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LA.ONE economics & consulting

An economic review of lime crushing & transport options in the Esperance Port Region

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KEY FINDINGS

The two key factors impacting on the return on investment for lime are:

- The distance from the lime source and therefore the cost of transport.
- The quality of the lime.

It is more cost effective for farmers in the Esperance Port region to crush on farm secondary carbonate or purchase lime from a local quarry than transporting lime sand from the West Coast. The results for the scenarios are ranked as follows:

Rank	Description of scenario	IRR
1	Using an on-farm secondary carbonate at $32 per tonne for extraction and spreading	42%
2	Using a local lime source from the South Coast	40%
3	Using lime sand from the West Coast	35%

Results vary depending on the distance a farm is located from a quarry and the quality of the lime. The cost of extracting and crushing a secondary carbonate on-farm appears to have merit, but individual farmers need to identify the best option for their own situation. Results are very similar; they provide an indication about the best option and what variables to consider. It is recommended that farmers do their own calculations.

The economic implications for applying lime is affected by several variables including seasonal conditions and prices, which vary from year to year, these changing variables increase the complexity associated with understanding and evaluating the response to lime. Applying lime for production improvements may not always achieve large economic benefits, but it reduces the risk of potential severe production losses resulting from high levels of soil acidity.

To achieve an economic benefit, minimising the costs is essential, as well as understanding the effective neutralising value of the lime used. The initial investment needs to be less than the benefits accumulated over time. A product is more cost effective when it is more efficient and has higher ENV.

Decision support tools to help understand the best option are available, iLime, a DPIRD tool is an application available to download from an ap store. FARMSMART® is designed for farmers to use to assist with their whole farm business investment and tactical decisions, availability is dependent of future funding opportunities.

EXECUTIVE SUMMARY

Soil acidification has been identified as the main limiting factor for agriculture in the southern agricultural region with a high proportion of soils either below optimum or at risk of increased acidity (DAFWA, 2013). Acidic soils can reduce crop yields by 10 to 12% and costs the southern area of WA an estimated $498 million per annum. Lime application is the primary amelioration technique for acidic soils. However, South Coast lime has lower neutralising values and larger particle size in comparison to lime from the West Coast.

This economic review was commissioned by South-Coast NRM in response to a key recommendation made in the Lime Situation Report 2015 South Coast NRM Region (Fry, 2015). In response to Fry's 2015 recommendations this review evaluates the difference between applying lime from the South Coast lime sources to transporting lime from the West Coast, it also examines the alternative of applying a lower quality on-farm secondary carbonate lime source.

Fry (2015) identified that the sources of lime in the South-Coast region are limited and have lower neutralising values than many lime-sand sources found on the West Coast.

> Lime supplies on the South Coast are limited, more expensive and are often of much lower efficiency at remediating acidic soils than the lime-sands of the West Coast. Nevertheless the economics of applying more South Coast lime versus transporting lime from the West Coast must be carefully considered, because it will vary with lime pit, efficiency of the lime and distances. (Fry,2015)

In WA the three main sources are: lime sand, limestone and dolomite lime. In this review the latest neutralising value and the price per tonne from 14 lime pits in WA was collected. Using a farm model representing a typical farm located 100 km from a local lime source in the medium rainfall (325 mm to 450 mm) on the south-coast with typical soil-types a number of scenarios were considered comparing to the baseline, (i) not applying any lime, (ii) applying lime from a local pit, (iii) paying the freight cost for better quality lime from the West Coast so less tonnes are required and (iv) using an on-farm alkaline soil to reduce soil acidity.

Soil acidity is measured using soil pH in calcium chloride (pH_{Ca}). The Department of Primary Industries and Regional Development (DPIRD) recommends soil pH_{Ca2} values at or above 5.5 in the topsoil and 4.8_{Ca2} in the subsurface. However, more than 70% of top- soils in the agricultural zone of WA, have a pH lower than the recommended 5.5. and almost half of the subsoils have a pH lower than the target 4.8 (Gazey et al., 2013).

In WA's agricultural zone, an estimated 1 million tonnes of lime per annum is currently applied. In the next ten years, application of approximately 2.5 million tonnes of lime will be required annually to achieve soil pH targets in this area (State of the Environment Report, 2011).

Farmers rely on productivity improvements to counteract declining terms of trade, therefore application of lime must improve productivity levels for farmers to invest, which means outputs must be higher than inputs and the value of the yield response (over time) must be greater than the cost of applying the lime in order to achieve a positive economic benefit. Therefore, yield response to the application of lime is a key economic driver which as Oliver (2014) identifies is variable in nature, and varies in response to season, soil type, soil pH depth and severity. Often yield benefits are not immediate, they can take three years and often approaching eight years to be realised. This helps explain why uncertainty about the benefits of adding lime exists amongst producers. It often takes a long time to see any yield response, and even when there is one, it's difficult to attribute this to being as a result of changes caused by liming (Fry 2015, Oliver et al., 2014).

The decision making around liming for farmers is complicated further because there is a wide variation in quality of lime and its level of effectiveness to neutralise the soil. It not only takes time, but it is a very variable product, and lime sources vary in quality. The ability of the lime to increase the pH of soil is called its neutralizing value (NV), and is based on the purity of the lime, or the amount of carbonate and oxide in the lime, which neutralizes the acid (Fry, 2015). The effective NV is calculated regarding the lime's neutralizing value, particle size distribution and the solubility of the lime (Fry, 2015). Particle size is important, as it determines the speed with which the lime will change soil pH. Finer particles are more effective at neutralizing acidity, as they have a greater surface area to react more quickly (Fry, 2015).

Besides yield the other key economic factors for lime application are the costs, this includes the purchase cost of lime at the quarry, the cost for transporting the lime to the farm and spreading costs or incorporation into sub-soil.

These costs are significant, transport costs especially when a farm is located a large distance from a lime quarry, and when benefits are not immediately evident, it leaves growers to question return on investment compared to other investment opportunities.

Alternatively, not applying lime means the continuing acidification of soils and the risk that eventually acidity levels in sub-soils reach below pH 4.1_{Ca2}, levels which are known to significantly impact on wheat production and levels much lower than barley and canola can tolerate being less acid tolerant than wheat.

In summary, many of the relationships between soil properties and crop yields are site specific, and relationships between applied lime, soil properties and yield at one location or region have different responses in another location, increasing the level of difficulty to understand the economic impact of applying lime. Farmers are not in business to generate public goods or services; their main motivation is economic and to generate profit to provide for a lifestyle and for a standard of living for their family. Liming requires a long-term view; requiring farmers to have a long-term intergenerational vision and future plan.

Despite some famers scepticism about the benefits of lime (Fry, 2015), most continue to apply lime, albeit at rates lower than the recommended amount which suggests they recognise the soil science and increasing acidification but are reluctant to invest.

However, improved pH allows for less acid tolerant crops to yield better and crop rotations to potentially be more profitable. The best quality lime does not necessarily mean it is the best in economic benefits; the distance and therefore transport costs alter the results. Alternatively, the on-farm secondary carbonate deposits have potential to be a good option, although the quality and extraction costs need to compared to the alternatives.

INTRODUCTION

This project enables farmers to make key management decisions to support positive natural resource management and productivity outcomes, explore options to value add to existing local lime resources, enable planners and developers to better consider the supply of raw materials (lime) and explore new business opportunities in the Esperance and Ravensthorpe region. The project will implement recommendations made by South Coast NRM's "Lime Situation Report 2015" from the 1st of July 2017 to 30 June 2019.

Soil acidification has been identified as the main limiting factor for agriculture in the southern agricultural region with a high proportion of soils either below optimum or at risk of increased acidity (DAFWA, 2013). Acidic soils can reduce crop yields by 10 to 12% and costs the southern area of WA an estimated $498 million per annum. Lime application is the primary amelioration technique for acidic soils. However, South Coast lime is comparatively poor in quality (low neutralising value and large particle size) and is less effective compared to lime sourced from the West Coast.

AIM

To support farmers in the Goldfields Esperance to better understand lime so they can manage their most precious resource, their soils.

- To assist farmers, agricultural industry, planners and service providers in making informed financial and management decisions relating to farm inputs (lime) and addressing soil health issues such as soil acidity.
- To increase awareness of soil acidity and its amelioration; and
- To influence change in behaviour of farmers relating to soil acidity and lime.

Outputs

Conduct an economic review to investigate the economics of further crushing of local lime sources versus the transportation of lime from other locations (e.g. The West Coast);

- Incorporate cost/benefit of other known soil acidity ameliorants;
- Include scenarios of loss, break even and profit: and
- Produce a final report documenting key findings of the review considering the economic drivers of practice change for farmers.

Background

WA has a Mediterranean-type climate characterised by long, hot dry summers and cool, wet winters. Seventy-five per cent of annual rainfall occurs during the winter months, between April and October (Anderton, 2016). Significant rainfall can occur in the summer months from high intensity thunderstorms or rain-bearing depressions associated with tropical cyclones.

The climate and geographical characteristics of the land varies by annual average rainfall, topography, length of growing season and soil type (Anderton, 2016). Soil fertility is mostly low to very low, with sand and duplex (sand over clay) being the most common soil types. These are also the least-tolerant soils to acidification due to their lower buffering capacity (Kalkhoran et al., 2018).

Figure 1 indicates the level of rainfall i.e. "L" means low rainfall (<325 mm/yr.), M is medium rainfall (325 to 450 mm/yr.), H is high rainfall (450 to 750 mm/yr.) and VH is very high rainfall (>750 mm/yr.).

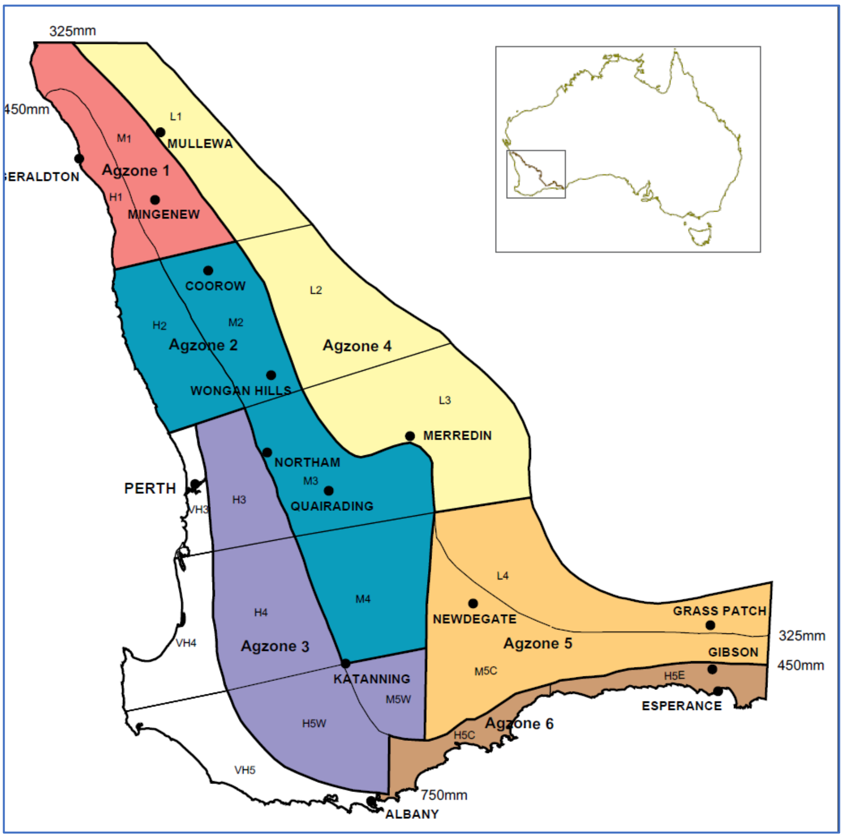


Figure 1. Map of WA's broadacre farming region and agro-ecological areas

The study region for this review is the Esperance port region which includes the Shires of Esperance and Ravensthorpe located in the HRE, M5E and L4 regions in Figure 1

Typical farming systems in WA

Farming systems are typically crop dominant, with annual crops sown in Autumn after the season's first moderate rain event, or the "break of the season" (Anderton, 2016). These crops grow during cool, wet winters, and set seed in spring and early summer when temperatures rise and rainfall decreases (Anderton, 2016). Harvest occurs in November and December. Farmers rotate growing cereal crops- primarily wheat and barley- with canola, legumes (peas or lupins) and pastures for disease and weed control (Anderton 2016). Management practices are reliant on large machinery to reduce labour requirements and create economies of scale. Normal farming practice include minimum tillage, fertiliser use, improved weed, disease and insect control, rotation of crops and pastures, and liming to reduce soil acidification (Anderton, 2016).

The WA grains industry is a major contributor to the agri-food sector, producing 13 million tonnes of grain per year on average (DPIRD, 2018). This generates more than $4 billion for the WA economy each year (DPIRD, 2018). Eighty percent of the annual grain production is exported to over 50 countries, with WA being the leading exporter of premium malting barley to China, wheat to the Japanese udon-noodle market, and feed barley to the Middle East (DPIRD, 2018).

Sheep graze all year round on pastures and stubbles. During the growing season, they have access to green pastures of annual grasses and legumes (Anderton, 2018). During summer and autumn, pastures dry out, and crop residues become available for feed (Anderton, 2018). The most critical time for feed is at the end of summer, when the quality of dry annual pasture and crop reside is low, so feed is supplemented with cereal grains to satisfy energy and protein requirements (Anderton 2016). The WA flock is predominantly Merino, the remainder being British breeds crossed with Merinos, creating a dual purpose, specialist meat breed, enabling the industry to produce both meat from lambs, and high-quality wool from adults (DPIRD 2017).

There are more than 5,000 sheep producers in WA, 80% managing flocks of more than 500, this is about 14.7 million sheep and lambs. In 2016/17, 3.8 million sheep and lambs were turned off, with a value of $366 million of this exported as sheep meat, and $206 million as live animals (DPIRD 2018). In this same period, 71.1 million kg of greasy wool was produced in WA. 95% of this was fine Merino wool under 24.5 micron, and 41% was super fine under 19.6 micron (DPIRD 2018).

Broadacre agriculture in WA continues to be dominated by integrated crop-livestock farming systems. There has been a continuing shift to a more diversified production system and a significant increase in the proportion of cropping (Anderton 2016). These changes are regionally variable, depending on the production potential of crops and pastures.

Farmers alter their allocation of land each year in response to market conditions, seasonal weather conditions, weed and rotational considerations and other complex management considerations (Ewing and Flugge, 2004; Kingwell, 2006). The landscape constantly evolves as farmers respond to the prevailing conditions.

The impact of climate change on WA farming systems

It is projected that WA will become generally warmer, with rainfall declining in western and southern areas but remaining unchanged or increasing in northern and inland areas, and with a greater risk of drought and more-intense storms and tropical cyclones (Sudmeyer et al., 2016).

Changes in crop and livestock production associated with future climate will vary with location, soil type and management (Sudmeyer et al., 2016). Crop and pasture yields are likely to increase in high rainfall south-western areas and generally decline in medium and low rainfall areas with the greatest declines on heavier, clay soil types (Sudmeyer et al., 2016). It is likely that the inter-annual variability will increase across most of WA. These changes will affect profitability and financial risk associated with farming enterprises, particularly at the margins of the wheatbelt (Sudmeyer et al., 2016).

Historical weather patterns for the eastern wheatbelt and the far eastern wheatbelt show a decline in growing season rainfall (GSR), rainfall that occurs between April and October, inclusive and so called because this is the main growing season for crops and pastures, but an increase in summer rainfall. Figure 2 illustrates this change in rainfall distribution for the eastern wheatbelt.

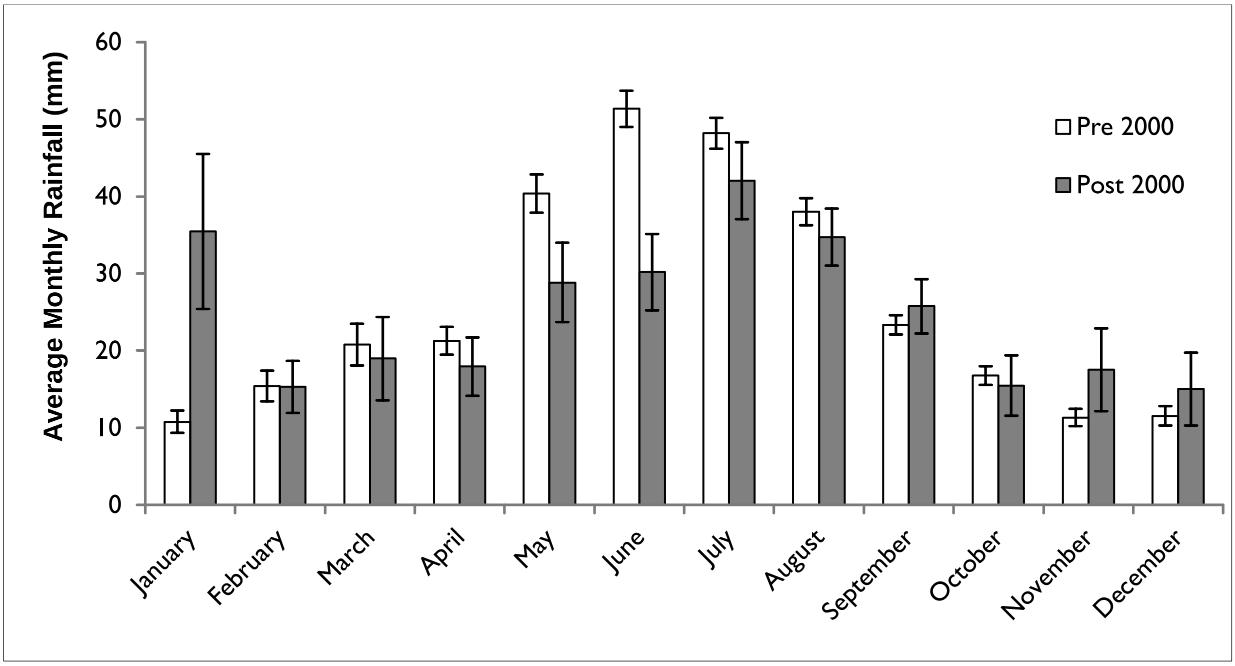


Figure 2. Eastern wheatbelt monthly rainfall (Bruce Rock, Kellerberrin, Koorda, Merredin, Mount Marshall, Mukinbudin, Narembeen, Nungarin and Trayning Sites). Error bars represent annual variability (Scanlon, 2015)

Similar climatic trends are apparent in the Esperance region, shown here by data from two weather stations (BOM, 2019).

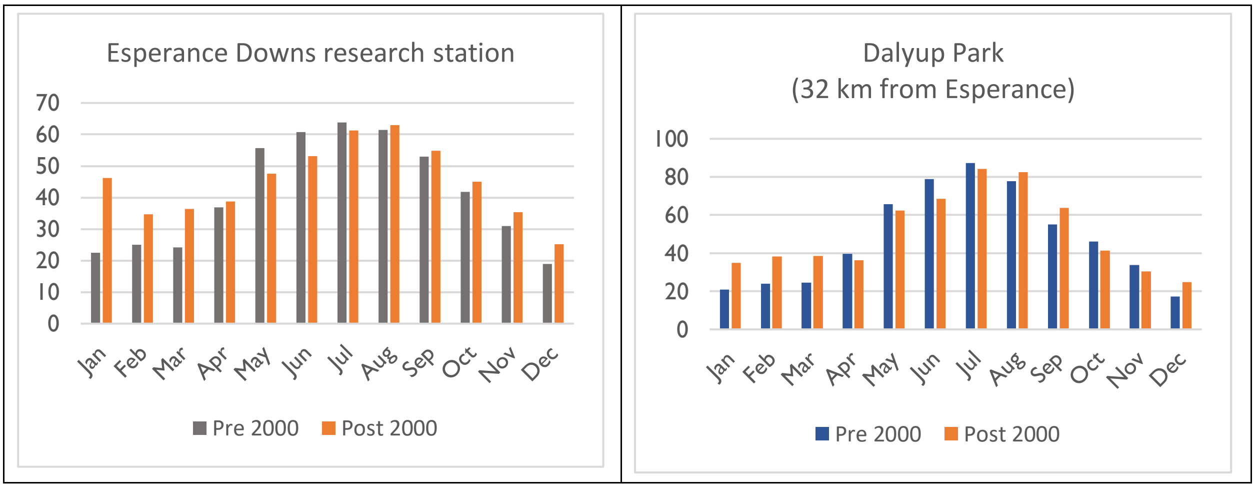


Figure 3. Rainfall data from two weather stations in the Esperance port zone

This change in rainfall distribution has implications for on farm agronomy practices and farm management decisions. Changes to the growing season, particularly in the early months, require changes to proportion of dry seeding done, levels of inputs used and potential crop yields (Scanlon, 2015). There is increased risk of losses for farm enterprises cropping a high proportion of their farm and large losses can damage the long-term viability of a farm (Anderton, 2016; Hutchings, 2013).

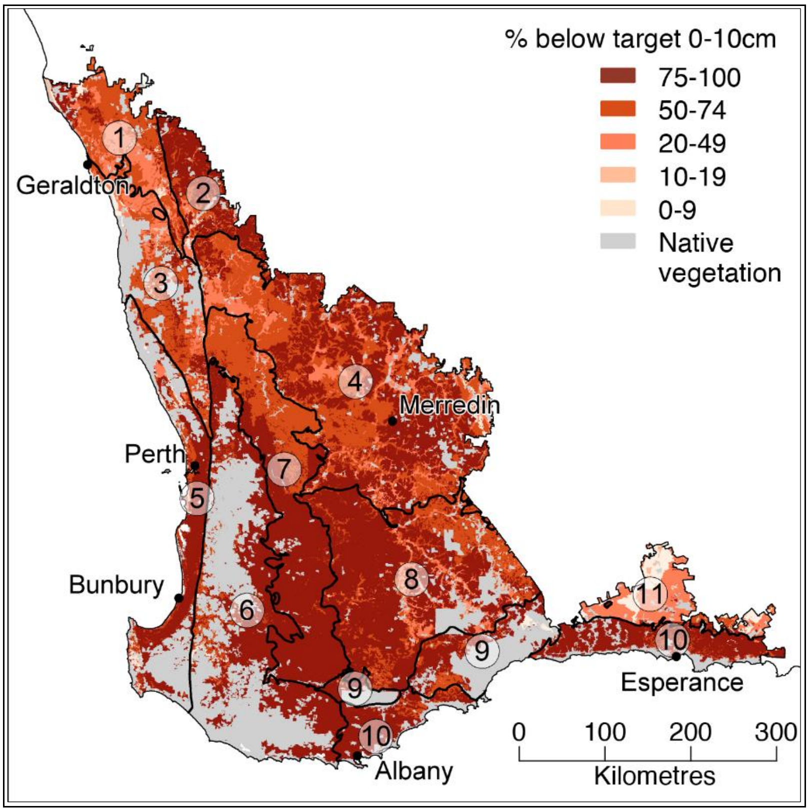
Soil Acidification

Acid is added to the soil as part of the carbon and nitrogen cycles in agricultural systems. As part of the carbon cycle plants take up more cations (CA^{2+}, Mg^{2+}, K^{+}) than anions (PO$_4^{3-}$, NO^{3-}, SO$_4^{2-}$). In response plants excrete weak acids (H) from their roots to maintain a neutral charge, resulting in increased soil acidity. Within the Nitrogen cycle the hydrolysis of urea and ammonium fertiliser to produce nitrate results in a net increase in soil acidity (DAFWA, 2009). There is a net increase in soil acidity when plant materials are removed or when nitrates are leached before being converted to plant matter (DAFWA, 2009). While the annual increase in acidity is small, continual acidic additions over time can have a profound effect, particularly in poorly buffered soils where only small quantities of acid are required to reduce the soil pH.

Poor buffering capacity is associated with low clay and organic matter content and historical leaching of base cations. Sand plain soils typically have low buffering capacity and are prone to acidification. As pH declines, hydrogen, manganese and aluminium ions become more available. In the topsoil, aluminium can bind to organic matter, and toxicity is more unlikely, but as pH becomes lower in the sub-soil, aluminium becomes soluble, and more available to plants (Fry 2015). Aluminium toxicity inhibits root growth, and nitrogen fixation, therefore decreasing the availability of essential nutrients and resulting in reduced crop yields (Fry 2015).

Sub-soil acidity has greater impact on yields than acidity in the topsoil and is more problematic to address.

In the agricultural zone of WA, more than 70% of top soils have a pH lower (more acidic) than the target of 5.5 set by the Department of Primary Industries and Regional Development (DPIRD) and almost half of the subsoils have a pH lower than the target 4.8 (Gazey et al., 2013).



Key for Fig.4 & Fig. 5

1. Mid-West
2. Mullewa to Morawa
3. West Midlands
4. Central Northern Wheatbelt
5. Swan to Scott Coastal Plains
6. Darling range to South Coast
7. Zone of rejuvenated drainage
8. Southern Wheatbelt
9. Stirlings to Ravensthorpe
10. South Coast – Albany to Esperance
11. Salmon Gums Mallee

Figure 4. Area (%) of topsoil below target pH in WA

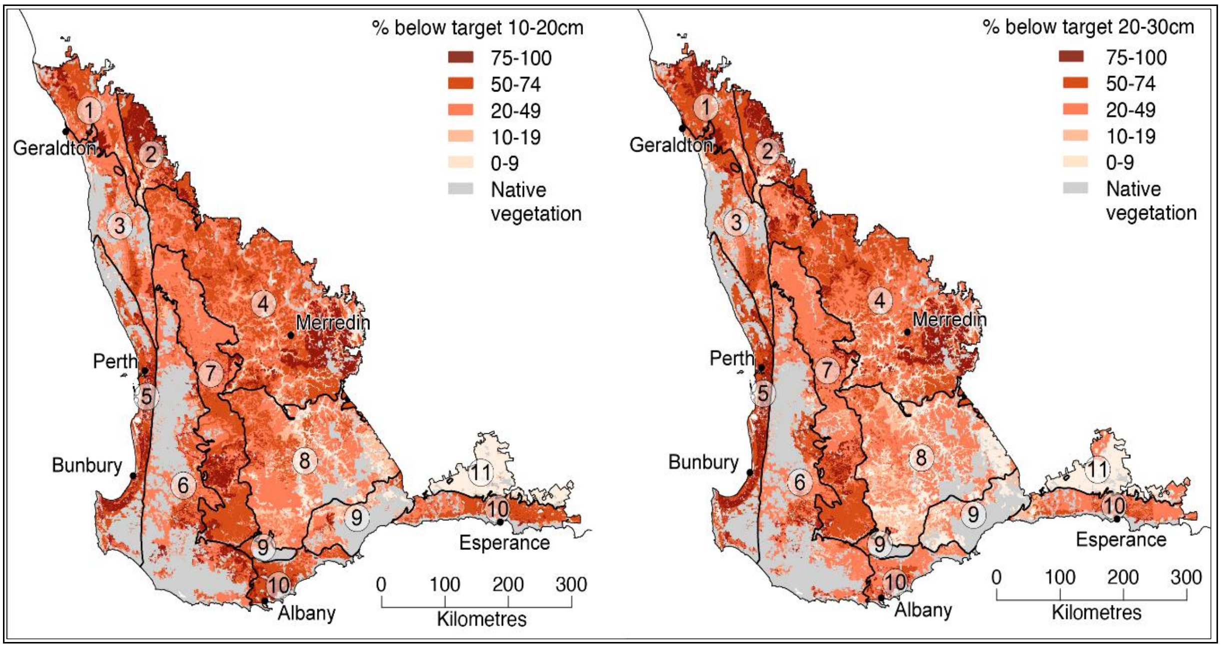


Figure 5. Area (%) below target pH for subsoil in WA

The South Coast has 1.8 million hectares of sandplain, ranging from Albany to Condingup and extending 80 km's inland. Acidification is particularly significant for sand plain soils, due to their poor buffering capacity (DAFWA, 2009). Around 65% of the South Coast agricultural region is acidic, with a high risk of sub-surface acidity, and a further 8% is at moderate risk (Fry 2015).

Diagnosing Soil Acidification

Measuring soil pH is the only way to diagnose soil acidity. Samples need to be taken at three depths throughout the soil profile; 0-10cm, 10-20cm, and 20-30cm, and at varying locations across the paddock (Fry, 2015). Sample sites should be geo-referenced so that the overall condition of the soil can be monitored over time. The target for optimal topsoil pH is 5.5, while sub-surface soils should be 4.8 pH (Gazey et al, 2014). Without ongoing management and amelioration, acidification continues. The risk being that it gets to a point where productivity is severely affected, and it becomes too expensive to recover.

Management of soil acidification

Some agricultural management practices can reduce the rate of acidification, but the continual removal of plant (alkaline) material will decrease the soil pH over time. The most common method to ameliorate acidic soils is surface application of lime (Fry, 2015, Kalkhoran et al., 2018). Current recommendations, based on soil pH values is between 2-4 t/ha (Gazey and Davies, 2009) which is more than normal farm practice of around 1-1.5t/ha. This involves spreading lime on the surface, without incorporation; however, due to the low mobility of lime in the soil, surface lime application does not reduce the acidity of sub-surface soil horizons in the short-term (Caires et al., 2005). This is not helped by the low soil disturbance in a minimum- or no-till system.

Deep placement of lime by direct injection during deep ripping is used as a way for decreasing sub-surface soil acidity and results are showing a rapid decrease is achievable with good yield responses, especially where compaction is also a soil constraint (Gazey et al., 2014). However, specialized equipment and a large amount of horsepower is required, and it is a slow and costly process.

The main sources of lime used in WA are limestone, which is mined and crushed from coastal deposits of Tamala, lime sand, mined from coastal sand dunes and dolomite, mined from old lake and inland drainage systems (Gazey et al., 2014). While lime is a relatively cheap bulk commodity and the quality of lime pits vary across WA, the distances required to transport lime on farm increases the costs.

Neutralizing Values of Lime Sources

Not all lime sources are of the same quality. The ability of the lime to increase the pH of soil is called its neutralizing value (NV), and is based on the purity of the lime, or the amount of carbonate in calcium and magnesium carbonate, and the oxide in calcium oxide, which neutralizes the acid (Fry, 2015). The NV is calculated by comparing the lime source to pure calcium carbonate, which is given a value of 100. The effective NV is based on the lime's neutralizing value, particle size distribution (% by weight) and the solubility of a lime (Fry, 2015). Particle size is important, as it determines the speed with which the lime will change soil pH. Fine particles are more effective at neutralizing because they have a greater surface area that enhances dissolution in the soil (Fry, 2015). Therefore, the rate of reaction of a liming material is determined by the particle sizes of the material. The ENV is the fraction of the materials calcium carbonate equivalent that will react with the soil in the first year. Whereas the NV is the total neutralizing value.

Lime supplies on the South Coast, tend not to have a very high carbonate percentage, or large particle sizes, resulting in lower NVs (Fry, 2015). This means that farmers using them need to apply 2-3 times the amount of lime recommended. However, while lime from the West Coast has higher NV values, so farmers require less of it, transport can be expensive, so the economics need to be carefully considered, and will vary with farm location, transport costs, and lime efficiency (Fry, 2015). Another option for farmers to investigate is the economics of crushing lime of larger particle sizes to improve ENV or using on-farm sources to reduce costs.

Calculating the Neutralizing Value (NV) of a Lime Source

The neutralizing value (NV) of larger particle sizes are discounted using the values of Cregan et al. (1989) to account for the reduced capacity to change soil pH in the short-term (Gazey et al., 2014). Lime pits in WA use a discounting method which discounts particles greater than 1mm by 80%, this means they are only 20% as effective as smaller particles in increasing soil pH, particles between 0.5mm and 1.0mm are discounted by 50%, while particles under 0.5mm (Cregan et al, 1989) are not discounted therefore 100% effective (SouthCoast NRM, 2018).

Table 1. Calculation to determine the overall per cent efficiency of lime (EP)

Size mm	% of lime	NV	% efficiency
0-0.125	2.2	89.1	2.0
0.125-0.25	26.6	86.8	23.1
0.25-0.5	38.1	92.7	35.3
0.5-1.0	32	60.5	19.4
> 1.0	1.2	54.7	0.7
Overall EP = sum of particle size EP			80.4

However, it is only particle sizes which are less than 25 mm that are 100% effective in the first year, but this is not considered in WA lime calculators (Fry, 2015), whereas the NSW and Victoria systems for calculating the NV for a lime source (APPENDIX 3) discount smaller particles. New South Wales (NSW) discount particles between 0.075-0.15 mm by 42% and particles ranging between 0.15-0.25 mm are discounted at 50% in comparison WA standards do not discount particle sizes less than 0.5 mm (Gazey et al., 2014).

Secondary carbonate deposits

An alternative source to lime purchased from a quarry is local secondary carbonate deposits on farm properties.

Potential soils can be identified from online soils categorization websites, DPIRD or Australian Soil Resource Information System, CSIRO. The alkaline soil types are calcareous loamy earths and alkaline shallow duplexes, they are more commonly known as Moort soils, Grey clay, Morrel soil, Salmon gum-gimlet, Lake bank, Merredin sandy loam and Kopi Soil (Easton, G., 2016). These types of soils usually have lower and possibly more variable neutralizing values than the more traditional commercial lime sources but are suitably alkaline to increase the pH of other soils with higher application rates.

Using an on-farm source of lime removes the cost of freight, however additional costs for extraction, crushing and handling the material for spreading, including freight across the farm, especially if there are different locations. Not all secondary carbonate on-farm sources will need to be crushed, although screening is essential for getting the right particle sizes.

For example, Bob and Daniel Nixon, farmers from Kalannie, a small town in the WA Wheatbelt 259km north-east of Perth, decided to focus their farming practices on producing the same yields with fewer inputs, leading them to investigate the option of using an on-farm source of lime to combat soil acidity (Martin, 2015). Their alternative source is a calcium-magnesium soil, known as Morrell lime, with a 45-50% NV (Nixon, 2017). Bob estimates there is 250,000 tonne available on their farm (Martin, 2015). Due to the lower NV, they are currently applying 4t/ha, which is double the rate used for lime sand, but once they have ameliorated the soil sufficiently they expect to require maintenance rates only, and their on-farm resource to last for over 20 years (Martin, 2015).

Morrell Lime

Morrell soil is very fertile, but it may be salty because it was deposited by wind with salt. It is also a poor producing soil in low rainfall years. The Nixon's turned their least productive paddock into an asset by transforming it into a lime pit, reducing the cost of their liming program (Martin, 2015). Using on-farm Morrell lime had other economic benefits, such as increasing the availability of nutrients, resulting in the Nixon's being able to reduce their fertiliser inputs (Martin, 2015). Trials done by Caroline Peek from DPIRD shows that the Morrell lime being applied on the Nixon's property in Kalannie is having a significant impact on soil pH levels throughout the entire soil profile, even in comparison to other lime resources (Figure 3).

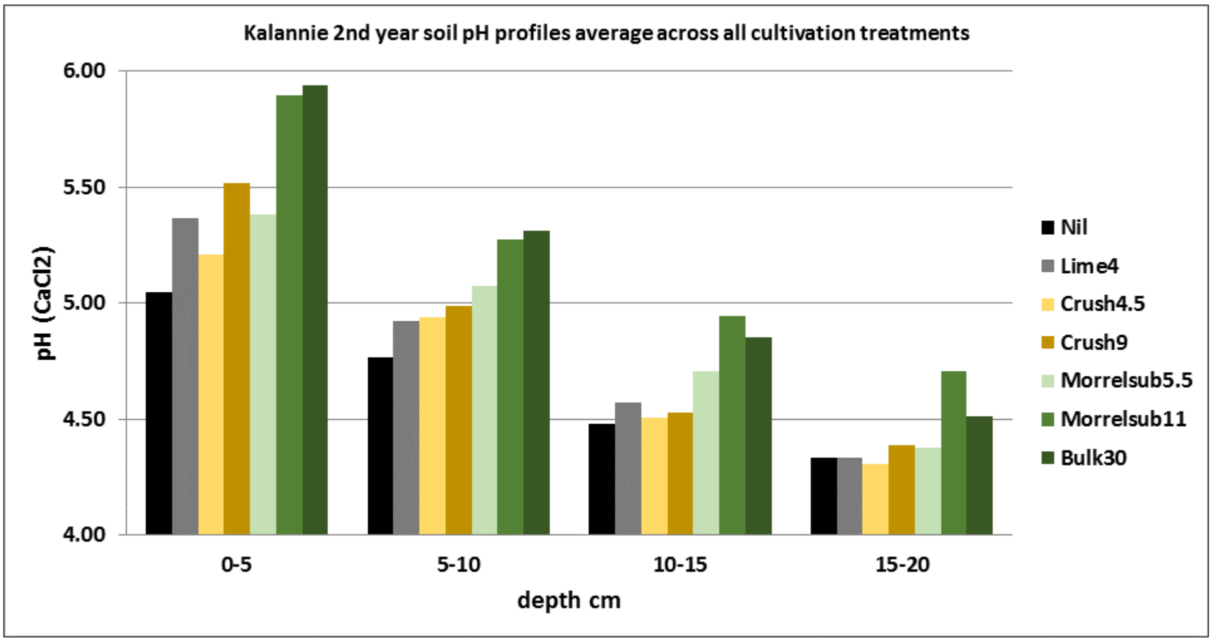


Figure 6. Soil pH averages throughout the profile at Kalannie across various liming treatments (Peek et al., 2019)

Yield Response to Liming

Yield benefits from lime are not generally immediate, they can take up to three years and often approaching eight years to be realised (Oliver et al., 2014).

A review and analysis by Oliver et al., (2014) of 20 years of lime trial data concluded that responses to lime vary with season, soil type and pH profile depth and severity. The average increase in yield was 12%, but the response ranged from 0 to 185%. The following sections about yield response summarize some of the key findings from the work by Oliver et al., (2014).

Yield response to lime related to depth and severity of acidity

Understanding how the severity and depth of soil acidity constrains plant growth can explain yield response to lime. Yield responses are greatest with the amelioration of soils with acidic profiles to significant depth (0.3m) and high severity of acidity (Oliver et al, 2014). Partial amelioration to a depth of 0.2m of soils that are acidic to 0.3m also has large yield benefits (Oliver et al, 2014). Unless acidity is severe, amelioration of acidic bands, or shallow acidic soils have low yield benefits (Oliver et al, 2014). This indicates the importance of managing acidity throughout the soil profile to significant depth, because this causes the greatest effect on root growth, and therefore yield.

Where acidity occurs in the profile is important, as the greater proportion of the profile depth that has a low pH, the greater the effect on root growth and yield (Oliver et al, 2014). Higher severity of acidity has a greater impact on maximum root depth than yield. There are large yield variations in soils that have high acidity, as yield is more greatly influenced by soil water supply in this situation, while root depth is more dependent on the depth of acidity in the soil profile (Oliver et al, 2014).

It is important to know the depth and severity of the acidity in the soil profile, and the changes that may occur when estimating yield benefits from liming (Gazey et al., 2014, Oliver et al, 2014).

Based on the parameters and functions of Optlime, a simulation model (Gazey, 2008; Sandison and Bathgate, 1997) which determines the pattern of lime application (rate and frequency) that maximises the Net Present Value of farm net income for a continuous wheat production system, wheat yield is more sensitive to sub-surface acidity than to surface acidity (Kalkhoran et al, 2018). In a study by Kalkhoran et al (2018) using Optlime to investigate and model the dynamic effects of lime on pH for a range of soil horizons, to determine optimal rates of lime applications and investigate the economics of deep placement of lime. They found that crop yield fell once sub-soils reached high levels of acidity, below pH 4.1ca. This pH is identified as a critical level for wheat production based on wheat being moderately tolerant of soil acidity (Gazey, 2008). This highlights the importance of sub-soil pH as an influence on yield, mainly because high acidity increases the concentration of aluminium to levels that are toxic to plants. They found only small yield reductions for acidity in soil surface.

Yield responses to lime affected by soil type

Understanding soil type, Plant Available Water Capacity (PAWC), the distribution of available water in the profile, and differences in soil chemistry can estimate the benefits of ameliorating acidic soils (Oliver et al, 2014). Amelioration of sands had greater responses to yield than amelioration of loamy sands and duplex soils. This can be related to sand having a lower PAWC, so small changes in available water have a significant impact on yield (Oliver et al, 2014). Duplex soils had lower yield benefits from liming, as they store more water in the top meter of soil, and plants are less affected by restricted root growth (Oliver et al, 2014).

Coloured sands and sandy earths are more affected by soil acidity and have greater yield response from liming than pale sand, and deep sandy duplexes (Oliver et al, 2014). This response may be a result of lime overcoming Aluminium (Al), which occurs more often in coloured sands. Pale sands have lower yield increases due to their high relative yield, indicating low severity of acidity (Oliver et al, 2014). The variation in yield responses in different soils highlights the impact water availability and distribution through the soil profile, and differences in soil chemistry can have on plant growth when soils are acidic.

Impact of seasonal variation on yield response to application of lime

Seasonal variability has a large impact on yield responses to liming. There are large yield increases when the soil profile is fully ameliorated, but there is no relationship between yield increases and total growing season and summer rainfall, indicating that distribution of rainfall determines yield benefit from liming, not total rainfall (Oliver et al, 2014). There was the least response to amelioration where there was little benefit for roots to access water deeper in the profile (Oliver et al, 2014).

Yield loss in response to amelioration sometimes occurs. Removal of acidity causing negative yield responses is more common with low rainfall when the severity of the acidity is moderate and found in an acid band or the top 0.2m of the profile (Oliver et al, 2014).

Economic variables to consider for application of lime

Although the soil science is clear around the need for lime to improve soil pH and reduce the acidity developed from normal farming practices, the economic benefit is less clear. The cost of applying lime and the variability in yield responses creates a level of uncertainty. The key economic factors to consider for the application of lime are:

1. Cost of lime.
2. Quantity of lime required to achieve the target pH which depends on the starting pH of soil, target pH and quality of lime being used.
3. Transport cost for lime from source pit to farm.
4. Spreading costs.
5. Incorporation of lime.
6. Yield response.

The following analysis considers these factors when comparing the different options for the Esperance port region.

Method

A whole-of-farm model represents a typical farm on the South Coast and calculates the net present value (NPV) and internal rate of return (IRR) for different scenarios that consider the cost of freight from different locations and the quality of lime.

FARMSMART® is a decision support tool for farmers to understand the impact of applying existing or new technology, options for enterprise mix and scale of farming enterprise. Underpinned by both financial and scientific principles the tool assists the user to understand the financial implications of their decisions and implementation of significant changes. This includes the application and investment in ameliorating soil for acidification.

A five-year profit and loss, and balance sheet is generated from the data input for enterprise mix and farming system allocated to the land-use on farm. Crop yields are calculated by using historical monthly rainfall data (1970 to current year) with an adapted French & Shultz (1984) water use efficiency model. Yields are also adjusted by a performance rating given to a paddock from 1 to 7, 1 being the best performing paddock. Yields are also adjusted for the application of lime which can only be applied in the first year.

Livestock stocking rates and supplementary feed costs are calculated using historical pasture growth rates and livestock energy demands using Lifetime Ewe Management™ practices.

The cashflow is discounted using standard practice to calculate the net present value (NPV) and internal rate of return (IRR), both measures are calculated from retained profit[7] and are used to rank investments. Appendix 1 explains NPV and IRR.

[7] Retained profit = Total Farm Income (Yield * Prices) minus Operating costs (Variable costs + Fixed costs) minus Interest & Tax minus Capital costs minus Depreciation minus Personal Drawings.

Using a 'typical' farm representing a typical farming system in the medium rainfall region with a focus on the South Coast of Western Australia, an investment analysis to evaluate the application of lime to meet a target pH of 5.5 in the topsoil (0-10cm) was conducted. The scenarios considered were:

i. No lime application and therefore increasing soil acidity and decreasing yields
ii. Application of lime sand from the West Coast
iii. Application of lime using a local lime source from the South Coast
iv. Application of lime using an on-farm secondary carbonate deposit

Data from Planfarm Bankwest benchmarks were used as a guide to generate a 'typical' representative farm. This data helped determine the size of the farm, area cropped, number of ewes mated, capital structure including debt levels. The details for this representative farm including rotations, type of crops and areas grown are outlined in Appendix 2.

Historical rainfall data from the Bureau of Meteorology (BOM) weather stations located in the medium rainfall region on the South Coast calculated the expected crop yields with and without lime.

Table 2. Characteristics of typical farms for the South Coast W.A.

MEDIUM RAINFALL	325 to 450 mm
Size (ha)	3,989
Total rainfall (mm)* (Decile 5 season)	465
GSR (mm)* (Decile 5 season)	292
Area of crop (ha)	3089
Crop area (%)	77%
Area of pasture (ha)	900
Livestock	Self-replacing Merino ewe flock for wool and lambs

*Historical rainfall data

The model includes the key economic factors affecting the economics of lime application:

1. Cost of lime,
2. Quantity of lime based on starting pH of soil, target pH and quality of lime being used.
3. Transport cost for lime from source pit to farm
4. Spreading costs
5. Incorporation of lime (optional)
6. Soil characteristics i.e. starting levels of pH
7. Yield response

Lime can be selected from one of 14 WA pits represented in FARMSMART® (

Table 3) and includes the 2018 price for lime ($/t), collected from the quarry operators, and the NV value from the latest analysis, most of which come from independent and audited results through the WA lime alliance.

Table 3. Lime pits, cost of lime (2018) and NV for lime at pit

Source Pit	NV using W.A standard	Cost $/t @pit 2018
BEAUFORT RIVER	18.4	$44.00
BORANUP	84.1	$15.70
BREMER BAY	64.2	$22.00
COOLJARLOO	79.4	$8.00
DALYUP	69.8	$13.50
DENMARK	64.2	$27.50
LAKE PRESTON	41.1	$18.50
LANCELIN (Aglime)	80.4	$11.55
LANCELIN (Rules)	93.9	$11.50
MANYPEAKS	35.2	$25.00
MASON BAY	48.1	$17.00
MYALUP (Carbone)	51.7	$16.50
MYALUP (Catalano)	62.0	$16.50
REDGATE	61.7	$18.45
ONFARM	27.6	$40.00

The on-farm option assumes an NV value of 27.6 and a cost of extraction and crushing of $40 per tonne. Unless incorporation costs are selected, it is assumed that lime is spread on the surface using conventional spreading techniques. The quantity of lime in tonnes per hectare (t/ha) is determined by the difference between the starting soil pH_0 and target pH_1 and the quality of lime applied.

The pure amount of $CaCO_3$ required to reach the target pH is calculated (equation 1) and converted to lime t/ha based on the quality of lime, or it's NV (equation 2).

$$\text{Pure } CaCO_3 \text{ (t/ha)} = pH_0 - pH_1 / \text{soil conversion factor} + 0.4 * (1\text{-gravel\%}/100) \quad (1)$$

$$\text{Lime t/ha} = \text{Pure } CaCO_3 /(\text{gravel\%}/100) * (1\text{-NV}/100) \quad (2)$$

The maximum amount of lime which can be applied is 3 tonnes per hectare (Petersen, et al., 2019)

Transport costs are calculated by the distance from pit to the farm location at $0.15 cents per km and spreading costs are $12 per tonne. Incorporation of lime, which is optional is $90/ha (Petersen et al., 2019) and the soil characteristics used for the representative farms are outlined in table 4.

Table 4. Land management units and soil characteristics for representative farm

Land Management Units	Level of pH (0-10mm)	Area of land (%) Medium rainfall
Alkaline shallow duplexes	5.2	2
Calcareous loamy earths	7	0
Clays and shallow loamy duplexes	5.2	4
Deep loamy duplexes and earths	5.2	2
Deep sandy duplexes	4.8	47
Ironstone gravels	4.8	4
Sands	4.8	8
Shallow sandy duplexes	4.8	34

Calculating yields

Crop yields are calculated using the DPIRD (2018) potential yield calculator adapted from the French and Shultz (1984) model (equation 3).

$$\text{Yield potential (tonnes/ha)} = (\text{WUE} * (\text{stored soil water} + \text{GSR} - \text{evaporation}) \quad (3)$$

Source: DPIRD, 2018

- WUE is water use efficiency (APPENDIX 4)
- Stored soil water is rainfall (mm) between November and March, inclusive,
- GSR is rainfall (mm) between April and October, inclusive and in the growing season.
- Evaporation (mm) is 110 for a warm season finish and 90 for a cool season finish.

Rainfall data from a South Coast medium rainfall location was downloaded from the bureau of meteorology into FARMSMART® and used with equation 3 to calculate potential crop yields.

The annual average rainfall is 500 mm ranging from 237 mm to 752 mm and the average growing season is 237 ranging from 109 mm to 571 mm. Figure 7 illustrates the monthly distribution of rainfall and the difference between deciles 3, 5 and 8 using data from 1970 to 2018 for the South Coast location.

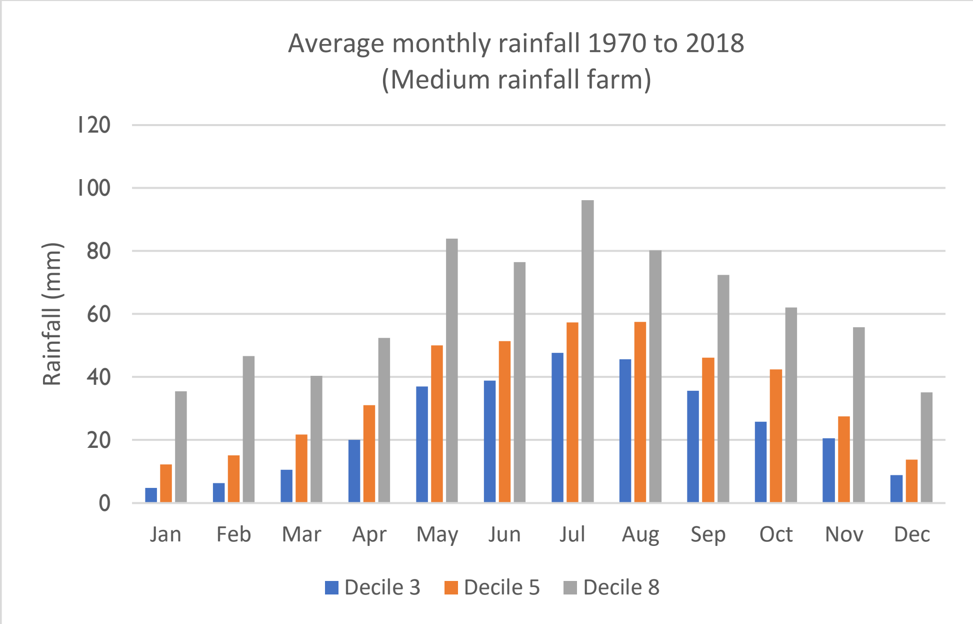


Figure 7. Monthly rainfall (medium rainfall farm) showing Decile 3, Decile 5 and Decile 8 rainfall years

The DPIRD (2018) potential yield calculation method calculates the maximum wheat yield possible in the absence of any other constraints. Adjustments to achieve more realistic crop yields in FARMSMART® are made by rating paddocks from 1 to 7 (1 being the best performing paddock), this means the yield for crops in paddocks which are rated lower performers are reduced from the maximum yield potential.

Equation 3 is calibrated for wheat only, therefore adjustments were made to the transpiration efficiency and soil evaporation values for Barley, Oats, Canola and Lupins (DAFWA, 2009).

This data is also organised to show the frequency of different years occurring (Figure 8) and was used to inform the seasons selected for each year for the representative farm, Table 5.

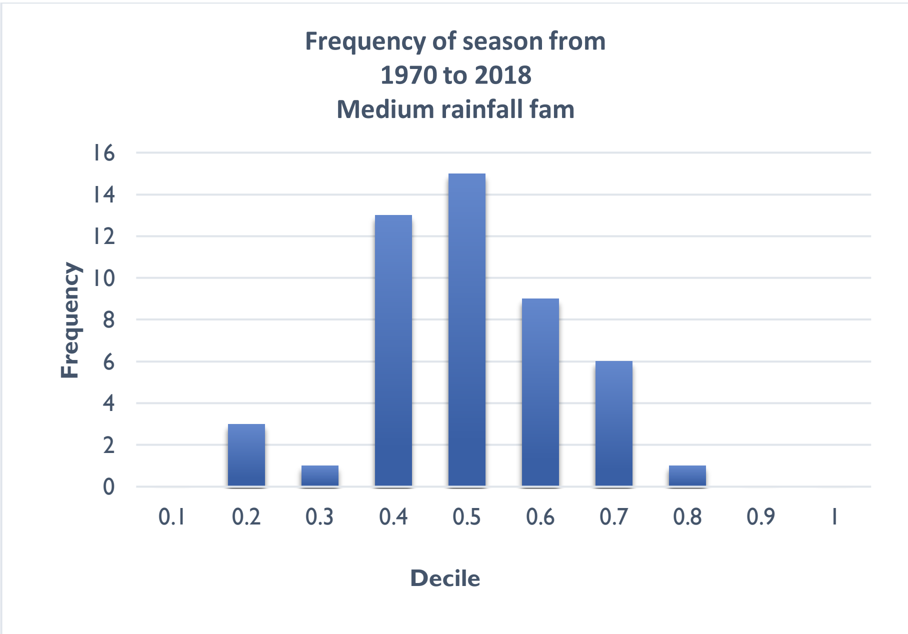


Figure 8. Frequency of season since 1970 for medium rainfall representative farm

Table 5. Seasonal conditions (decile) assumed in scenarios

Year	Medium rainfall
Year 1	5
Year 2	6
Year 3	3
Year 4	5
Year 5	5

Yield response to applying lime

FARMSMART® also adjusts crop yields when lime is applied, Figure 9 (Petersen et al., 2018). Yield response peaks in year 3, after application of lime and then slowly declines, whereas yields continually decrease (Figure 9) when no lime is applied. If lime is incorporated or 'on-farm' lime is applied, yield's peak in the second year after application, representing the quicker yield response expected from either of these two situations. Barley and canola are more sensitive to acidic soils and are more responsive to the application of lime, so the percentage increase in yield is higher as shown in Figure 9 and Figure 11.

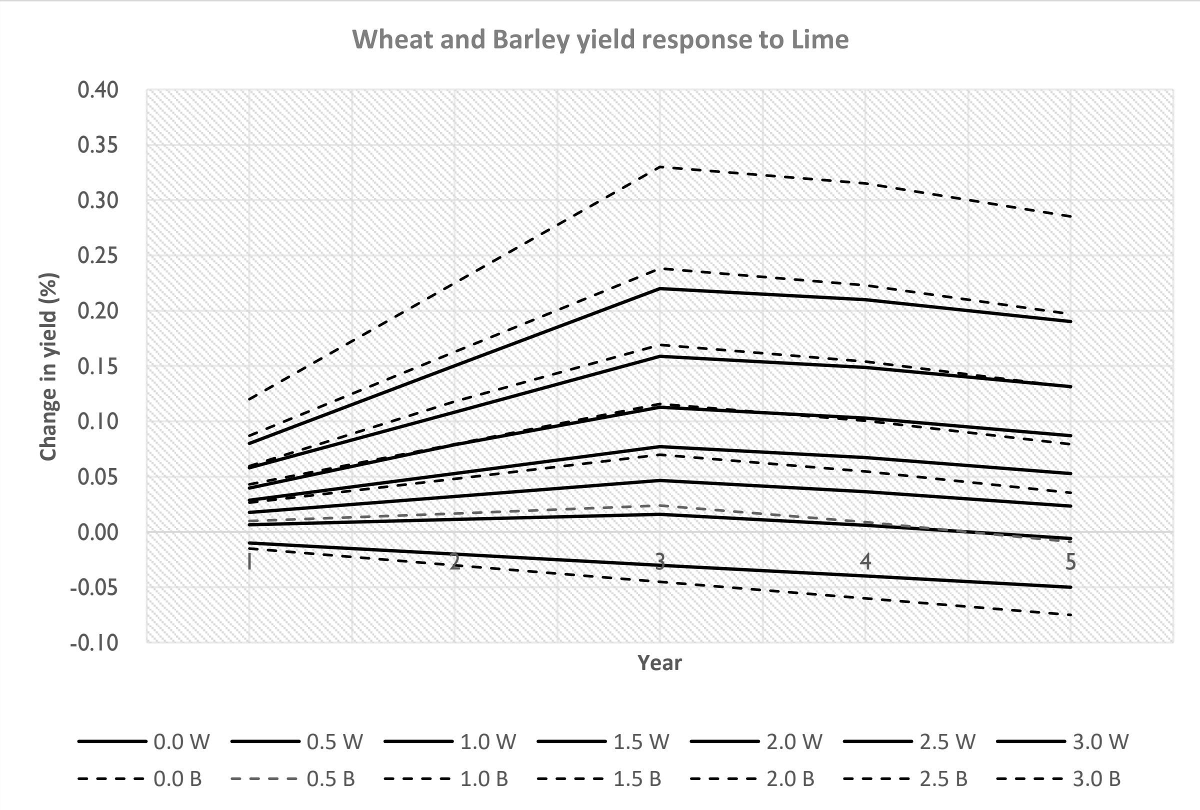


Figure 9. Wheat and Barley yield response to applying lime (%)

Source: Adapted from Soil Amelioration Profit Calculator (2014) (Petersen et al., 2018).

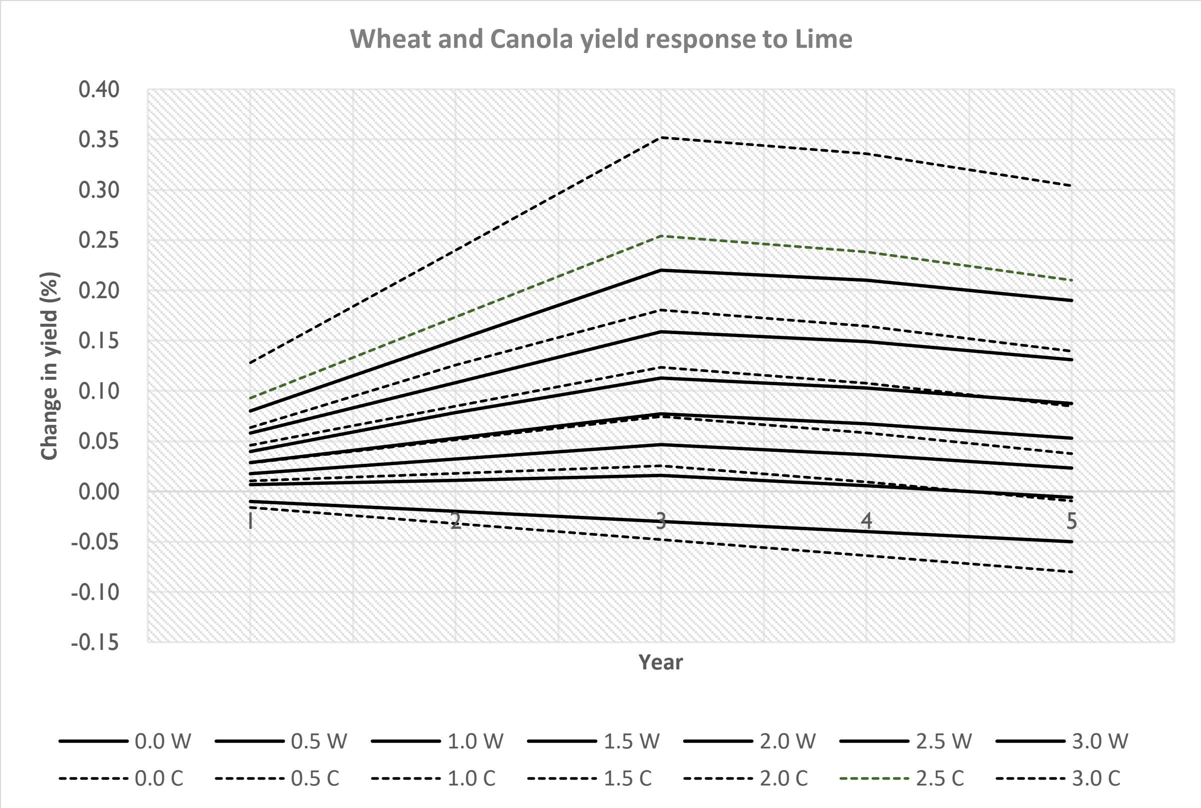


Figure 10. Wheat and Canola yield response to applying lime (%)

Figure 11 demonstrates the change in yield response to lime application as predicted in Figure 9 for a 3-tonne wheat crop. For example, wheat yield will decrease to 2.88t/ha by year 5 for a crop producing 3 tonnes per without lime, however, if lime is applied yield increases to 3.63 t/ha by year 5.

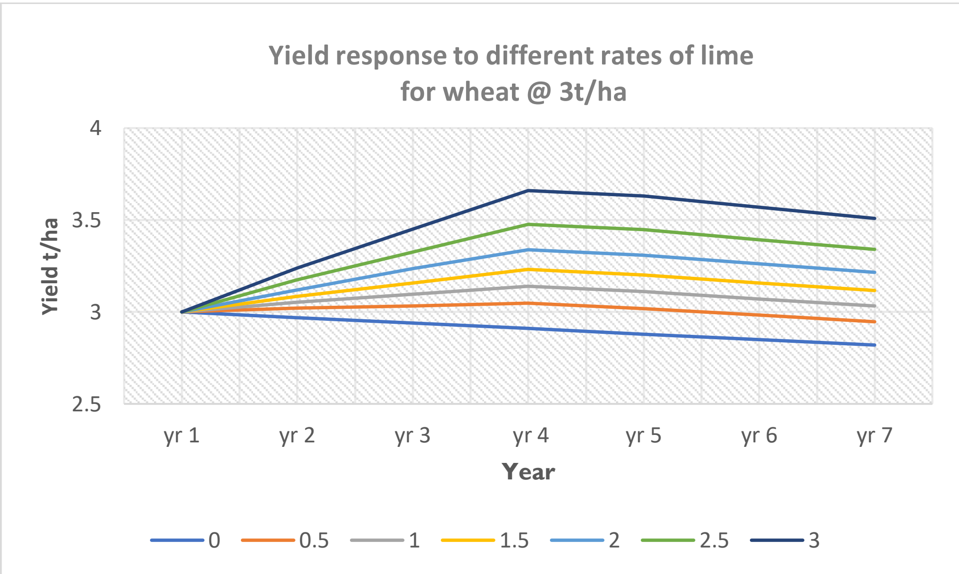


Figure 11. Yield response assumption to application of lime for wheat

To summarise, FARMSMART® yield calculations use several variables, they are calculated on seasonal conditions and water use efficiency equations, including warm or cool finish to the season, stored soil moisture and then adjusted by paddock performance and application of lime. Table 11 provides an example of wheat yields (t/ha), year 1, in a decile 5 season for the base-line scenario where no lime is applied.

Table 6. Wheat yields used for decile 5 year (medium rainfall)

Season	Yield Potential		Water use efficiency				Evaporation (mm)	
Decile	Warm Finish	Cool Finish	Warm finish	Cool Finish	Stored soil moisture	GSR	Warm finish	Cool Finish
0.1	0.52	0.76	12	12	9	145	110	90
0.2	1.22	1.46	12	12	14	198	110	90
0.3	1.90	2.67	12	15	17	251	110	90
0.4	3.06	3.36	15	15	22	292	110	90
0.5	3.59	3.87	14	14	30	336	110	90
0.6	3.68	3.92	12	12	42	375	110	90
0.7	3.77	3.77	10	10	52	435	110	110
0.8	4.37	4.37	9	9	71	524	110	110
0.9	3.69	3.69	6	6	109	617	110	110
1.0	4.04	4.54	4	4.5	225	894	110	110

Other key assumptions

Lime is applied to 720 hectares on paddocks growing canola and barley crops in the first year. This is 18% of the total farm area.

The prices used for crops and the key variables use for the livestock enterprise are listed in Table 7 and Table 8.

Table 7. Prices for grains ($/t)

Wheat	$285
Barley	$260
Oats	$260
Canola	$540
Lupins	$320

Table 8. Prices & yields for sheep and wool

Wool price $/kg	22
Wool Yield	62%
Wool price $/kg (on farm)	11.13
Wool yield kg/head for ewes	6
Wool yield kg/head for lambs	3
Average price for sheep $/hd	$108
Lamb Marking %	85%

Results

The amount of lime required to meet target pH

The amount of lime required to reach the target pH of 5.5 for a top-soil (0-10 cm) of a shallow duplex sandy soil with a starting pH of 4.8, depends on the effective neutralising value and ranges between 1.6 and 8.0 tonnes per hectare, (Eq. 1 & 2). Table 9 lists most WA lime sources, the amount of lime required to meet the target pH for topsoil of a shallow sandy duplex type soil and the cost of the lime per tonne.

Table 9. Amount of lime (t/ha) required to ameliorate soil

Quarry	Effective NV using W.A standard	Lime required to meet target pH for top-soil shallow sandy duplex[8] t/ha
BEAUFORT RIVER[9]	18.4	8.0
BORANUP	84.1	1.7
BREMER BAY	64.2	2.9
COOLJARLOO	79.4	1.9
DALYUP	69.8	2.1
DENMARK	64.2	2.3
LAKE PRESTON	41.1	3.6
LANCELIN (Aglime)	80.4	1.8
LANCELIN (Rules)	93.9	1.6
MANYPEAKS	35.2	4.2
MASON BAY	48.1	3.1
MYALUP (Carbone)	51.7	2.8
MYALUP (Catalano)	62.0	2.4
REDGATE	61.7	2.4
ONFARM	27.6	5.3

[8] Actual pH 4.8 Target pH 5.5

[9] Dolomite from Beaufort River has high levels of Magnesium and therefore might be applied for this purpose as well as it's neutralising value.

Table 10. Yields adjusted for paddock performance rated from 1 to 7

Decile year	1	2	3	4	5	6	7
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.76	0.56	0.36	0.16	0.00	0.00	0.00
2	1.46	1.26	1.06	0.86	0.66	0.46	0.26
3	2.67	2.47	2.27	2.07	1.87	1.67	1.47
4	3.36	3.16	2.96	2.76	2.56	2.36	2.16
5	3.87	3.67	3.47	3.27	3.07	2.87	2.67
6	3.92	3.72	3.52	3.32	3.12	2.92	2.72
7	3.77	3.57	3.37	3.17	2.97	2.77	2.57
8	4.37	4.17	3.97	3.77	3.57	3.37	3.17
9	3.69	3.49	3.29	3.09	2.89	2.69	2.49
10	4.54	4.34	4.14	3.94	3.74	3.54	3.34

The total tonnes of lime required to ameliorate 720 hectares on the typical farm depends on the type of lime used, Table 11. The lime-sand from the West Coast has the highest NV so less lime is required to meet target pH, whereas the typically low NV for the on-farm source requires more product to meet target pH.

Table 11. Total lime required for 720 hectares

Scenario	Application of lime-sand from the West Coast	Application of lime using a local lime source from	Application of lime using an on-farm alkaline source
ENV (%)	80.3	70	27.6
Total lime required (t)	1340	1440	2160[10]

The cost for purchasing lime, transporting it to farm and spreading or incorporating ranged from $81 to $278 per hectare, the least cost at $81 per hectare and $58,320 total investment from the local lime quarry has the same IRR as using the on-farm lime source when this scenario costs $52 per tonne including spreading ($36 per hectare) or the scenario when no lime is applied. The costliest scenario is to transport lime from the West Coast, despite its higher effective neutralising value and lower amount required, the cost of transport reduces the internal rate of return to 35%, Table 12.

[10] On-farm secondary carbonate with 27.6 NV requires 5.2 tonnes per hectare but the maximum application possible in FARMSMART® is 3 tonnes/ha.

Table 12. NPV and IRR results for Medium rainfall farm

	Application of lime t/ha	Distance for freight km	Total cost including freight & spreading $	Cost per hectare (limed)	NPV	IRR
No lime application Increasing soil acidity and decreasing yields	0				$1,094,345	40%
Application of lime-sand from the West Coast	1.8	840	$200,397	$278	$1,087,800	35%
Application of lime using a local lime source from the South Coast	2	100	$58,320	$81	$1,170,900	40%
With incorporation	2		$123,120	$171	$1,095,840	36%
Application of lime using an on-farm secondary carbonate at $52/tonne ($36/hectare) including spreading	3	0	$112,320	$156	$1,220,650	40%
On-farm at $32/tonne and $22/hectare					$1,244,384	42%
On-farm with incorporation	3	0	$177,120	$246	$170,877	36%

Incorporating lime increases the costs by 52% and reduces the IRR from 40% to 36%, an increase in yield response compared to the assumptions used (Figure 13) or a reduction in costs, is less than $90 per hectare this result would be closer to the 40% result for the base-line scenario.

Discussion

Farmers rely on productivity improvements to counteract declining terms of trade, investment in lime is more likely when it improves productivity, this means the outputs must be greater than the inputs. Farmers do not provide public goods or services they operate to generate profits to meet lifestyle goals and to re-invest in their businesses for sustainability. Liming is arguably required for long-term sustainability purposes.

This study has looked at liming solely as a private investment only. It is a significant investment to maintain medium to long-term sustainability and this study finds the return on investment is neutral in comparison to not applying lime, and when the additional cost of incorporation is included the return on investment is lower than the baseline (no-lime).

On-farm lime source is ranked the best option, clearly above transporting lime from the West Coast, despite the lower neutralising values compared to the West Coast lime sand. But only marginally better than using a local lime source from a nearby lime quarry.

The cost of extraction, including the value of labour or opportunity cost of labour, the need for crushing and logistics for moving around the farm, especially on public roads all need to be considered (SouthCoast NRM, 2018). The distance a farm is located from a lime quarry will determine the benefit of using an on-farm secondary carbonate. Even sources with low NV can be the best investment but it needs to be compared to the cost of freight for higher NV lime from another source and the cost for extraction. If the cost is more than $52/tonne or $36/hectare for extraction and spreading it is better to transport from a local lime source, assuming it is no more than 100 km from the farm.

Not all farmers will have the option to use on-farm resources for liming in this way, but for some farmers in WA, who have secondary carbonate suitable to use, and by doing the correct analysis can evaluate if this is a viable option. There are some recent publications that can assist famers, for example On-farm Lime Extraction Guidelines (SouthCoast NRM, 2018).

To achieve an economic benefit from applying lime, the value of the yield response over time must be higher than the cost of the investment. Therefore, yield response to the application of lime is a key economic driver and although improving yields increase outputs, productivity will not improve if the costs are greater than the benefits (yield (t/ha) x price ($/t)). Alternative lime sources were investigated as part of this study, but none were more cost effective than the sources used in this analysis.

This study uses the discounting method for calculating NV for the lime sources which is used by Lime WA, and DPIRD (2014), the increase efficiency for particles around 0.25 mm is not taken into account, as noted by Fry (2015). The NSW method does account for the efficiency of these particles and the increased speed in which they work. Using lime sources with high effective neutralising values, i.e. with finer particle sizes that will react faster and more likely in the first year will improve the economic results.

The initial analysis used long-term average prices for grain, Table 7. When the same analysis is repeated using lower prices (Decile 2), the additional yield from applying lime has a small positive impact and the IRR for applying lime from the local lime source is higher than not applying any lime, indicating that the application of lime, and increasing yield becomes more important as prices decrease. But, conversely the additional cost of applying lime has a negative impact when there are poor seasonal conditions, the option for no lime has a higher IRR.

This result increases the difficulty for decision making for farmers because the investment in lime is less profitable in poor seasonal conditions, because the costs are more than the total benefits.

These results reflect producer practices, often lime is applied in years where there have been strong financial outcomes, although this is usually a retrospective management decision, because lime is usually applied when the season is unknown. Producer's see lime application as a way of increasing productivity and reducing tax liabilities.

Table 13. Results with lower crop prices ($/tonne) and decile 3 seasonal conditions

Price of grains $/tonne		No lime application Increasing soil acidity and decreasing yields	Application of lime-sand from the West Coast	Application of lime using a local lime source from the South Coast	Application of lime using an on-farm alkaline source[11]
Wheat $220 Barley $200 Canola $480 Lupins $250	NPV	$49,000	$21,469	$105,300	$140,000
	IRR	2%	1%	4%	5%
Decile 3 Seasonal conditions	NPV	$561,678	$409,000	$495,700	$687,689
	IRR	12%	9%	10%	14%

Individuals need to make the decision most appropriate for their own circumstances. The distance and cost of freight alters the economic outcomes; by increasing the distance to 250 km between the farm and the local lime pit the IRR alters, Table 14.

Table 14. Distance from quarry

	Application of lime t/ha	Distance for freight km	Total cost including freight & spreading $	Cost per hectare (area limed)	NPV	IRR
Application of lime-sand from the West Coast	1.8	530	$148,137	$205	$960,628	32%
Application of lime using a local lime source from the South Coast	2	230	$86,400	$120	$999,560	34%

[11] These results are overestimated by a small amount because only 3 tonnes applied and not 5 tonnes which is required to achieve the yield response.

Managing acidity could have public-good implications, soil acidity threatens ecosystem health and liming is recognised as an important mitigation and is considered the most common remedy (Holland et al., 2018; Lawrence et al., 2016). It also has important benefits for greenhouse gas emissions, the dissolution of lime can be a net sink for CO_2 in soils with high pH, but a net source of CO_2 in acidic soils (West and McBride, 2005). Avoiding applying lime to mitigate greenhouse gas emissions will result in other adverse environmental effects like soil acidification (Kalkhoran et al., 2018)

This study mostly concurs with Kalkhoran et al., (2018) that optimal decision rules are relatively sensitive to changes in the economic parameters, wheat and lime prices, distance from lime pit and the discount rate and extremely sensitive towards the initial soil pH. They reported that the sensitivity analysis highlights the importance of checking the flatness of the payoff functions in determining optimal lime decision rules (Pannell, 2006). Their model optimised very high initial lime rates at 8 t/ha over 80-year time frame, but also, much lower rates, more in line with farmer practice, are only slightly less profitable. This study, however, suggests that applying 8t/ha of lime is not of economic benefit, due to the high cost this would incur.

Conclusion

The results reflect the complexity surrounding the decision making for producers on the application of lime. The benefits are not immediate and sometimes not evident, however the ongoing decrease in soil pH and increasing acidification of soil negatively impacts on production in the long-term. To achieve an economic benefit from liming, the cost for applying lime needs to be less than the benefits achieved from mitigating the problem.

Producers need to consider all elements, the cost of transport, the ENV of the lime source, the initial soil pH to determine the amount of lime required, soil testing, which is a key management tool to assist with the decisions related to applying lime. And, decision support tools such as iLime and the Lime Profit Calculator developed by the Liebe group are also available to assist.

This review concludes that extracting and crushing on-farm secondary carbonate, even at low neutralising values is clearly a better option than transporting lime sand from the West Coast to the Esperance port region, despite the lime sands higher neutralising values. And, a lime source from a local quarry with reasonable neutralising values is also a better option than transporting from the West Coast, but it depends on the cost of extraction and crushing, and the quality of the on-farm secondary carbonate which is the better option between the on-farm secondary carbonate and local quarry lime, the results using the assumptions in this review are very similar.

The return on investment for applying lime is affected by several variables including seasonal conditions and prices, which vary from year to year, this increases the complexity associated with understanding and evaluating the response to lime. Applying lime for production improvements may not always achieve large economic benefits, but it reduces the risk of economic loss due to production losses resulting from high levels of soil acidity.

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APPENDIX 1

NPV and IRR explained

Net present value is a method for determining the current value of all future cash flows generated by a project after accounting for the initial investment. It is widely used in capital budgeting to establish which projects are likely to turn the greatest profit (Boyte-White, 2017). Often referred to as a cost-benefit analysis (CBA) or benefit cost analysis (BCA) it provides an objective framework for weighing up different impacts, including impacts that occur in different periods. This objectivity is supported by converting all impacts into present value dollar terms. Sometimes, full quantification of some impacts is not possible (Office of Best Practice Regulation, 2016).

The need to discount future cash flows can be viewed from two perspectives, both of which focus on the opportunity cost of the cash flows. The first is that individuals prefer a dollar today to a dollar in the future and is most obvious in the fact that banks need to pay interest on deposits to entice individuals to forgo current spending. This preference for current consumption is known as the 'rate of time preference' and relates to all economic benefit (and costs), not just those that are financial in nature. (Office of Best Practice Regulation, 2016).

Society's preferences place greater weight on consumption occurring closer to the present and since individuals are not indifferent between cash flows from different periods, those flows cannot be directly compared unless they are discounted back to current dollar terms.

The second perspective is there is an opportunity cost for investment. The costs need to be funded in some way either through the interest paid for borrowing the money, or the returns forgone when the funds are not used for other purposes. Therefore, the project will only be beneficial when it provides an excess of the cost for deferring consumption, or the return that could have been earned on the best alternative use of funds. Applying a discount rate to future cash flows, the required rate of return is explicitly considered in the net present value calculation. A 6% discount rate was applied to the future cash flows in this analysis; a cash return on capital of 4.3% and change in land value of 2.0% (Planfarm Bankwest Benchmarks, 2017).

The steps for conducting an NPV analysis are outlined in Table 15.

Table 15. Steps in preparing a cost-benefit analysis

Steps in preparing a cost-benefit analysis
1. Specify the set of options
2. Identify costs and benefits
3. Identify the impacts and select measurement indicators
4. Predict impacts over the lifetime of project investment
5. Monetize (attach dollar values to) impacts
6. Discount future cost and benefits to obtain present values
7. Compute NPV of each option
8. Perform sensitivity analysis

Source; Adapted from Boardman et al. (2010)

Net present value is an absolute measure i.e. it represents the dollar amount of value added or lost by undertaking a project. IRR on the other hand is a relative measure i.e. it is the rate of return a project offers over its lifespan.

NPV and IRR are two of the most widely used investment analysis and capital budgeting decision tools. Both are discounting models i.e. they consider the time value of money phenomena. However, each method has its strengths and weaknesses and there are situations in which they do not agree on the ranking of acceptability of projects. For example, there might be a situation in which project A has higher NPV but lower IRR than project B. This NPV and IRR conflict depends on whether the projects are independent or mutually exclusive. Independent projects are projects in which decision regarding acceptance of one project does not affect decision regarding others.

Since all independent projects can all be accepted if they add value, NPV and IRR conflict doesn't arise. The company can accept all projects with positive NPV.

Mutually exclusive projects are projects in which acceptance of one project excludes the others from consideration. In such a scenario the best project is accepted. NPV and IRR conflict, which can sometimes arise in case of mutually exclusive projects, becomes critical. The conflict either arises due to the relative size of the project or due to the different cash flow distribution of the projects.

Since NPV is an absolute measure, it will rank a project adding more dollar value higher regardless of the original investment required. IRR is a relative measure, and it will rank projects offering best investment return higher regardless of the total value added.

APPENDIX 2

Details for typical medium rainfall farm

Table 16. Soil types, area and pH for soils on medium rainfall farm

Land Management Units	Land area (%)	Hectares	Level of pH (0-10mm)
Alkaline shallow duplexes	2	85	5
Calcareous loamy earths	0	0	7
Clays and shallow loamy duplexes	4	150	5.2
Deep loamy duplexes and earths	2	60	5.2
Deep sandy duplexes	47	1859	4.8
Ironstone gravels	4	140	4.8
Sands	8	320	4.8
Shallow sandy duplexes	34	1375	4.8

Table 17. Crop rotation for medium rainfall farm (Ha, (%))

Crop type	Year 1	Year 2	Year 3	Year 4	Year 5
Wheat	1,180 (38%)	1,430 (46%)	1,389 (45%)	1,070 (35%)	1,560 (51%)
Barley	970 (31%)	775 (25%)	1030 (33%)	984 (32%)	970 (31%)
Oats	109 (4%)	270 (9%)	200 (6%)	250 (8%)	109 (4%)
Canola	540 (17%)	409 (13%)	270 (9%)	520 (17%)	220 (7%)
Lupins	290 (9%)	205 (7%)	200 (6%)	265 (9%)	230 (7%)

Table 18. Seasonal conditions and yields for year 2 to year 5

MULTI-YEAR ASSUMPTIONS	Year 2	Year 3	Year 4	Year 5
SEASONAL CONDITIONS	6	3	5	5
CONDITIONS AT FINISH	Warm	Warm	Warm	Warm
CROP YIELDS (t)				
Wheat	3.26	1.48	3.03	3.00
Barley	3.17	1.58	3.21	3.24
Oats	2.65	0.93	3.12	2.22
Canola	2.11	0.83	1.74	2.66
Lupins	1.81	0.54	1.80	1.55

Table 19. Gross margins for crops

	Wheat	Barley	Oats	Canola	Lupins
YIELD (t/HA)	**3.14**	**3.14**	**2.34**	**2.09**	**1.63**
PRICE PER TONNE (FIS)	**285**	**260**	**260**	**540**	**290**
$/t (NET ON FARM)	240.50	214.17	214.17	489.50	275.70
CROP COSTS					
CHEMICAL ($/HA)	78	80	42	70	40
SEED ($/HA)	25	23	20	9	29
FERTILISER ($/HA)	117	117	117	117	117
OPERATION ($/HA)	0	0	0	0	0
FUEL ($/HA)	6.5	6.5	6.5	51.5	6.5
R & M ($/HA)	35	35	35	35	35
LABOUR	28	28	28	28	28
INSURANCE	3.36	3.36	3.36	3.36	3.36
Other	14	14	10	9	7
Total costs (per HA)	$ 307	$ 307	$ 262	$ 323	$ 266
Gross margin ($/HA)	$ 449	$ 364	$ 238	$ 701	$ 184

APPENDIX 3

Cost of lime ($/t) from W.A quarries, 2018.

Table 20.Cost of lime $/tonne and neutralising value at W.A quarries

Quarry	Cost $/t @pit 2018	Effective NV using W.A discounting	Effective NV using NSW discounting[12]
BEAUFORT RIVER	$44.00	18.4	10.6
BORANUP	$15.70	84.1	41.2
BREMER BAY	$22.00	64.2	33.3
COOLJARLOO	$8.00	79.4	37.5
DALYUP	$13.50	69.8	33.1
DENMARK	$27.50	64.2	34.5
LAKE PRESTON	$18.50	41.1	20.2
LANCELIN (Aglime)	$11.55	80.4	28.3
LANCELIN (Rules)	$11.50	93.9	45.7
MANYPEAKS	$25.00	35.2	21.9
MASON BAY	$17.00	48.1	30.7
MYALUP (Carbone)	$16.50	51.7	26.7
MYALUP (Catalano)	$16.50	62.0	33.7
REDGATE	$18.45	61.7	27.4
ONFARM	$40.00	27.6	23.7

Table 21. Discount of NV depending on particle size of lime source

Particle size mm	**WA Discount**	Particle size mm	**Victoria Discount**	Particle size mm	**NSW Discount**
<0.5	0%	**<0.3**	0%	**<0.075**	0
0.5–1.0	50%	**0.3–0.85**	40%	**0.075–0.15**	42%
>1.0	80%	**>0.85**	90%	**0.15-0.25**	50%
				0.25-0.50	58%
				0.50-1.0	66%
				1.0-2.0	78%
				>2.0	88%

[12] Approximate values due to difference in range of particle sizes measured

APPENDIX 4

Assumptions for water use efficiency equations

Table 22.Water Use Efficiency (WUE) and evaporation (Source, DPIRD, 2009)

Typical combinations of WUE and evaporation.		
Situation	WUE (t/mm)	Evaporation (mm)
Normal season (decile 4, 5, 6) deep sandy duplex and loamy earth, warm finish.	15	110
Wet season (decile 7, 8, 9), deep duplex, loamy earth and deep well-structured clays, stored water from summer or very good spring rain.	20	110
Normal season (decile, 4, 5, 6, 7), duplex soils, cool finish with better rain in spring.	15	90
Dry season (decile 1,2), soil with low water holding capacity give up water easily, late emergence or very poor early growth, warm spring.	12	110
Dry season (decile 3), shallow soil or soil with low water holding capacity, late emergence or very poor early growth.	12	90