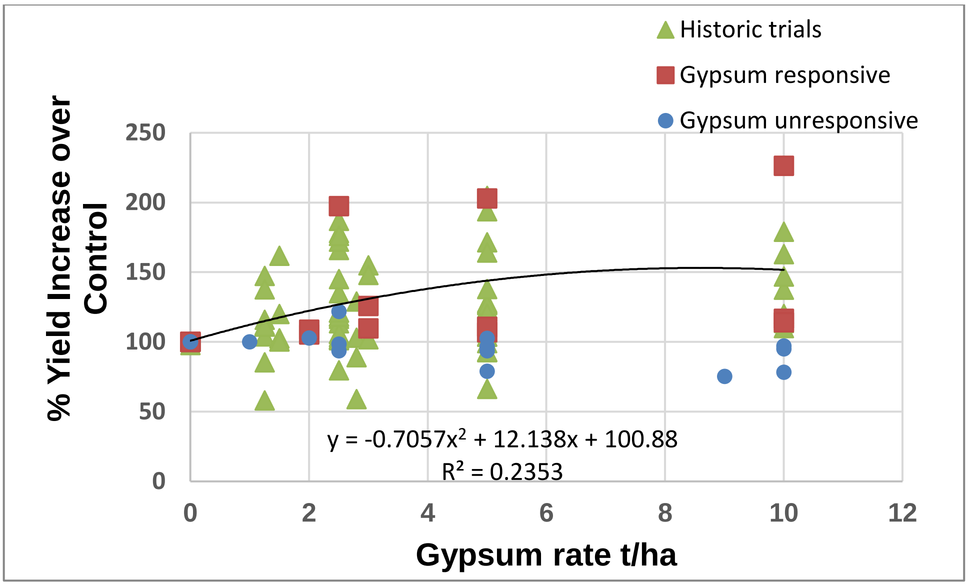

Figure. 2 Gypsum response curve based a 160 data points from experiments conducted in the WA wheatbelt. Data recorded between 1977 and 2010.

Identifying gypsum responsive soils.

ESP and the Stability Index were the two indices most likely to distinguish between the gypsum responsive and unresponsive sites. The average values within the 0–30 cm layer for ESP and SI in the gypsum responsive sites were greater than 15 and less than -1 respectively (Table 3). The simple aggregate immersion test (DI) was also able to distinguish between the gypsum responsive and unresponsive soils to a similar degree to the Ca:Mg ratio and more so than EC/ESP and OC%. There was considerable overlap in the ranges between the gypsum responsive and unresponsive data sets (Table 3). This indicates that chemical and physical tests for identifying gypsum responsive and unresponsive soils are at best a guide.

Table 3. Comparison of soil properties used to differentiate between gypsum responsive from unresponsive soils for all sites. The higher the absolute *t* statistical number, regardless of whether it is positive or negative, the greater the differentiation between gypsum responsive and unresponsive sites. Means and ranges in brackets for each soil property are given for the gypsum responsive (n = 65) and unresponsive (n=71) sites.

Soil property (0-30cm)	**t Statistic**	**Prob[#]**	**Gypsum Responsive Mean (range)**	**Gypsum Unresponsive Mean (range)**
ESP	**10**	***	**15.1** (2 - 33)	**4.1** (0.4 - 14)
Stability Index (SI)	**-9.12**	***	**-1.3** (-3 – 2)	**0.8** (-3 – 3)
Ca:Mg	**-5.63**	***	**1.6** (0.2 – 5.8)	**2.9** (0.4 – 6.5)
Dispersion Index (DI)	**5.2**	***	**3.4** (0 – 7.6)	**1.7** (0 – 6)
EC/ESP	**-4.8**	***	**0.07** (0.01 – 0.61)	**0.24** (0.02 1.28)
Organic Carbon %	**-4.8**	***	**0.6** (0 – 1.2)	**0.83** (0.4 – 1.6)

[#] Probability *** (P<0.001)

Conclusions

Aggregate dispersion was found to be mainly correlated with ESP in the soils tested with Ca:Mg ratio, Stability Index, OC% and EC/ESP being significant factors but accounting for less variation in dispersion. The optimum gypsum rate from the sites presented here and those from historic trials was between 2.5 and 5 t/ha. ESP and Stability Index were most effective in discriminating between gypsum responsive and unresponsive soils in southern WA. Given the overlap in the ranges of the soil chemical and physical properties used to discriminate gypsum response, gypsum strip trials remain a useful tool in diagnosing soils that are likely to respond to gypsum.

Key words: Sodicity, gypsum, relative yields, dispersion, southern Western Australia.

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Reviewer: Dr James Fisher