Gypsy

Discounted Cash Flow Analysis for Application of Gypsum to Sodic Soils under Sugarcane

Manual

COOPERATIVE RESEARCH CENTRE *for*
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Gypsy v1.5

Discounted Cash Flow Analysis for Application of Gypsum to Sodic Soils under Sugarcane

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ALL YOU NEED TO READ

About Gypsy

The purpose of Gypsy is to help Australian sugarcane growers make decisions on what rates of gypsum to apply to sodic soils. It is a tool designed for use by advisory staff and growers, together with the manual 'Diagnosis and Management of Sodic Soils under Sugarcane' (Nelson et al., 2000), the 'Field Guide for Diagnosis of Sodic Soils in the Sugar Industry' (Nelson, 2000), and local experience.

Sugarcane growth and yield is badly affected by soil sodicity in considerable areas. Adding gypsum, which is a relatively soluble source of calcium, can often reduce soil sodicity. The optimum amount to add depends on several soil properties, as well as costs and prices. Growers commonly apply different rates to different parts of a block, and in the current climate of increasing costs and decreasing prices, the need to apply optimum rates to each area is becoming critical.

Gypsy estimates the influence of a gypsum addition on cane yield and cash flow on neutral-alkaline soils, using known relationships between yield and sodicity, and the effect of gypsum on sodicity. The inputs are cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) for the 0-25 cm and 25-50 cm depth layers, cost and quality of the gypsum, price of cane, and a discount rate. The output is a cash flow analysis, with a graph showing net benefit against gypsum rate.

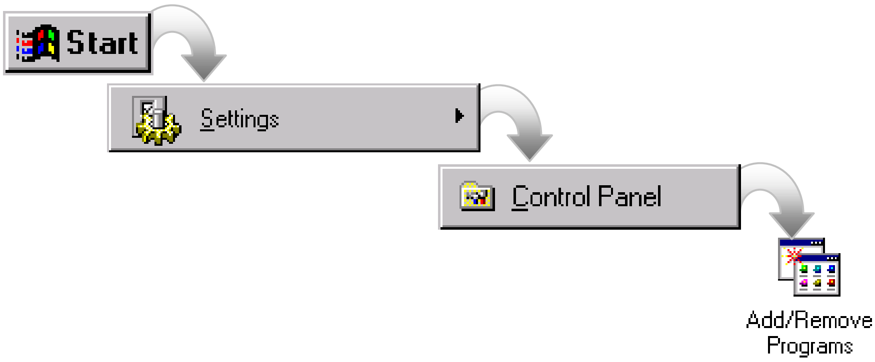
As irrigation water quality is critical to managing sodic soils, Gypsy can also be used to calculate how irrigation water quality can be modified using a dissolvenator or by mixing water from different sources (conjunctive use). Gypsy can also be used to calculate CEC and ESP from exchangeable cation values, to convert between different units for electrical conductivity (EC), and to estimate changes in ESP when lime is added to acid sodic topsoils.

The program is designed to run with a minimum of inputs and therefore involves various assumptions, so it is intended as an approximate guide only. Any comments or suggestions for improvements are welcome, and could be incorporated into subsequent versions.

For comments or questions, contact Philip Charlesworth, CSIRO Land and Water. Tel. (07) 4753 8500, Fax. (07) 4753 8600, E-mail. Philip.Charlesworth@clw.csiro.au

Installing Gypsy

If you have an older version of Gypsy on your computer, remove it before installing the new one. To do this, go to Start > Settings > Control Panel > Add/remove programs, and remove Gypsy.



Installing from the Web

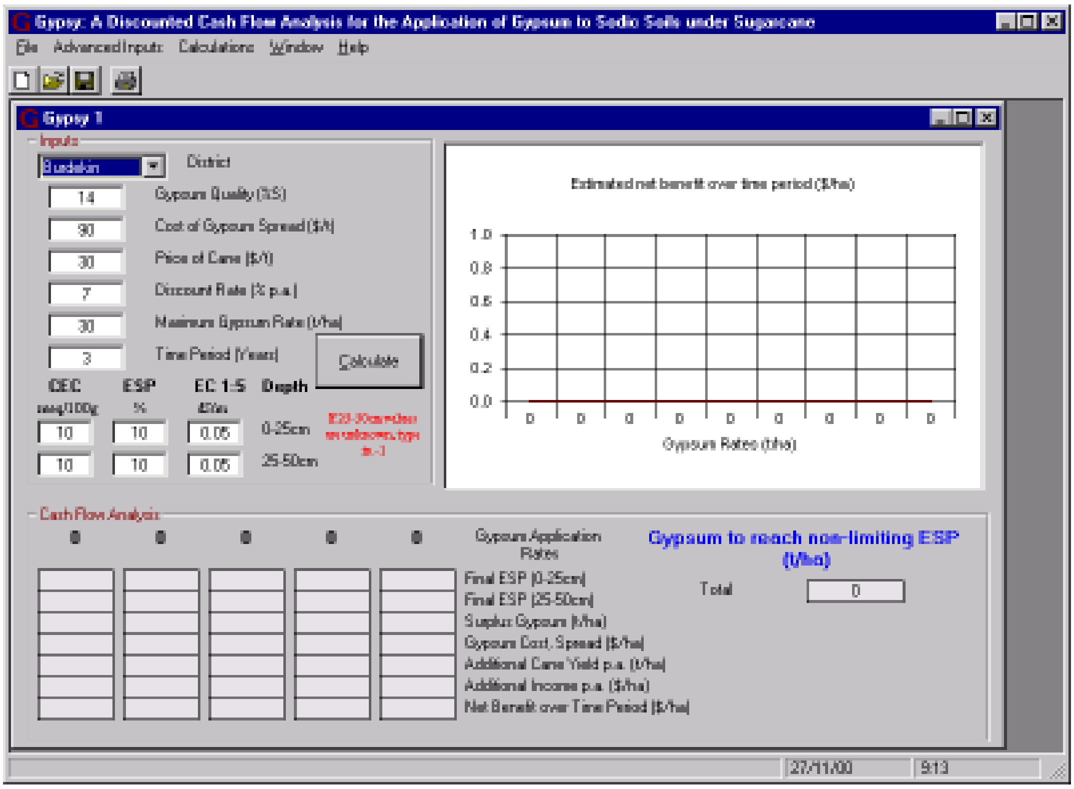
- The preferred way of installing Gypsy is via the CRC Sugar Web site (http://www-sugar.jcu.edu.au/), as this ensures you have the latest version. Go to the ‘Research’ page and follow the links to more detailed information on research projects.
- When installed, you will be able to open Gypsy by clicking the “Start” button, looking in Programs, and clicking the Gypsy icon

Installing from floppy discs

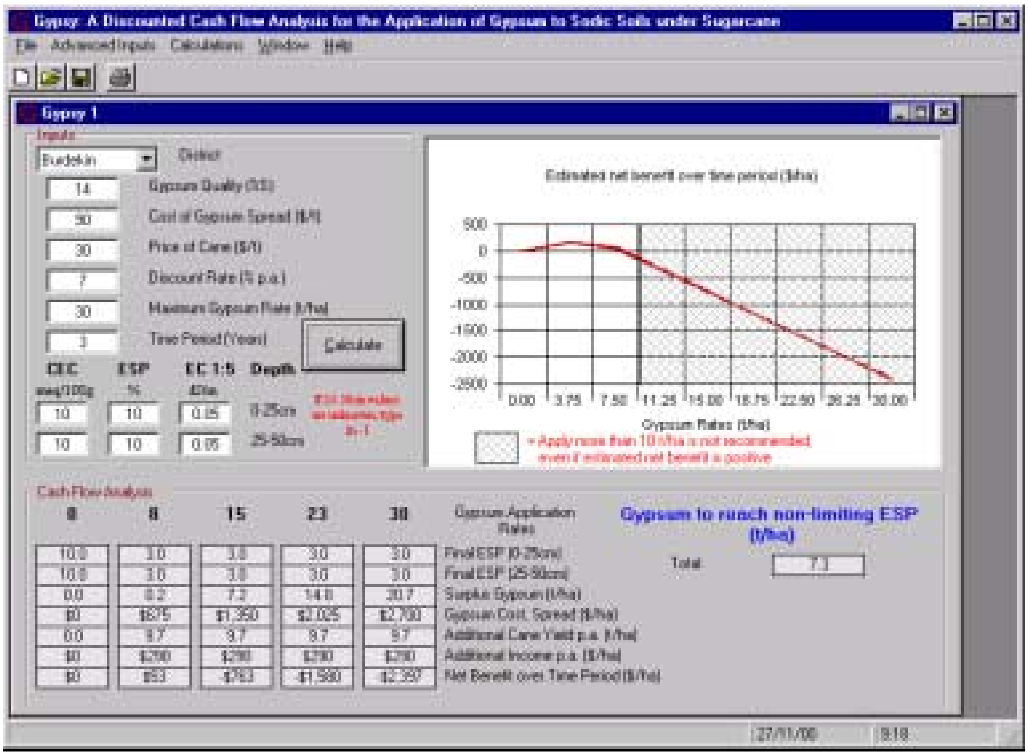
- Close all programs, insert disk 1 and run Setup.exe
- Follow the prompts, inserting disk 2 when asked
- When installed, you will be able to open Gypsy by clicking the “Start” button, looking in Programs, and clicking the Gypsy icon

Getting started

The main screen of Gypsy is shown below, with default values



- The window can be manipulated like any Windows window.
- It is divided into three sections: “Inputs”, “Cash Flow Analysis” and the graph of net benefit versus gypsum rate.
- To run Gypsy, type soil test and other values into the spaces on the “Inputs” section, and click the “Calculate” button.
- If you don’t have soil test values for the 25-50 cm depth layer, type in –1, and Gypsy will calculate the values for you.
- You can find help on any of the inputs by pressing the F1 key while the cursor is in that input box. Alternatively, you can use the “Help” button on the top menu bar.
- After pressing “Calculate”, the results of cash flow analysis are shown and the bottom line (net benefit over the time period specified) is shown in the graph, as shown below for the default example.

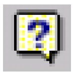


- Gypsy calculates the cash flow analysis for a gypsum rate of zero, for the maximum gypsum rate specified, and for several points in between. In the example above, there is a net loss for gypsum rates above 7.5 t/ha. To increase the resolution around the optimum gypsum rate, change the maximum gypsum rate to around 7.5 and click the "Calculate" button again.
- Applying rates of gypsum greater than 10 t/ha is not recommended, even if there is an estimated net benefit. If rates greater than 10 t/ha appear to be profitable, it is recommended that 10 t/ha be applied and the situation reassessed at the end of the crop cycle.
- "Gypsum to reach non-limiting ESP" is the amount of gypsum needed to bring sodicity down to a level low enough not to limit cane growth. It is not necessarily the most profitable rate.
- Depending on soil properties, warnings may sometimes appear in the bottom right hand corner.

Saving, printing, opening

- Gypsy sessions can be saved, opened and printed using the buttons on the toolbar.
- You can have as many main windows open at once as you like, so that you can do the cash flow analysis for several sites at once. The "Windows" button on the main menu gives you easy access to all the open windows.

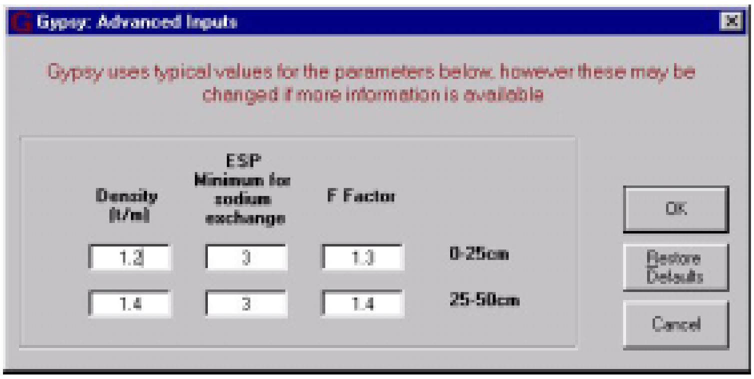
Help



- You can access help on any of the inputs by pressing the F1 key while your cursor is in that input.
- Alternatively, you can search for help on any topic by clicking the “Help” button on the main menu.

Advanced inputs

Clicking “Advanced inputs” inputs on the main menu will give you the following window:

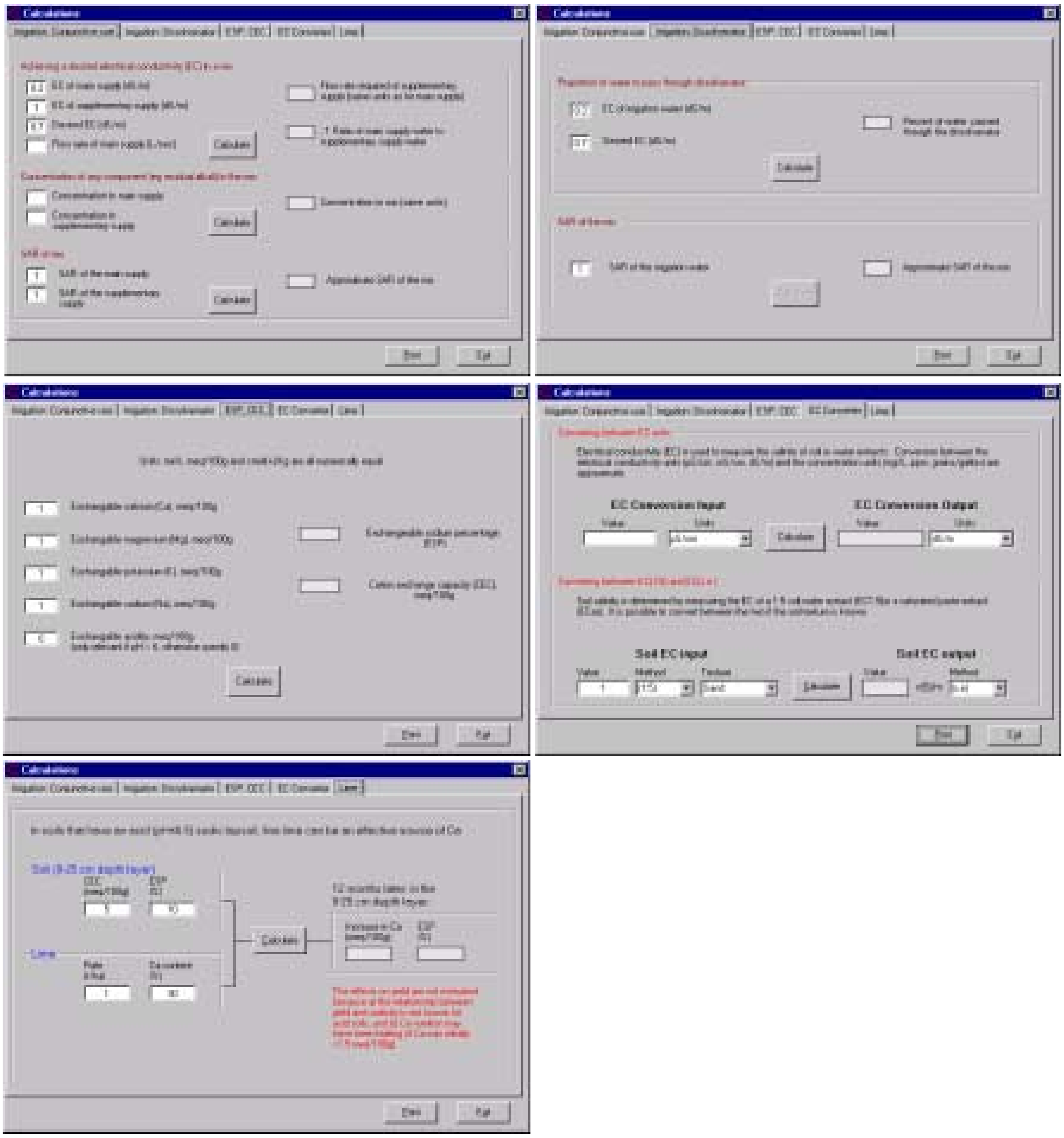


- You don’t normally need to change any of these values from the default settings, but if you want to know anything about them or think you would like to change them, look in Help (F1 key).

Calculations

Clicking “Calculations” on the main menu will give you one of the five windows shown below. You can change between them using the tabs

- To do the calculations, type in the relevant values in the white boxes on the left, press “Calculate”, and read the answers from the boxes on the right.
- For help on any of the inputs, press the F1 key.



BORING BACKGROUND STUFF ABOUT THE PROGRAM

1. Introduction

Soil sodicity has been conservatively estimated to cost the Australian sugar industry 500,000 t of cane per annum (Ham et al., 1997). Approximately 10-24% of the cane-growing soils outside of the wet tropics are sodic, and the proportion is higher in areas into which the industry is expanding. Trials, summarised by Ham et al. (1997) have shown gypsum applications of 10 t ha^{-1} to be economic on sodic soils. However, the optimum rates of gypsum application are not known for soils that are more or less sodic than those used in the trials. Growers commonly apply different rates to different parts of a block, and in the current climate of increasing costs and decreasing prices, the need to apply optimum rates to each area is becoming more critical. The increasing capacity to map yield on variably sodic blocks and to apply gypsum at variable rates is also leading to a demand for appropriate rate recommendations.

The results of recent trials quantifying the relationship between cane yield and soil sodicity in the Burdekin (Nelson and Ham, 2000), in combination with previous information (Oster and Jayawardane, 1998; Spalding, 1983), are used to estimate the economics of gypsum application to neutral-alkaline sodic soils under sugarcane in this algorithm. The algorithm is written as a stand-alone Windows program in Visual Basic.

2. Algorithm

2.1 User inputs

Min. and max refer to the values below or above which an error message is displayed

Gypsum application calculations

- Gypsum quality as percent sulfur (GYPQUAL). Min 10, max 18.6, default 14.
- Cost of gypsum, spread, in \$ t^{-1} (GYPCOST). Min 40, max 150, default 90.
- Price of cane in \$ t^{-1} (CANEPRICE). Min 10, max 50, default 30.
- Discount rate (eg. interest on borrowed funds) in % per annum (DISCRATE). Min 0, max 30, default 7.
- District: choice of Mareeba, Herbert, Burdekin, Proserpine, Central Qld. (including Mackay and Sarina) or Southern Qld. (including Bundaberg, Childers, Isis and Maryborough) (DISTRICT). Default Burdekin.
- Number of years over which the cash flow analysis is carried out (YEARS). Min 0, Max 10, default 4.

- Cation exchange capacity of 0-25 cm depth layer in $cmol_c$ kg^{-1}. (CECa). Min 0.01, max 60, default 10.
- Cation exchange capacity of 25-50 cm depth layer in $cmol_c$ kg^{-1} (CECb) (estimated by Gypsy if a value of -1 is given). Min 0.01, max 60, default 10.
- Initial exchangeable sodium percentage of 0-25 cm depth layer (ESPINIa). Min 0, max 100, default 10.
- Initial exchangeable sodium percentage of 25-50 cm layer (ESPINIb) (estimated by Gypsy if a value of -1 is given). Min 0, max 100, default 10.
- Electrical conductivity of a 1:5 extract of the 0-25 cm layer, in dS m^{-1} (SECa). Min 0, max 5, default 0.05.
- Electrical conductivity of a 1:5 extract of the 25-50 cm layer, in dS m^{-1} (SECb) (estimated by Gypsy if a value of –1 is given). Min 0, max 5, default 0.05.

- Maximum rate of gypsum for analysis, in t ha^{-1} (GYPMAX). Min 10, max 80, default 30.

Irrigation water calculations: conjunctive use

- Electrical conductivity of main supply in dS m^{-1} (ECMc). Min 0, max 3.2, default 0.2.
- Electrical conductivity of supplementary supply in dS m^{-1} (ECSc). Min 0, max 10, default 1.
- Desired EC in dS m^{-1} (ECDc). Min 0, max 3.2, default 0.7.
- Flow rate of main supply in any units of volume per time (FLOWMc).
- Concentration of any component (such as residual alkali) in the main supply, in any units (CONCMc).
- Concentration of the same component in the supplementary supply (CONCSc), in the same units.
- Sodium adsorption ratio (SAR) of main supply (SARMc). Min 0, max 30, default 1.
- SAR of supplementary supply (SARSc). Min 0, max 30, default 1.

Irrigation water calculations: dissolvenator

- EC of irrigation water in dS m^{-1} (ECMd). Min 0, max 2.0, default 0.2.
- Desired EC in dS m^{-1} (ECDd). Min 0, max 2.1, default 0.7.
- SAR of irrigation water (SARMd). Min 0, max 30, default 1.

ESP, CEC calculations

- Exchangeable Ca, Mg, K, Na and acidity all have min 0, max 50.Default is 1, except for exchangeable acidity, which has a default of 0.

EC calculations

- For "Converting between EC units", the input value has min 0, no max, default 1, and default units of μS/cm. The output value has default units of dS/m. For "Converting between EC(1:5) and EC(s.e.)", the input value has min. 0, no max., default value 1, default method (1:5) and default Texture of Loam, and the output has default method (s.e.).

Lime calculations

- CEC of 0-25 cm layer, in $cmol_c$ kg^{-1} (CECl). Min 0.1, max 50, default 5.
- ESP of 0-25 cm layer, in % (ESPINIl). Min 0, max 100, default 10.
- Rate of lime application in t ha^{-1} (LIMERATE). Min 0, max 20, default 1.
- Quality of lime, as percentage Ca (LIMEQUAL). Min 5, max 70, default 30.

2.2 Advanced level inputs

These parameters should normally be left at the default values. However, they can be modified to suit local conditions.

- Density of 0-25 cm depth layer in t m^{-3} (DENSa). Min 0.8, max 2, default 1.3.
- Density of 25-50 cm depth layer in t m^{-3} (DENSb). Min 1, max 2.5, default 1.4.
- ESP of 0-25 cm depth layer below which gypsum moves down to next layer (ESPMINa). Min 0, max 10, default 3.
- ESP of 25-50 cm depth layer below which gypsum moves down to next layer (ESPMINb). Min 0, max 10, default 3.
- F factor (unitless) for 0-25 cm depth layer (Fa). Min 1.1, max 1.3, default 1.3.
- F factor (unitless) for 25-50 cm depth layer (Fb). Min 1.1, max 1.3, default 1.3.

2.3 Notes regarding advanced level inputs

Bulk density varies from approximately 1 t m^{-3} for a very loose, recently cultivated layer, to approximately 1.6 t m^{-3} for a very hard, compact layer.

The ESP below which gypsum moves down into the next layer is based on the assumption that once ESP is down to 3, hydraulic conductivity will be relatively high, and the efficiency of exchange of Ca for Na will be relatively low, so gypsum will move down into the next layer. This parameter also defines the ESP below which no benefit is expected.

The F factor ranges from 1.1 for a final ESP of 15 to 1.3 for a final ESP of 5 (Oster and Jayawardane, 1998). The default value is conservative.

2.4 Calculations: gypsum application calculations

If CECb, ESPb or SECb values are not available (and a value of –1 has been used as input), they are calculated as follows:

If CECb = -1 and DISTRICT is Mareeba
Then CECb = 0.690 × CECa + 1.972

If CECb = -1 and DISTRICT is Herbert
Then CECb = 1.387 × CECa + 1.861

If CECb = -1 and DISTRICT is Burdekin
Then CECb = 0.732 × CECa + 6.658

If CECb = -1 and DISTRICT is Proserpine
Then CECb = 1.237 × CECa + 3.283

If CECb = -1 and DISTRICT is Central Qld.
Then CECb = 1.209 × CECa + 1.730

If CECb = -1 and DISTRICT is Southern Qld.
Then CECb = 0.719 × CECa + 2.355

If ESPb = -1 and DISTRICT is Mareeba
Then ESPb = 2.340 × ESPa + 3.480

If ESPb = -1 and DISTRICT is Herbert
Then ESPb = 0.849 × ESPa + 7.595

If ESPb = -1 and DISTRICT is Burdekin
Then ESPb = 1.319 × ESPa +4.153

If ESPb = -1 and DISTRICT is Proserpine
Then ESPb = 0.960 × ESPa + 4.504

If ESPb = -1 and DISTRICT is Central Qld.
Then ESPb = 1.226 × ESPa + 3.062

If ESPb = -1 and DISTRICT is Southern Qld.
Then ESPb = ESPa + 4

If SECb = -1 and DISTRICT is Mareeba
Then SECb = 1.99 × SECa – 0.03

If SECb = -1 and DISTRICT is Herbert
Then SECb = 1.33 × SECa + 0.04

If SECb = -1 and DISTRICT is Burdekin
Then $SECb = 1.12 \times SECa + 0.10$

If SECb = -1 and DISTRICT is Proserpine
Then $SECb = 0.89 \times SECa + 0.02$

If SECb = -1 and DISTRICT is Central Qld.
Then $SECb = 1.02 \times SECa + 0.05$

If SECb = -1 and DISTRICT is Southern Qld.
Then $SECb = 0.51 \times SECa + 0.08$

If a soil sample is saline ($EC_{1:5}$ > 0.3 dS m^{-1}), standard laboratory soil tests overestimate the ESP value. If a chloride content is available on the soil test, then the option is given to correct the soil test CEC and ESP. If chloride content of the 25-50 cm layer (CLb) is not available (and a value of –1 has been used as input), it is calculated as follows:

If CLb = -1, then $CLb = CLa \times SECb / SECa$

Then CEC and ESP are corrected using the following equations:

$$CEC = z - (x / 355)$$

$$ESP = \frac{(y \times z / 100) - (x / 355) \times 100}{z - (x / 355)}$$

Where: x = Chloride content in mg kg^{-1} (or ppm)
y = Soil test ESP
z = Soil test CEC in $cmol_c$ kg^{-1} (or meq %)

Nine rates of gypsum (t ha^{-1}) are calculated for the analysis:

GYPRATE1 = 0
GYPRATE2 = GYPMAX × 0.125
GYPRATE3 = GYPMAX × 0.25
GYPRATE4 = GYPMAX × 0.375
GYPRATE5 = GYPMAX × 0.5
GYPRATE6 = GYPMAX × 0.625
GYPRATE7 = GYPMAX × 0.75
GYPRATE8 = GYPMAX × 0.875
GYPRATE9 = GYPMAX

For each rate of gypsum, the rate of pure gypsum applied to the surface (PGYPRATEa), in t ha^{-1}, is calculated based on the sulfur content of the applied gypsum, and the sulfur content of pure gypsum (18.6%). A rate factor (RATEFAC) is also included. The rate factor accounts for possible losses of gypsum in surface runoff, and negative salinity effects at high application rates.

If GYPRATE1 < 10, RATEFAC1 = 1
If 10 < GYPRATE1 < 30, RATEFAC1 = (10 + 0.9 (GYPRATE1 – 10)) / GYPRATE1
If 30 < GYPRATE1, RATEFAC1 = (28 + 0.8 (GYPRATE1 – 30)) / GYPRATE1

PGYPRATEa1 = GYPRATE1 × RATEFAC1 × GYPQUAL / 18.6

And so on for the other gypsum rates.

For each gypsum rate, the amount of gypsum used in the 0-25 cm layer to reduce ESPINIa to ESPMINa, or the total amount of gypsum added, whichever is less (PGYPUSEDa), is calculated. In order to calculate PGYPUSEDa, the gypsum requirement for the 0-25 cm layer (PGYPREQa) is calculated according to the equation given by Oster and Jayawardane (1998).

If ESPMINa < ESPINIa, then PGYPREQa = 0.086 × Fa x 0.25 × DENSa × CECa × (ESPINIa –ESPMINa)
If not, then PGYPREQa = 0

If PGYPREQa > PGYPRATE1, then PGYPUSEDa1 = PGYPRATE1
If not, then PGYPUSEDa1 = PGYPREQa

And so on for the other gypsum rates.

For each gypsum rate, the amount of gypsum that enters the 25-50 cm layer (PGYPRATEb) is calculated. Then, the amount of gypsum used in the 25-50 cm layer to reduce ESPINIb to ESPMINb, or the total amount of gypsum added, whichever is less (PGYPUSEDb), is calculated. The gypsum requirement for the 25-50 cm layer (PGYPREQb) is calculated according to the equation given by Oster and Jayawardane (1998).

PGYPRATEb1 = PGYPRATEa1 – PGYPUSEDa1

If ESPMINb < ESPINIb, then PGYPREQb = 0.086 × Fb × 0.25 × DENSb × CECb × (ESPINIb –ESPMINb)
If not, then PGYPREQb = 0

If PGYPREQb > PGYPRATEb1, then PGYPUSEDb1 = PGYPRATEb1
If not, then PGYPUSEDb1 = PGYPREQb

And so on for the other gypsum rates.

For each gypsum rate, the amount of gypsum that is leached below 50 cm depth (GYPSURP) is calculated

GYPSURP1 = (PGYPRATEa1 – PGYPUSEDa1 – PGYPUSEDb1) × 18.6 / GYPQUAL

And so on for the other gypsum rates.

For each gypsum rate, the final ESP of the 0-25 cm layer (ESPFINa)and 25-50 cm layer (ESPFINb) are calculated

$$ESPFINa1 = ESPINIa – (PGYUSEDa1 / (0.086 \times Fa \times 0.25 \times DENSa \times CECa))$$

$$ESPFINb1 = ESPINIb – (PGYUSEDb1 / (0.086 \times Fb \times 0.25 \times DENSb \times CECb))$$

And so on for the other gypsum rates.

For each gypsum rate, the initial and final amounts of exchangeable sodium in the 0-50 cm zone, weighted for depth, and expressed in cmol$_c$ kg^{-1} (EXSODINI and EXSODFIN), are calculated.

$$EXSODINI = ((0.619 \times ESPINIa \times CECa) + (0.381 \times ESPINIb \times CECb)) / 100$$

$$EXSODFIN1 = ((0.619 \times ESPFINa1 \times CECa) + (0.381 \times ESPFINb1 \times CECb)) / 100$$

And so on for the other gypsum rates.

For each gypsum rate, the additional annual cane yield in t ha^{-1}, averaged over the crop cycle (YIELDADD) is calculated, using the yield factor (YIELDFAC), which is set according to district. The yield factor is the increased yield in t ha^{-1} for every 1 cmol$_c$ kg^{-1} drop in weighted exchangeable sodium. The additional yield calculation includes a time factor, assuming that half of the benefit of the gypsum application is realised in the first year, and the full benefit is realised in subsequent years.

If DISTRICT = Burdekin or Mareeba, YIELDFAC = 14.8
If not, YIELDFAC = 10.6

$$YIELDADD1 = YIELDFAC \times (EXSODINI – EXSODFIN1) \times ((YEARS – 0.2) / YEARS)$$

And so on for the other gypsum rates.

The amount of gypsum required to reach the minimum ESP in both soil layers (GYPOPT), assuming no losses, is calculated using the Oster equation:

$$GYPOPT = 18.6 \times (PGYPREQa + PGYPREQb) / GYPQUAL$$

For each gypsum rate, the additional annual income, averaged over the specified period (INCADD) and the total cost (COSTADD) in \$ ha^{-1} are calculated

$$INCADD1 = YIELDADD1 \times CANEPRICE$$

$$COSTADD1 = GYPCOST \times GYPRATE1$$

And so on for the other gypsum rates.

The net benefit over the specified crop cycle, in \$ ha^{-1} (NETBEN) is calculated

$$NETBEN1 = YEARS \times INCADD1 - COSTADD1 - ((DISCRATE \times COSTADD1 \times 0.01) \times YEARS)$$

And so on for the other gypsum rates

A graph showing NETBEN vs GYPRATE is then plotted

Results can be printed or saved to file.

2.5 Irrigation water calculations: conjunctive use

These calculations are independent of the gypsum application calculations. Given the electrical conductivity of the main irrigation water supply (ECMc) and supplementary supply ECSc), and the desired EC (ECDc), the ratio of main supply water volume to supplementary supply water volume (Rc) is calculated.

$$Rc = (ECSc - ECDc) / (ECDc - ECMc)$$

Given a flow rate of the main supply as well (FLOWMc), the flow rate of the supplementary supply is calculated.

$$FLOWSc = FLOWMc \times (ECDc - ECMc) / (ECSc - ECDc)$$

Given the concentrations of any particular solute (eg. residual alkali) in the main supply (CONCMc) and supplementary supply (CONCSc), the concentration of that solute in the mix (CONCMIXc) is calculated.

$$CONCMIXc = ((CONCMc \times Rc) + CONCSc) / (Rc + 1)$$

Given the SAR of the main supply (SARMc) and supplementary supply (SARSc), the approximate SAR of the mix (SARMIXc) is calculated. First, the concentration of sodium in the main supply (NAMc) and supplementary supply (NASc) is calculated. The calcium plus magnesium concentration of the main supply (CAMc) and supplementary supply (CASc) is then estimated, assuming no potassium is present.

$$NAMc = (-SARMc^2 + \sqrt{(SARMc^4 + 8 \times SARMc^2 \times ECMc \times 10)}) / 4$$
$$NASc = (-SARSc^2 + \sqrt{(SARSc^4 + 8 \times SARSc^2 \times ECSc \times 10)}) / 4$$

$$CAMc = (ECMc \times 10) - NAMc$$
$$CASc = (ECSc \times 10) - NASc$$

Then the approximate SAR of the mix (SARMIXc) is calculated.

$$SARMIXc = \frac{((NAMc \times Rc / (Rc + 1)) + (NASc / Rc))}{\sqrt{((CAMc \times Rc / (Rc +1)) + (CASc / (Rc + 1))) / 2}}.$$

2.6 Irrigation water calculations: dissolvenator

These calculations are independent of the gypsum application calculations. Given the electrical conductivity of the main irrigation water supply (ECMd) and a desired electrical conductivity (ECDd), the percentage of water that should pass through the dissolvenator (PERCd) is calculated. The calculation assumes that the water passing through the dissolvenator attains an EC equal to ECMd plus the EC of a saturated gypsum solution (2.1 dS m^{-1}).

$$\text{PERCd} = 100 \times (\text{ECDd} - \text{ECMd}) / 2.1$$

Given an SAR of the irrigation water (SARMd), an approximate SAR of the mix (SARMIXd) is calculated. First, the concentration of sodium (NAMd) and calcium plus magnesium (CAMd) in the irrigation water are calculated as described for the conjunctive use calculations, then the SAR of the mix is calculated.

$$\text{SARMIXd} = \frac{\text{NAMd}}{\sqrt{(0.21\ \text{PERCd} + \text{CAMd}) / 2}}$$

2.7 ESP, CEC calculations

These calculations are independent of any other calculations. They allow exchangeable sodium percentage (ESP) and cation exchange capacity (CEC) to be calculated from soil test values for exchangeable cations.

CEC = exch. Ca + exch. Mg + exch. K + exch. Na + exch. acidity

ESP = exch. Na $\times$ 100 / CEC

2.8 EC calculations

These calculations are independent of any other calculations. They allow conversion between different units of electrical conductivity and salt concentration and between different methods of measuring soil EC. The conversions are taken from the following tables.

To convert Column 1 into Column 2 multiply by	Column 1	Column 2	To convert Column 2 into Column 1 multiply by
Salt concentration and electrical conductivity of water and soil extracts*			
1000	dS /m	µS /cm	0.001
1	dS /m	mS /cm	1
1	dS /m	mmho /cm	1
1	$mmol_c$ /L	meq /L	1
0.1 (approx.)	$mmol_c$ /L	dS /m	10 (approx.)
600 (approx.)	dS /m	mg /L	0.0017 (approx.)
1	mg /L	ppm	1
45 (approx.)	dS /m	Grains per gallon	0.022 (approx.)
0.07	mg /L	Grains per gallon	14.3
1	µS /cm	‘EC units’	1

Texture	To convert $EC_{1:5}$ to EC_{se}, multiply by (Salinity Management Handbook, 1997)
Sand	15
Sandy loam	13
Loam	11
Clay loam	9
Medium clay	8
Heavy clay	6

2.9 Lime calculation

This calculation is independent of any other calculations. It allows the change in exchangeable Ca content (CAINC) and final ESP (ESPFINl) to be calculated for acid sodic soils to which lime has been added. The calculation is based on the equation of Kingston and Aitken (1996) for increase in Ca content based on lime addition, and assumes that if exchangeable Na is present, it will be the first cation displaced by the added Ca. The calculation is applicable to the 0-25 cm depth layer only, and assumes the soil is acidic enough (pH<6.5) and the lime fine enough to result in complete dissolution within a year.

If (0.002 * LIMERATE * LIMEQUAL * 10) <0
Then CAINC =0
If not, then CAINC = (0.002 * LIMERATE * LIMEQUAL * 10)

If (ESPINIl – (CAINC * 100 / CECl)) < 0
Then ESPFINl = 0
If not, then ESPFINl = (ESPINIl – (CAINC * 100 / CECl))

3. Explanation of calculations

3.1 Soil sampling and analysis

Each soil sample should be representative of a relatively uniform area. Samples should not be bulked across parts of the block that differ in soil type or crop yield. The analysis is only valid for the sampled area. Samples should be taken from the 0-25 cm and 25-50 cm depth layers.

Commercial soil testing laboratories currently use one method (ammonium acetate extraction at pH 7) to measure exchangeable cations in all soils. This method is not the most appropriate one for saline soils, as it includes soluble cations with the exchangeable cations. The dominant soluble cation in most saline Australian soils is Na, so ESP tends to be overestimated in these soils. If a soil is saline (electrical conductivity, $EC_{1:5}$ > 0.3 dS m^{-1}) and the soil test includes a chloride analysis, the reported ESP and CEC are corrected using equations [1] and [2].

CECc = CECr – (Cl / 355) [1]

$$ESPc = \frac{((ESPr \times CECr) / 100) - (x / 355) \times 100}{CECr - (Cl / 355)} \quad [2]$$

Where: Cl = chloride concentration in mg kg^{-1} (or ppm)
CECc = corrected CEC, in cmol(+) kg^{-1} (or meq %)
CECr = reported CEC, in cmol(+) kg^{-1} (or meq %)
ESPc = corrected ESP
ESPr = reported ESP

For saline soils it is preferable to use the corrected ESP and CEC values in the algorithm rather than the reported values.

If chloride content is only available for the 0-25 cm layer, the value for the deeper layer is calculated using equations 3-8. These equations are actually the relationships between EC in the two layers. Estimation of chloride content in the deeper layer is not recommended, as the analysis will be less accurate than if an actual value is used.

For Mareeba,	$SECb = 1.99 \times SECa - 0.03$	$r^2 = 0.80$	[3]
For Herbert,	$SECb = 1.33 \times SECa + 0.04$	$r^2 = 0.70$	[4]
For Burdekin,	$SECb = 1.12 \times SECa + 0.10$	$r^2 = 0.71$	[5]
For Proserpine,	$SECb = 0.89 \times SECa + 0.02$	$r^2 = 0.74$	[6]
For Central Qld.,	$SECb = 1.02 \times SECa + 0.05$	$r^2 = 0.67$	[7]
For Southern Qld.,	$SECb = 0.51 \times SECa + 0.08$	$r^2 = 0.07$	[8]

The equations are derived from Nelson et al. (2001)

Where the ESP value being used is derived from the Field Kit 1-to-5 extract method, no correction is necessary, because the 1-to-5 extract test was calibrated using appropriate methods for measuring exchangeable cations.

3.2 Estimation of CEC and ESP values for the 25-50 cm layer

The algorithm requires CEC and ESP values for both the 0-25 cm and 25-50 cm depth layers to run. If values are only available for the 0-25 cm layer, the values for the deeper layer are estimated using equations 9-20. However, estimation of the 25-50 cm values is not recommended; the analysis will less accurate than if the actual values are used.

For Mareeba,	$CECb = 0.690 \times CECa + 1.972$	$r^2 = 0.531$	[9]
For Herbert,	$CECb = 1.387 \times CECa + 1.861$	$r^2 = 0.501$	[10]
For Burdekin,	$CECb = 0.732 \times CECa + 66.58$	$r^2 = 0.457$	[11]
For Proserpine,	$CECb = 1.237 \times CECa + 3.283$	$r^2 = 0.383$	[12]
For Central Qld.,	$CECb = 1.209 \times CECa + 1.730$	$r^2 = 0.831$	[13]
For Southern Qld.,	$CECb = 0.719 \times CECa + 2.355$	$r^2 = 0.406$	[14]

For Mareeba,	$ESPb = 2.340 \times ESPa + 3.480$	$r^2 = 0.841$	[15]
For Herbert,	$ESPb = 0.849 \times ESPa + 7.595$	$r^2 = 0.746$	[16]
For Burdekin,	$ESPb = 1.319 \times ESPa +4.153$	$r^2 = 0.878$	[17]
For Proserpine,	$ESPb = 0.960 \times ESPa + 4.504$	$r^2 = 0.638$	[18]
For Central Qld.,	$ESPb = 1.226 \times ESPa + 3.062$	$r^2 = 0.782$	[19]

For Southern Qld., ESPb = ESPa + 4 [20]

The equations are derived from Nelson et al. (2001). Equation 14 has no measure of variation as there was no significant relationship for the Southern Qld. samples; the equation is estimated from the other districts. Therefore, it is highly recommended that and actual ESPb value is obtained for soils in the Southern Qld. district.

3.3 Gypsum quality and pure gypsum application rate

The rate of pure gypsum ($CaSO_4.2H_2O$) applied is calculated based on the S content of the applied gypsum. The pure gypsum application rate is used in the subsequent calculations. Sulfur content is used as a measure of gypsum purity rather than Ca, because impurities often contain Ca (eg Ca carbonates, Ca silicates), but tend not to contain S. The rate of gypsum applied should be expressed as dry weight, allowing for water content. Mined gypsums tend to have S contents of between 12 and 14%, whereas chemical or by-product gypsum tends to have a S content of around 14%. Pure gypsum has a S content of 18.6%. Particle size influences the rate at which gypsum dissolves, but is not as critical as it is for lime, due to the relatively high solubility of gypsum. Therefore, over a growth season, mined and chemical gypsum can be expected to behave similarly, given the same purity. Dissolvenators require fine, pure gypsum, but they are not specifically dealt with in this algorithm. Growers should be made aware of the contaminants in various sources of gypsum.

The calculated pure gypsum application rate is moderated by a factor termed the rate factor. The rate factor is included to allow for possible losses of gypsum in surface runoff, and negative salinity effects at high application rates. Virtually no information is available on the amounts of gypsum lost in runoff at high application rates. With high application rates, shallow or no incorporation, low permeability and high irrigation/precipitation rates, losses in runoff could be expected to be high. However, in furrow irrigated cane in the Burdekin, Gary Ham (pers. comm.) has reported negligible losses in tail-water runoff at an application rate of 20 t ha^{-1}. In the absence of any further information, the effective application rates have been arbitrarily set as shown in Fig. 1. Equations 21-24 are used to calculate the rate factor (RATEFAC). The inclusion of the rate factors results in more conservative estimates of yield response. As the algorithm does not include any detrimental salinity effect of gypsum in saline soils, the application efficiency factor may also allow for possible detrimental salinity effects of gypsum at high application rates in saline soils.

For $0 < \text{GYPRATE} \leq 10$, Effective rate = GYPRATE [21]
For $10 < \text{GYPRATE} \leq 30$, Effective rate = 10 + 0.9 (GYPRATE – 10) [22]
For $30 < \text{GYPRATE}$, Effective rate = 28 + 0.8 (GYPRATE – 30) [23]

RATEFAC = Effective rate / GYPRATE [24]

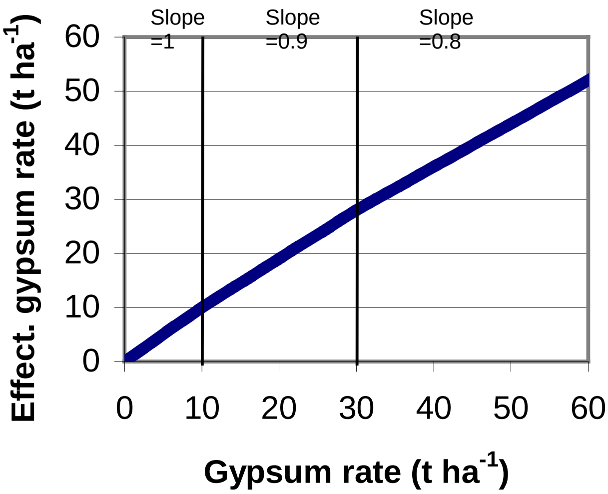


Fig.1. The relationship between effective and actual gypsum application rate, used to calculate RATEFAC in equations 21-24.

3.4 Effect of gypsum on soil ESP

The equation for gypsum requirement (equation 25) given by Oster and Jayawardane (1998) is used to calculate the change in ESP for any given application of gypsum.

Gyps. Require. = 0.086 × F × depth × density × CEC × (initial ESP – final ESP) [25]

Where:
F (unitless) is an exchange efficiency factor that varies from 1.1 for a final ESP of 15 to 1.3 for a final ESP of 5
Depth is expressed in m
Density is expressed in t m^{-3}
CEC is expressed in $cmol_c$ kg^{-1} (meq %)

The algorithm is of the tipping bucket type; increasing the rate of gypsum application decreases the final ESP of the 0-25 cm layer, until either the gypsum is depleted, or the minimum ESP is reached. The default minimum ESP is set at 3, and assumes that below this ESP, hydraulic conductivity will be relatively high, and the efficiency of exchange will be relatively low, so gypsum will move down into the next layer. The minimum ESP also defines the ESP below which no extra benefit is expected. The minimum ESP may be changed based on local experience. Gypsum surplus to the requirement of the 0-25 cm layer moves into the 25-50 cm layer, and is treated the same way as for the 0-25 cm layer. Gypsum surplus to the requirements of the 25-50 cm layer is assumed to leach below this layer and have no influence on crop growth. This is a conservative assumption, because some roots will explore deeper than 50 cm given favourable soil conditions. However, the assumption is deliberately conservative because it may be balanced by accumulation of Na below 50 cm, which would have a negative effect on root growth.

3.5 Effect of decreased ESP on yield

In the studies of Nelson and Ham (2000) and Spalding (1983), cane yield was best correlated with ESP. However, in those studies, all soils had CEC > 5 $cmol_c$ kg^{-1} in the 0-25 cm layer and > 8 in the 25-50 cm layer. The algorithm may be used for soils having considerably lower values of CEC, so the use of ESP may result in erroneously high responses to gypsum. For example, reducing ESP from 10 to 5 will have a much larger effect on crop growth in a soil with a CEC of 20 $cmol_c$ kg^{-1} than in a soil with a CEC of 2 $cmol_c$ kg^{-1}. Therefore, exchangeable Na content is used rather than ESP. Nelson and Ham (2000) found that cane yield was related to exchangeable Na content (to 75 cm depth, weighted according to root distribution) by equation 26:

Cane yield (t ha^{-1}) = $-14.8 \times \text{ENa} + 166.8$ $r^2 = 0.61$ [26]

Where ENa = depth-weighted exchangeable Na content in $cmol_c$ kg^{-1}

The algorithm approximates the depth weighting of Nelson and Ham (2000) by using a factor of 0.619 for the 0-25 cm depth layer and 0.381 for the 25-50 cm depth layer. The slope of Equation 2 (called the yield factor, or YIELDFAC) is used in the algorithm to estimate the effect of sodicity on yield in the Burdekin district. The same yield factor is used for the Mareeba district, assuming similar climate, management and soils to the Burdekin. Nelson and Ham (2000) showed that the effect of sodicity on cane yield was greater in the Burdekin than in the Mackay region, and attributed the difference to climatic, cultural and soil factors. However, as weighted exchangeable Na contents were not reported by Spalding (1983), they could not be used in the algorithm. Instead, a yield factor for the Mackay district was derived from the Burdekin yield factor of -14.8 using equation 27.

Mackay yield factor = $x \times y / z$ [27]

Where:
x = Burdekin yield factor (14.8)
y = the decrease in yield (t ha^{-1}) for every 1% increase in ESP in the 25-50 cm layer in Mackay (1.5)
z = the decrease in yield (t ha^{-1}) for every 1% increase in ESP in the 25-50 cm layer in the Burdekin (2.1)
Hence:
Mackay yield factor = 10.6

The Mackay yield factor was used for the Herbert, Proserpine,Central Qld. And Southern Qld. Districts, assuming similar climate, management and soils.

The effect of decreased ESP on yield is moderated by a time factor, which assumes that only 80% of the calculated benefit from decreased ESP is realised in the first year, and the full benefit is only realised in subsequent years. The time factor is included to allow for a) a temporary detrimental salinity effect, as sodic soils tend to also be saline, and gypsum increases the soil EC even further, and b) in areas where water supply from rainfall or irrigation is limited, or soils have very low hydraulic conductivity, it may take some time for adequate leaching to occur through the 0-50 cm layer. Leaching must occur for Ca to replace Na. The values used for the time factor (0.8 for first year and 1 for subsequent years) are arbitrary, and would depend on soil properties, particularly initial EC and hydraulic conductivity throughout the profile, and the amount of water (rainfall plus irrigation) available for leaching. The algorithm assumes that there is adequate water available and adequate hydraulic conductivity for Ca and Na to be leached through the 0-50 cm layer by the second year.

3.6 Economics

The additional annual income due to gypsum addition is calculated by multiplying additional yield by the cane price. Total cost is calculated by multiplying gypsum application rate by gypsum price. The net benefit over the specified crop cycle is calculated, taking into account the specified discount rate.

3.7 Time scale of estimate

The algorithm is intended for use over one crop cycle or less. Estimates over longer time periods could be expected to become less and less accurate as errors accumulate and undescribed factors have their effect. At the end of the crop cycle the soils should be re-analysed and the analysis performed again.

3.8 Applicability to various soils and districts

The algorithm assumes that if the soil is being irrigated, the irrigation water is of good quality, ie. salinisation/sodification is not occurring. If saline or sodic water is being used for irrigation, the beneficial effect of gypsum will be less than that estimated by the algorithm. The amount of water available for leaching, whether that be from rainfall or irrigation, is discussed above in relation to the time factor.

The data on which the algorithm is based (Nelson and Ham, 2000; Spalding, 1983) is all derived from neutral to alkaline soils. This algorithm should not be used to estimate crop response to gypsum use on acid sodic soils. However, the outputs not involving crop response or economics (ie. the calculated changes in ESP), are applicable to acid as well as neutral-alkaline soils. The calculations window allows the effect of lime additions on ESP in acid sodic topsoils to be calculated.

In many sodic soils, cane yield is limited by the combined effects of salinity and sodicity. In soils that are saline close to the surface, gypsum adds to the salinity, and may temporarily depress yield. The algorithm accounts for this effect through the time and rate factors, discussed above. However, when ameliorating saline-sodic soils, the fate of salt must be considered. Management should aim at a net reduction of salinity in the root zone. Salt removal by leaching tends to raise the level of the water table; subsurface drainage and disposal of saline drainage water may be necessary, as salt moves up into the root zone from shallow water tables. The management of salinity is dealt with elsewhere.

Soils with low permeability due to low electrolyte concentration (or EC) benefit from the application of gypsum, particularly when irrigated with low EC water. Gypsum raises their EC and thereby improves permeability and cane growth. However, this algorithm does not account for the effect of gypsum on non-sodic soils with low EC.

3.9 Other management factors

While gypsum application is the only ameliorative factor included in Gypsy, it must be kept in mind that other factors play an important role in the management of sodic soils. Those factors are dealt with elsewhere, but they include: careful block design and levelling; irrigation method, scheduling and water quality; trash retention and strategic cultivation; and the use of dissolvenators.

3.10 Improvements to the algorithm

The algorithm is designed to run with a minimum of inputs and therefore involves various assumptions, all of which are described above. It is intended as a guide only, mainly to compare various gypsum rates on various parts of the farm. The relative comparisons should be fairly robust. Users can adjust the model based on their experience, using the advanced level inputs. Any comments or suggestions for improvements would be welcome, and could be incorporated into subsequent versions.

4. References

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5. Parameter list

Where parameters end with a number, the number refers to the gypsum rate: ‘1’ = 0 t ha^{-1}, ‘9’ = the maximum specified rate (GYPMAX), and the other numbers are equally spaced increments between 0 and GYPMAX. Where parameters contain a lower case letter, ‘a’ refers to the 0-25 cm depth layer, ‘b’ refers to the 25-50 cm depth layer, ‘c’ refers to conjunctive use equations, ‘d’ refers to dissolvenator equations, and ‘l’ refers to lime calculations.

CAINC	Increase in exchangeable Ca content (cmol$_c$ kg^{-1}) of 0-25 cm layer in lime calculations.
CAMc	Calcium concentration (mmol(+) L^{-1}) in main supply in conjunctive use equations.
CAMd	Calcium concentration (mmol(+) L^{-1}) in main supply in dissolvenator equations.
CASc	Calcium concentration (mmol(+) L^{-1}) in supplementary supply in conjunctive use equations.
CANEPRICE	Cane price in \$ t^{-1}.
CECa	Cation exchange capacity of 0-25 cm depth layer in cmol$_c$ kg^{-1}.
CECb	Cation exchange capacity of 25-50 cm depth layer in cmol$_c$ kg^{-1}.
CEC1	Cation exchange capacity (cmol$_c$ kg^{-1}) of 0-25 cm layer in lime calculations
CLa	Chloride concentration of 0-25 cm depth layer in mg kg^{-1}.
CLb	Chloride concentration of 25-50 cm depth layer in mg kg^{-1}.
CONCMc	Concentration of any component (such as residual alkali) in the main irrigation water supply for conjunctive use calculations, in any units.
CONCMIXc	Concentration of component in the mix, for conjunctive use equations. Units are the same as CONCMc and CONCSc.
CONCSc	Concentration of the same component as CONCMc, in the supplementary irrigation water supply, in the same units as CONCMc.
COSTADD	Cost of gypsum application in \$ ha^{-1}.
DENSa	Density of 0-25 cm depth layer in t m^{-3}.
DENSb	Density of 25-50 cm depth layer in t m^{-3}.
DISCRATE	Discount rate, in %.
DISTRICT	District.
ECDc	Desired EC of irrigation water mix in conjunctive use equations, in dS m^{-1}.
ECDd	Desired EC of irrigation water in dissolvenator calculations, in dS m^{-1}.
ECMc	EC of main irrigation water supply in conjunctive use calculations, in dS m^{-1}.
ECMd	EC of irrigation water in dissolvenator calculations, in dS m^{-1}.
ECSc	EC of supplementary irrigation water supply in conjunctive use calculations, in dS m^{-1}.
ESPINIl	Initial ESP of 0-25 cm layer in lime calculations.
ESPINIa	The initial ESP of the 0-25 cm depth layer.
ESPINIb	The initial ESP of the 25-50 cm depth layer.
ESPFINl	Final ESP of 0-25 cm layer in lime calculations.
ESPFINa	The final ESP of the 0-25 cm depth layer.
ESPFINb	The final ESP of the 25-50 cm depth layer.
ESPMINa	The ESP at which further gypsum addition does not reduce ESP any further, but moves down to 25-50 cm depth layer.

ESPMINb The ESP at which further gypsum addition does not reduce ESP any further, but moves down beyond 50 cm depth.
Fa The F factor for the Oster equation for the 0-25 cm depth layer.
Fb The F factor for the Oster equation for the 25-50 cm depth layer.
FLOWMc Flow rate of main irrigation water supply in conjunctive use equations, in any units of volume per time.
FLOWSc Flow rate of supplementary supply in conjunctive use equations, in same units as FLOWMc
GYPCOST Cost of gypsum (as supplied), spread, in \$ ha^{-1}.
GYPMAX The maximum gypsum (as supplied) application rate defined for the analysis, in t ha^{-1}.
GYPQUAL Gypsum quality, expressed as percent sulfur.
GYPOPT The amount of gypsum required to reach the ESPMIN in both soil layers, assuming no losses, in t ha^{-1}.
GYPRATE The rate of gypsum (as supplied) application, in t ha^{-1}.
GYPSURP The amount of gypsum (as supplied) that leaches below 50 cm depth, in t ha^{-1}.
INCADD The additional annual income (averaged over the time period specified) in \$ ha^{-1}, for a given gypsum application.
LIMEQUAL Quality of lime, as percentage Ca, in lime calculations.
LIMERATE Application rate of lime (t ha-1) in lime calculations
NAMc Sodium concentration (mmol(+) L^{-1}) in main supply in conjunctive use equations.
NAMd Sodium concentration (mmol(+) L^{-1}) in main supply in dissolvenator equations.
NASc Sodium concentration (mmol(+) L^{-1}) in supplementary supply in conjunctive use equations.
NETBEN Net benefit over a plant crop plus 3 ratoons, in \$ ha^{-1}.
PERd Percentage of water to pass through dissolvenator in dissolvenator equations.
PGYPRATEa The amount of gypsum (pure) that enters the 0-25 cm layer, in t ha^{-1}.
PGYPRATEb The amount of gypsum (pure) that enters the 25-50 cm layer, in t ha^{-1}.
PGYPREQa The amount of gypsum (pure) needed to reduce ESP from ESPINIa to ESPMINa. If ESPINIa is less than, or equal to ESPMINa, then PGYPREQa equals zero, in t ha^{-1}.
PGYPREQb The amount of gypsum (pure) needed to reduce ESP from ESPINIb to ESPMINb. If ESPINIb is less than, or equal to ESPMINb, then PGYPREQb equals zero, in t ha^{-1}.
PGYPUSEDa The amount of gypsum (pure) used in the 0-25 cm layer to reduce ESP from ESPINIa to ESPMINa, or the total amount of gypsum added to that layer, whichever is less, in t ha^{-1}.
PGYPUSEDb The amount of gypsum (pure) used in the 25-50 cm layer to reduce ESP from ESPINIb to ESPMINb, or the total amount of gypsum added to that layer, whichever is less, in t ha^{-1}.
RATEFAC Application efficiency factor, allowing for lateral losses of gypsum, and negative salinity effects at high application rates. Set at 1 for gypsum application rates $\leq$ 10 t ha^{-1}, 0.9 for application rates between 10 and 30 t ha^{-1}, and 0.75 for application rates > 30 t ha^{-1}.
Rc Ratio of mix for conjunctive use equations (main supply volume over supplementary supply volume)
SARMc Sodium adsorption ratio of main irrigation water supply for conjunctive use calculations.

SARMd	Sodium adsorption ratio of irrigation water for dissolvenator calculations.
SARMIXc	Sodium adsorption ratio of mix in conjunctive use equations.
SARMIXd	Sodium adsorption ratio of mix in dissolvenator equations.
SARSc	Sodium adsorption ratio of supplementary irrigation water supply for conjunctive use calculations.
SECa	Electrical conductivity of a 1:5 extract of the 0-25 cm layer, in dS m^{-1}.
SECb	Electrical conductivity of a 1:5 extract of the 25-50 cm layer, in dS m^{-1}.
YEARS	Number of years over which the cash flow analysis is carried out
YIELDADD	The additional annual cane yield, in t ha^{-1}, expected from a given application of gypsum.
YIELDFAC	The increase in cane yield expected for a given decrease in exchangeable sodium content of the soil, expressed in t ha^{-1} cane yield per $cmol_c$ kg^{-1} drop in weighted exchangeable sodium.