A simple model to evaluate acidic and alkaline processes in dripper irrigated vineyards.

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Abstract
As a preliminary step to evaluate acidification and alkalinisation processes in dripper irrigated vineyards, a simple model was developed to guide lime applications and to predict the potential for accelerated acidification or alkalinisation to occur in viticultural soils managed under different vineyard systems.

Soil samples were taken from below drippers and the inter-row in 12 vineyards from three viticultural regions in SA and analysed as a basis for verification. Vineyard management information was collected for dripper architecture, delivery rates, irrigation frequency, water quality, fertiliser application rates and berry yields for each vineyard.

The model indicated that the most important factors affecting acidification processes were the alkalinity levels of the irrigation water applied, the rates of use of ammoniacal fertilisers, and, in high yielding vineyards, the ash alkalinity of the grapes removed.

The model was found to adequately predict the pH changes observed in the verification samples with minor modifications. It was then used to predict, in instances where net acidification was predicted, the time in years to reach critical surface soil pH_{ca} values of 5.5 and 4.8, known to decrease root growth. Many vineyard soils in eastern Australia are already significantly acidified and have the potential to acidify further.

The development of the model and its verification indicated that the following key information is needed:
1. alkalinity and sodium adsorption ratios of irrigation water,
2. ash alkalinity values for wine grape varieties,
3. better information on dripper wetting pattern,
4. ash alkalinity and application rates of mulching materials, and,
5. appropriate allowance for leaching of water alkalinity.

Introduction
A project to evaluate the pH and pH buffering capacity (pHBC) of the surface layers of viticultural soils using the Soil Test Inventory of the Australian National Land and Water Audit (NLWRA) showed that a significant number of existing or potential vineyard soils from all eastern states and South Australia risked production problems. Grapevines are regarded as moderately sensitive to soil acidity through restriction to root growth. The major effect on the vine may be related to its inability to explore the soil volume for water (Kirchof *et al.* 1990; Robinson 1993). High soil pH can affect the growth of grapevines, such as when grown on alkaline sodic soils, where they become more susceptible to zinc, iron, manganese and copper deficiency. Although these trace metal deficiencies can be corrected by application of trace elements, in some soils, iron deficiency is difficult to treat.

Viticultural research and development managers recognise extreme soil pH is d as an issue. However, extreme soil pH is generally regarded as a low priority because there are few sites where low pH is intractable, and generally micronutrients can be efficiently applied to vines in foliar nutrient sprays in high pH soils. Earlier observations have indicated a tendency toward acidification in the Riverland of SA, while some other districts have tended toward alkalinisation, presumably due to the alkalinity of irrigation water (Robinson, 1993). Seeliger and French (1971) observed that acidification can occur under mature vineyards after long use of high rates of nitrogen fertiliser. Clark *et al.* (2002) have also shown alkalinisation occurs following use of saline irrigation water with a high Sodium Adsorption Ratio.

The general effects of acidification of agricultural land, especially through the use of ammoniacal fertilisers, and of alkalinisation and sodicity development in irrigated soils has been understood for a long period. Increasing intensification and technical development in management of irrigated vineyards points to a need for better understanding within this industry.

This project was designed to further explore the potential formation of extreme pH conditions in vineyards and to assist the wine and grape industries to determine the priority level it should give to the issue.

As a preliminary step to evaluate acidification and alkalinisation processes in dripper irrigated vineyards, a simple model was developed to provide guidance for lime applications and to predict the potential for accelerated acidification or alkalinisation in soils managed under different vineyard systems. The model helps to clarify the significance of processes – fertiliser use, alkalinity of irrigation water, product removal and irrigation practice – that control change in soil pH and could also be used as a learning tool for vineyard managers. It identifies critical soil, water and vineyard management properties that should be monitored and where important data, such as ash alkalinities of grape berries, needs to be obtained. Verification of the model used case studies of soil and vineyard management data from 12 vineyards from three regions of South Australia.

Method

Development of the model

The model was constructed using Microsoft Excel™. It consists of two spreadsheets that

- calculate, using simple inputs, the lime required to adjust the pH of either the surface layers of the soil using conventional application, or to adjust the pH of only the estimated dripper-wetted volume of irrigated soil, and
- predict, from a range of inputs related to acidification processes, whether the soil of the dripper-wetted volume should become more acidic or alkaline.

If the soil is acidifying, the period of time in years to reach critical pH_{ca} values of 5.5 or 4.8 is calculated. If the sodium adsorption ratio (SAR) of the irrigation water is known, a warning is given if the situation is expected to lead to sodicity of the irrigated soil. The changes in soil pH that result from the use of mulches were not considered in the model as little specific data exist for application rates.

The main processes controlling soil pH change considered here are similar to those outlined by Helyar and Porter (1989) and are presented diagrammatically in Figure 1.

Soil pH buffer capacity was calculated from a function developed by Merry (1997, unpublished report) for 170 surface soils (A1 and A2 horizons) from South Australia and Victoria, which incorporated measurements of % total soil carbon (% TC) and % clay content ($100R^2 = 76.2$). For a unit increase in soil pH, the quantity of lime required is given by:

Lime requirement (t/ha.10cm) = 0.2 + 0.364 %TC + 0.0213 FT-Clay %

where: %TC is total soil organic carbon (if the Walkley and Black method was used, %TC was derived by multiplying soil organic C % by 1.3); FT-Clay % (Field Texture Clay %) was derived from the relationship of "class average" soil clay % with soil texture indicated in McDonald *et al.* (1990).

Dry bulk density (BD) is calculated using a pedotransfer function (JO Skjemstad, CSIRO Land and Water, personal communication) that relates bulk density to % clay content.

Soil moisture condition for soil texture classes was based on the model of Saxton *et al*. (1986). Recent versions of the calculator can be found at http://www.bsyse.wsu.edu/saxton/. Although the values are based on the silt class limits used in the USA, they are very similar to those used conventionally in field evaluation of vineyard soils in Australia. Values used for the "average" acidity that results from nitrification of ammoniacal fertilizers are those of Adams (1984). The single ash alkalinity value for table grapes (Moody and Aitkin 1997) is the only one published for Australia, to the authors' awareness, and has been used here.

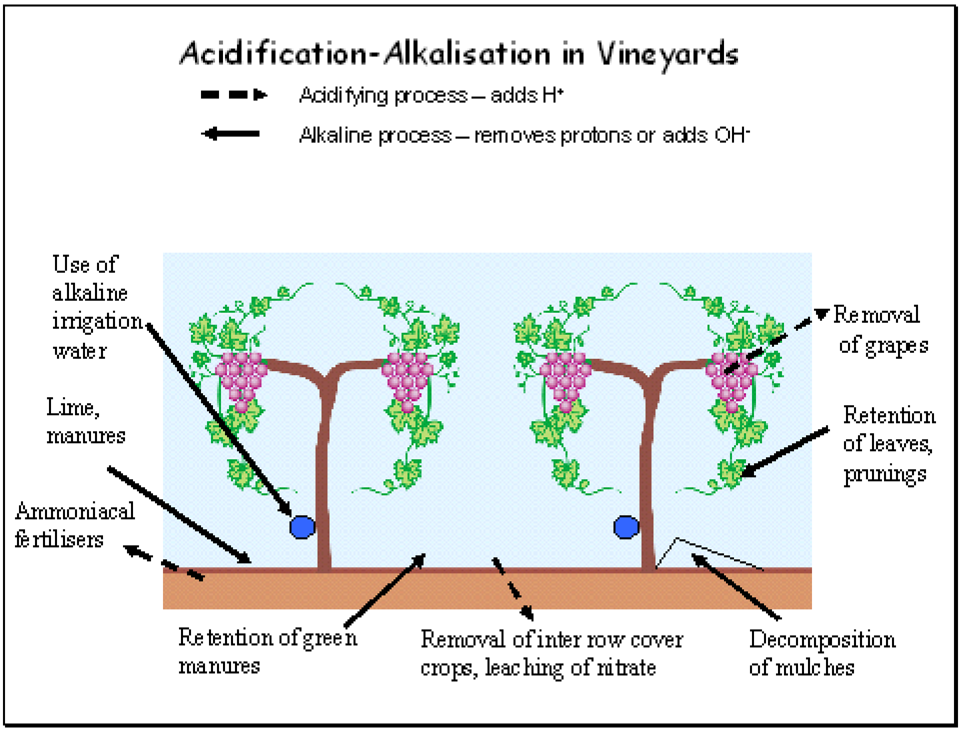

Figure 1. Diagram of the main acidifying and alkalinising processes in fertigated vineyards.

All values that relate to the processes increasing acidity or alkalinity were expressed in $CaCO_3$ equivalents as this was felt to be simpler and more readily understood than, for example, kmol H^+ (where 1 kmol H^+ is equivalent to 50 kg $CaCO_3$).

The lime application model

As outlined above, the model presents two "calculators", a simple lime application calculator, and a model that evaluates acidification/alkalinisation processes and predicts likely changes in soil pH. The lime application model requires inputs for current and "target" soil pH_{ca}, clay % and soil organic carbon %. It calculates pHBC and BD, and the tonnes of lime per hectare required to attain the target pH for the top 15 cm, or any other layer of a selected depth. With input of information such as number of drippers per hectare, dripper delivery rate and average amount of water applied, it also calculates the expected wetted volume and amount of lime needed to attain the target pH in the wetted volume only.

The acidification process model

The acidification process model was developed around several modules. Briefly, each addresses the following aspects for the dripper-wetted volume of soil:

- Soil module: inputs of required soil properties from analysis or a look-up table; calculates soil pHBC and bulk density
- Water module: inputs of water alkalinity, SAR, megalitres of water per ha applied, number of irrigation sessions per season; calculates litres delivered per dripper and alkalinity.
- Fertigation module: the annual application rates, in kg ha^{-1}, of acidifying (urea, ammonium nitrate, MAP, DAP) or alkalinising (calcium nitrate, lime) soil amendments to the dripper-wetted volume; calculates, in $CaCO_3$ equivalents, the expected net effect of applied amendments.
- Vineyard module: input of berry yield, in kg ha^{-1}, vines per hectare and drippers per vine; calculates the export of alkalinity in grape berries.

By summing these processes, the model indicates whether the soil is expected to be acidifying or alkalinising, and, if the soil is acidifying, uses current inputs and yields to estimate the time to critical pH_{ca} values of 5.5 and 4.8, which were shown by Robinson (1993) to be the values at which, respectively, vine root production declined and, in some soils, ceased. Special cases include irrigation water with SAR values greater the 3 (Rengasamy and Olssen 1993), where soils are expect to become sodic, unless of a light texture, and soils with free $CaCO_3$, where the estimated time required to consume the lime is calculated.

An example of the output for the process model worksheet is shown in Figure 2.

Calculator of Annual Soil Acidification for Dripper Irrigated Vineyard Soils

Values calculated are indicative only.

This calculator is a simple acidity/alkalinity balance that aims to help predict the effects of vineyard management on soil pH changes. It requires simple annual inputs that should help managers make decisions about whether or not a vineyard is acidifying or becoming alkanine.

Always use soil testing to check soil condition.

Work downwards through the worksheet

Yellow boxes data require values	Blue boxes calculate answers/predictions
Green boxes calculate an alkaline input	Clear boxes are constants or calculated values
Orange boxes calculate an acidic input	

If soil tests show that the soil is layered, you can use depth weighted averages, otherwise assume the soil is uniform.

Column L contains hidden cells used in calculations

Soil Module

Fill in data from soil tests or table to the right

pH_{ca}	Organic C %	Ave Clay %	AW *vol%*	Soil $CaCO_3$ %	pHBC	Bulk Density
5.2	0.8	15	7.9	0	0.63	1.55
or use pH_w - 0.9					*t $CaCO_3$/ha 10*	*g/cc*

Field texture	Average Clay % Ave Clay %	Available Water AW vol %
Sand	2	6.1
Loamy sand	5	6.8
Clayey sands	7.5	7.1
Sandy loam	15	7.9
Loam	20	8.7
Silt loam	20	11.9
Sandy clay loam	25	8.2
Clay loam	28	10.2
Silty clay loam (& silty clay)	32	13.5
Sandy clay	32	8.3
Light clay	40	9.9
Medium clay	50	10.7
Heavy clay	55	11.1

Water Module

Water alkalinity *mg/L* as $CaCO_3$	Sodium Adsorption Ratio *SAR*	Total Volume *ML/ha/year*	Water delivered *Litres/dripper*	No of irrigations per year	Water alkalinity per dripper	
50	2	1.7	436.2	30	**0.0218**	*kg $CaCO_3$*

Fertigation Module

Type	Amount applied to vines/drippers *kg N/ha*	Equivalent soil acidity or alkalinity *kg $CaCO_3$*		Fertiliser acidity/alkalinity per dripper	
Urea or am nitrate - N	50	-90		**-0.0231**	*kg $CaCO_3$*
DAP - N	0	0		**0.0000**	*kg $CaCO_3$*
MAP - N	0	0		**0.0000**	*kg $CaCO_3$*
Calcium nitrate - N	0	0		**0.0000**	*kg $CaCO_3$*
Lime ($CaCO_3$)	0	0	Note: requires *kg/dripper*	**0.0000**	*kg $CaCO_3$*

See Calculator 1 for appropriate values.

Vineyard Module

Grape Yield *kg/ha* (at harvest)	Ash alkalinity of grapes *kg $CaCO_3$/kg*	Vines per ha *no.*	Drippers per vine *no.*	Acidity through grape export per dripper	
15000	0.01	1821	2.14	**-0.0050**	*kg $CaCO_3$*

Assumes that most alkalinity exported as grapes comes from the area wetted by dripper.

Calculator results

The soil wetted by the dripper is becoming more:

acidic	**Yes**
alkaline	**No**
sodic	**No**

Acidity calculator

Net *acidification* (-ve) or *alkalisation* (+ve) rate based on annual inputs and exports — **-0.0063** *kg $CaCO_3$/dripper/year*

Estimated time to pH_{ca} 5.5 — **Already acidified** *years*

A negative number means the soil is becoming alkaline and the estimated time should be ignored.

Estimated time to pH_{ca} 4.8 — **11.5** *years*

A negative number means the soil is becoming alkaline and the estimated time should be ignored.

If the soil has free lime ($CaCO_3$), that is, there is a value in cell E24 above, and the soil is acidifying:

It will take about **0** **years to neutralise it and decrease the soil pH**

Add this number to the times in years given above.

"Not acidifying" means that the soil is becoming more alkaline and the calcium carbonate in the soil should not decompose.

Note on water chemistry

Water chemistry is critical if soil pH is found to be increasing, especially its sodium and calcium content (or SAR). High sodium values will cause the soil to become sodic (high exchangeable sodium) and the pHca may increase beyond about 7.5 (pH_w = 8.4). Sodium salts are very soluble and may leach in winter, lowering pH.

A critical value for SAR of 3 is used here, following Rengasamy and Olssen (1993).

Figure 2. Example of an output worksheet for the vineyard acidification/alkalinisation process model.

The model assumes that acidity and alkalinity is equally distributed through the wetted volume of soil. This is unlikely always to be true as there is likely to be uneven distribution of dissolved fertilisers, precipitation of $CaCO_3$ from irrigation water in some instances, as well as leaching of soluble bicarbonates and carbonates.

Model verification
Verification of the model was approached by applying a slightly modified version of the soil process model to data obtained in 12 case studies, four each from three regions in South Australia with a range in management, rainfall, water quality and the buffering capacity of soils. They were located at Qualco in the Riverland, the Adelaide Hills and Padthaway. Each vineyard was dripper irrigated and managers were able to supply most management and production data for a period of at least five years.

Soil samples were collected according to a simple sampling protocol, *viz*.,
- 3 regions, 4 sampling sites per region, 1 vineyard at each site,
- 2 sampling positions per site (offset 20 cm under a dripper and mid row),
- 2 sampling depths (0-15cm and 30 to 45 cm), and
- each sample was a composite of 20 cores.

Hence, 48 individual composite samples were collected and analysed by a commercial laboratory for pH_{ca} and organic carbon using the Heanes method. The two sampling positions – under a dripper and mid row – attempted to obtain data for pH in the dripper-affected area to compare with the mid row, which may reflect the pH of the original soil. The pH difference could then be used as an indicator of acidity changes over the life of the vineyard. In practice, this was complicated in the Adelaide Hills vineyards by uncontrolled modifications to the soil profile by ripping, lime additions and hilling along the vine row, details of which were not always available and the consequences difficult to foresee. No water alkalinity data was provided for the four Adelaide Hills sites, but indicative values were available for bores from the region. It was assumed that "average" vineyard management practices, yields and water use over the five-year period for which records were provided also applied over the longer periods (6 to 23 years).

To verify the model, the slightly modified version of the soil process model (Figure 2) was used with the vineyard management and soil data from the 12 case studies to predict the soil pH change over the life of each vineyard (*ie*, 6 to 23 years).

Prediction of acidity changes for soils of other regions
Since soil acidification is potentially a serious problem in many viticultural regions in the eastern states, the soil process model was used to predict the time periods required to reach critical soil pH_{ca} values (5.5 and 4.8) under standard conditions of berry yield, fertiliser use and water alkalinity. Data for soils vineyards in eastern states were selected from the NLWRA Soil Test Inventory. It should be noted that the NLWRA Soil Test Inventory indicated that many of the viticultural soils from the eastern states are already significantly acidified.

Results and discussion

Model verification
The model appeared to perform quite well, where soil, water and vineyard management data was adequate. Verification for the Adelaide Hills sites was difficult as there was no associated water alkalinity data and several vineyards had been ripped and/or hilled along the vine row, reducing the validity of the measured soil pH differences, that is, the difference between under the dripper and between row soil pH values that were used as a crude estimate of soil pH change over the life of the vineyard. All Adelaide Hills soils became more alkaline over the life of the vineyards. However, the time course of these soil pH changes could readily be predicted by adjusting the water alkalinity to values that are common in the region.

In the Padthaway region, all water alkalinities were high (in the region of 300 mg L^{-1}). This became the overriding factor and the model predicted that the observed pH increases of about 1 unit would have been achieved within one or two irrigation seasons. This is common experience in other irrigated production in the region. The soil pH is then controlled by the properties of the applied water, with some pH decrease over winter due to leaching by rainfall.

In the Riverland, the soil samples indicated that three of the four vineyard soils had acidified, sometimes by more than 1 pH unit. The fourth soil had sufficient residual lime to be buffered against acidification processes. For the three acidified soils, the model predicted the time course of the pH changes well, provided that the low levels of alkalinity in the Murray River water were ignored. It was expected that a proportion of the applied alkalinity, especially sodium bicarbonate, would be leached.

A deficiency in the data available for ash alkalinity of wine grape berries meant that a single value for table grapes from Queensland (Moody and Aitken, 1997) had to be used. With large yields of berries being obtained under irrigation, it is important that additional data be obtained for wine grape varieties.

Prediction of acidity changes
The model was used to predict the time period for significant soil pH changes for viticultural soils from the NLWRA Soil Test Inventory. As mentioned above, many soils from the eastern states are already significantly acidified and the soils of many regions also have low pH buffering capacities. Simulations were constructed by varying the values of fertiliser inputs, water alkalinity and berry yield through a range of expected values. The model confirmed that water alkalinity is likely to be of greatest importance (and its SAR should be measured) in influencing soil pH change. The use of high quality (low alkalinity) irrigation water will accelerate acidification rates, as will also be needed if increasing amounts of ammoniacal fertilisers are applied. The ash alkalinity of grape berries is of less importance unless yields are high, though this result could change if new analyses show that the values for wine grapes differ significantly from the value for table grapes.

The application of the model in this way is regarded as an important demonstration of its potential use in the planning, development and sustainable management of vineyards.

Continuing model development
The lime application calculator is largely straightforward and uses accepted methodology. However, the soil acidification process model could be further developed by a better account being taken of leaching of the alkalinity applied with irrigation water and assessment of ash alkalinity of wine grapes. An increasingly common practice in some vineyards is the application of mulches for water conservation and soil improvement. Mulches have not been included in the present version of the model. The significance or otherwise of mulch decomposition on acidification processes should be investigated and a mulch module could easily be developed.

The existing model is thought to be fairly user friendly and includes notes, documentation and references. It may require further development or simplification to suit the technical awareness of potential users. A consistent comment from users has been that the model has provided them with an improved understanding of acidity and alkalinity issues in dripper irrigated vineyards.

Conclusions
The spreadsheet-based model was constructed to assist in managing soil acidity and alkalinity in vineyards. The acidifying and alkalinising processes operating in dripper-irrigated vineyards can be assessed. The case studies used for verification and other simulations suggest that it works reasonably well, but some further modification should be made in the light of user needs or the acquisition of additional key data, such as ash alkalinity of wine grapes.

In general, we can conclude the following.

- Alkalinity in irrigation water can have a large and over-riding effect on soil pH changes over short time periods. In many cases this is a protective effect against acidification, but may be detrimental in other ways if sodium bicarbonate is present.
- A strong protective effect occurs where significant free lime exists in the topsoil.
- Where these protective influences are absent, soil acidification occurs and the time frame over which it occurs can be quite short if the buffering capacity of the soil is low.
- The acid/alkali balance of vineyards can be complex and may require some specialist advice when interpreting the situation for individual vineyards.
- The model can be used to assess the effects of vineyard management on soil pH in an indicative way, *but should always be supported with appropriate soil testing*.

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