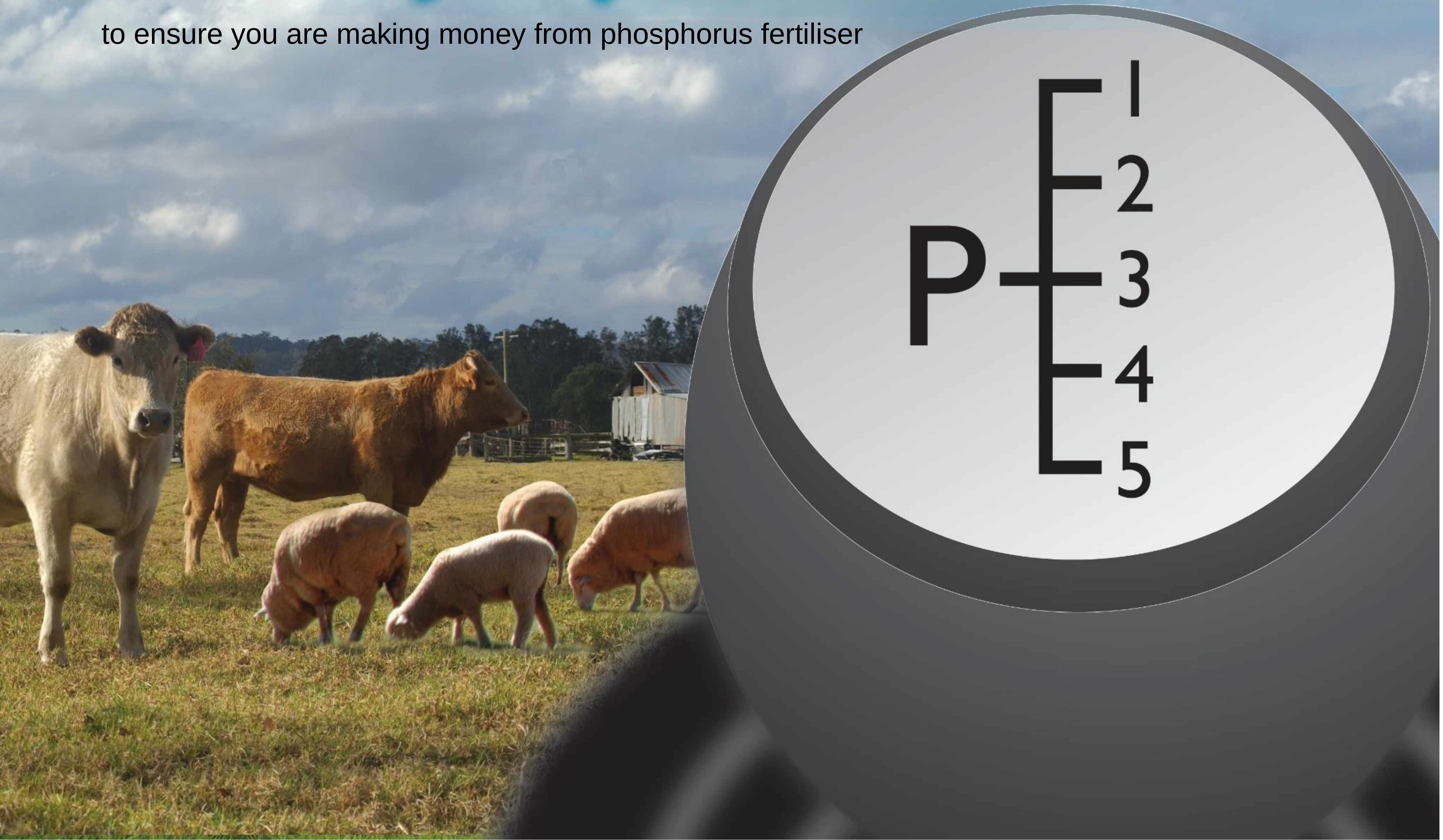
Five easy steps

to ensure you are making money from phosphorus fertiliser



Five Easy Steps

to ensure you are making money from phosphorus fertiliser

This booklet is relevant for the management of temperate legume-based pastures grazed by sheep and beef cattle on acid soils in southern Australia

Disclaimer

Acknowledgements

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P Tool – important information to read before using this booklet and tool

The value of soil testing and how to use soil test information

The 'Five Easy Steps' information package has brought several strands of information together into a format which allows producers and advisors to understand the value of soil testing and how to use soil test information to plan fertiliser and livestock investments.

Many development workshop participants found the information and concepts challenging, but their feedback indicated the information package has provided a better framework for understanding and planning the use of P-fertilisers.

The tool is intended to assist producers to determine suitable levels of P-fertilisation for temperate legume-based pastures grazed by sheep and beef cattle on acid soils in southern Australia. Ultimately, however, fertiliser decisions are made by the user (not the tool).

A support tool rather than a decision-making tool

The calculations of potential stocking rate and the P-inputs required to build and maintain soil fertility used in the tool are based on data from field trials. However, there are a number of reasons why the tool should only be used to support your thinking and fertiliser decisions, rather than as decision-making tool.

For example: Correct input data is essential. It is easy to get animal or soil 'loss factors' slightly wrong when classifying the attributes of a paddock or landscape. Confidence intervals around estimates of the amounts of P required to lift soil fertility by one Olsen or Colwell unit are reasonably broad. The calculations are for average seasons and could be either high or low, depending on prevailing seasonal plant growth conditions.

Typical seasonal and yearly fluctuations in soil test results can often mean initial assumptions about soil fertility maybe based on "ballpark" estimates.

Potential carrying capacity estimates are difficult to make at the best of times and are influenced by pasture species, management decisions, etc. - not just growing season length.

Location-specific issues

The calculations on which the tool relies have had limited road testing. Not every soil situation has been rigorously addressed. They should be applicable in most areas of southern Australia. However, there is always the potential for location-specific issues which have not been captured in the underpinning research.

For these and other reasons, it is usually best to develop a soil fertility management schedule which is followed over a number of years and monitored with annual soil testing. Ideally the tool should be used in consultation with your fertiliser advisor, ensuring any local issues are considered.

The booklet is a compilation of research results and knowledge generated by many people in departments of agriculture, CSIRO and universities across Australia. Some unpublished data, data from the public record and other advisory information is used with permission as acknowledged. Fiona Leech, Adam Stefanski, Matthew Lieschke, Stuart Burge, Nigel Phillips, Jim Virgona, Jim Shovelton, Karel Mokany, Meredith Mitchell, Cameron Gourley and David Weaver are gratefully acknowledged for their feedback and suggestions. Work with farmer members of the Bookham Agricultural Bureau and Monaro Farming Systems was instrumental in the development and testing of many concepts and practices outlined in the booklet and computer tool.

Contents

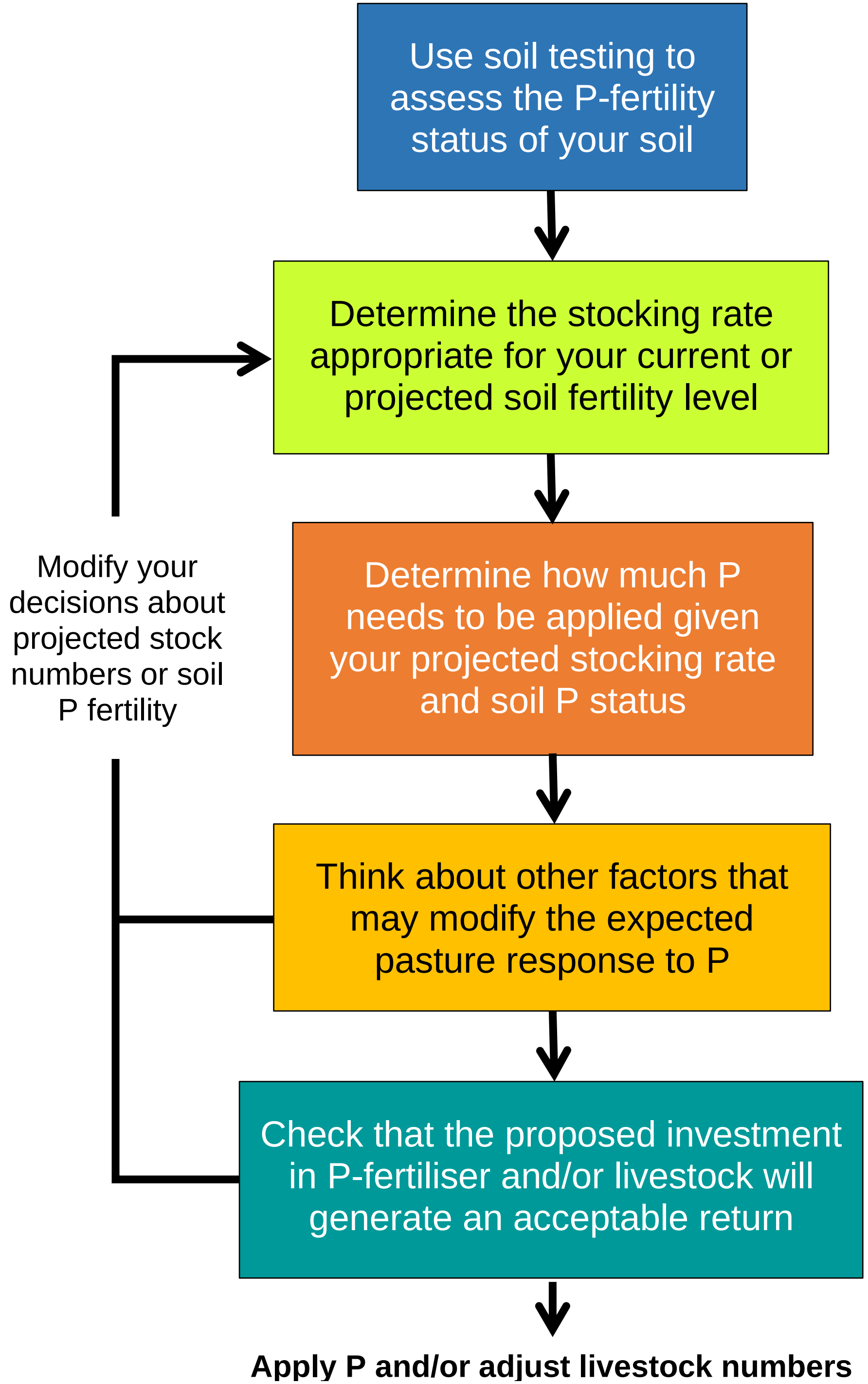
Why apply phosphorus fertiliser?
Phosphorus (P) is applied to Australian pastures because many soils have low P-availability for plant growth, and pasture growth is constrained by P “deficiency”. In a legume-based pasture, improving P availability boosts the legume content of the pasture and increases the amount of biological nitrogen fixation by the pasture system. Nitrogen is often the most limiting soil nutrient. Thus, P-fertiliser practise drives overall pasture productivity.

Ultimately, the objective of applying P is to lift or maintain stocking rate and, consequently, to improve profit per hectare.

This booklet and the accompanying computer tool are intended to assist producers in determining suitable soil P levels for the fertilising temperate legume-based pastures grazed by sheep and beef cattle on acid soils in southern Australia.

How to proceed
Each step is dealt with sequentially in this booklet. Work through the steps in turn, as illustrated in the diagram (on right).

Using the Five Easy Steps online tool
Once familiar with the ‘steps’ you will find it is beneficial and easier to use the online version of this P tool (https://www.mla.com.au//extension-training-and-tools/tools-calculators/phosphorus-tool). This tool has many useful features such as the ability to print reports for your records. Step 5 (checking the profitability of your fertiliser investment) is much easier to do using the P tool.



STEP
I

Step 1: Using soil tests to determine current soil fertility and the ‘critical’ soil test P requirement.

Soils always contain much more phosphorus (P) than is available to plants during the current growing season. Most of the P is in compounds which plants cannot use directly, is tightly bound to soil particles, or in compounds which are only sparingly-soluble. Various soil tests can be used to assess whether fertiliser additions will result in more pasture growth. All extract a small proportion of the total P in a soil. Ideally, they extract a P-fraction which consistently indicates how much P is available for plant growth.

Because different soil P tests differ in the extraction solution used or the method of extraction, the number generated by each test may differ substantially. It is, therefore, important to be familiar with the test you use and the “critical” test value above which no significant response to fertiliser application is likely.

This booklet deals only with interpretation of the Olsen extractable-P soil test (Olsen *et al.* 1954) and the Colwell extractable-P test (Colwell 1963) because they are the most widely-used P tests in southern Australia.

Both tests are applicable to acid soils but may not be suited to calcareous soils (e.g., Bertrand *et al.* 2003). The Colwell P test is an adaptation of the Olsen P test intended to improve soil test reliability (Colwell 1963). However, the changes made to the test methods mean that interpretation of the Colwell P test is soil-specific. Colwell P test results vary with the P buffering capacity of the soil (Helyar and Spencer 1977) and are interpreted with this in mind.

Figure 1 shows the relationship between pasture yield and Olsen P over a wide range of Australian soils. These data are interpreted to indicate pasture will respond to fertiliser P application, if the Olsen P soil test value is less than 15 mg Olsen P/kg soil, irrespective of soil type. Above this Olsen P value, pasture yield will not be increased markedly.

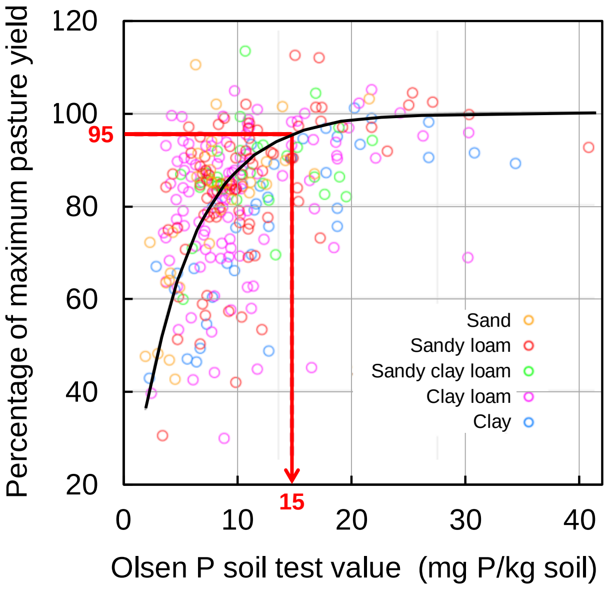


Figure 1: The relationship between percentage of maximum pasture yield and the Olsen P concentration of topsoil (0-10 cm) derived from experiments collated nationally by Gourley *et al.* (2007; 2019). The critical Olsen P soil test value at 95% of maximum pasture production is 15 mg P/kg soil (all soil types).

In contrast, interpretation of the Colwell P test is a two-step procedure because the critical P value of a soil varies with its Phosphorus Buffering Index (PBI) value (Figure 2).

PBI is a measure of a soil’s ability to readily sorb (bind) P from soil solution (Burkitt *et al.* 2002; Burkitt *et al.* 2008).

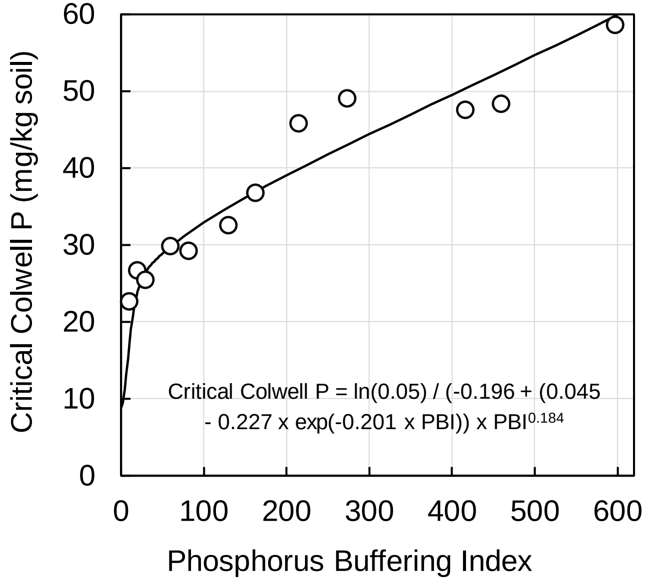


Figure 2: The relationship between the critical Colwell P concentration and the PBI values of topsoil (0-10 cm) derived originally from experiments collated nationally by Gourley *et al.* (2007; 2019).

The original relationship was updated by Gourley *et al.* (2019) and is shown here in a modified form that reflects the national dataset. The updated relationship recognises lower critical Colwell P concentrations in very-low, low and moderately-low PBI soils (e.g. PBI less than ~35) as proposed by Moody (2007) and Yeates (1993).

The critical Colwell P value is the soil test value which is expected to support 95% of maximum pasture yield.

Figure 3a shows the growth response of sub-clover-based pasture in relation to the Colwell P concentration of topsoil at Bookham, NSW. The soil had a PBI = 80. The graph also illustrates how the 'critical' Colwell P requirement of the pasture is determined. The critical soil test P (STP) concentration is the level at which 95% of maximum growth is expected.

When you do not have access to a local fertiliser experiment, the critical Colwell P for a clover-based pasture can be predicted from the PBI of the soil using the relationship shown in Figures. 2 and 3b. On this basis, the critical Colwell P for this pasture is expected to be about 31 mg P/kg. This aligns reasonably well with the critical Colwell value measured in the experiment at the site (Fig. 3a).

This means pasture yield is expected to be improved by applying P if the Colwell soil test is less than 31 mg P/kg, but there will be little extra pasture grown if the Colwell P soil test value is greater than the critical P value.

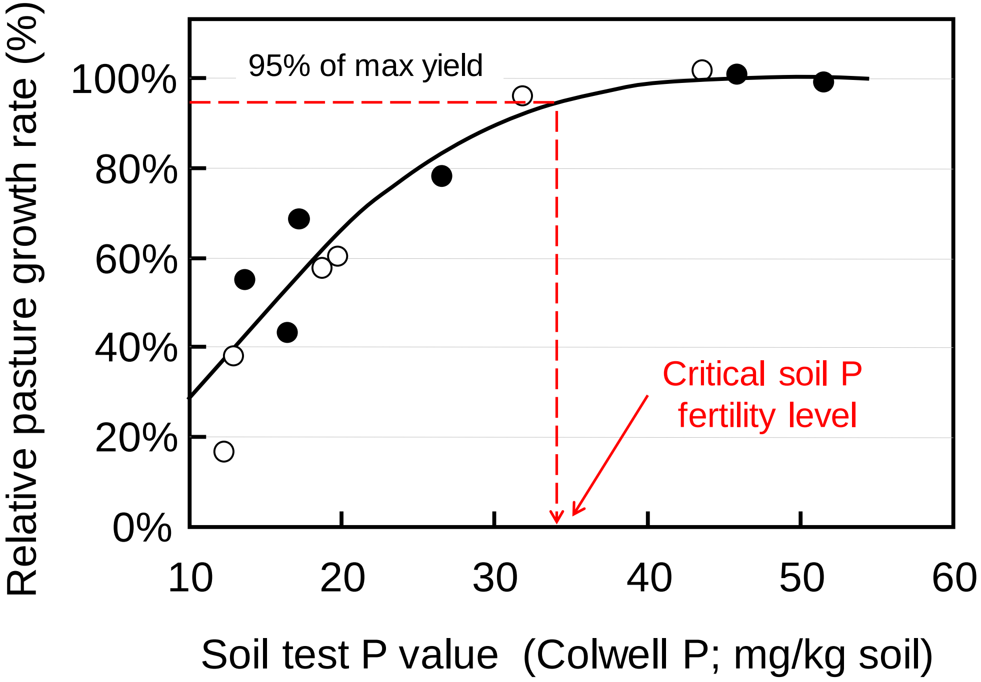


Figure 3a: Response to soil P fertility during spring of subterranean clover-rich pasture (clover = 60% of pasture dry matter) in two separate years (○ 2002; ● 2003) at Bookham, NSW. PBI for this soil = 80. The critical soil test P concentration that supports 95% of maximum growth rate is indicated by the arrow.

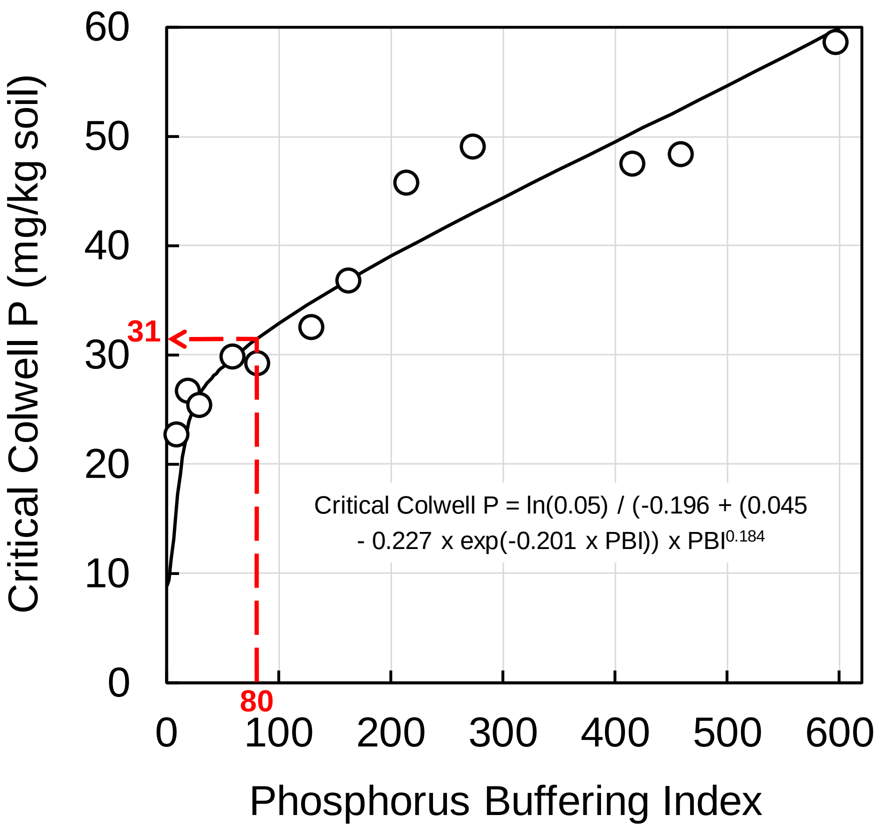


Figure 3b: Prediction of the critical Colwell P requirement of clover-based pasture from the PBI of the soil. **NB: The national dataset (Gourley *et al*. (2019) does not contain many experiments on soils with PBI >600. Attempts to predict critical Colwell P values for soils with PBI >600 will not be well-supported by data.**

The clovers and medics used in the legume-based pastures of southern Australia have higher critical P requirements than the grasses with which they are grown (Ozanne *et al*. 1969; 1976; Helyar and Anderson 1970; Sandral *et al*. 2019). In addition, nitrogen (N) fixation by the legume solely, or predominantly provides the N inputs that drive the overall productivity of the grazing system. These circumstances mean the critical soil test P (STP) requirement of the legume essentially determines the long-term critical P requirement of the pasture system. Pastures which are fertilised with mineral N fertilisers and do not rely on legume N-fixation will, consequently, have lower critical STP requirements but there is insufficient data to describe lower critical P requirements for N-fertilised, grassy pastures.

P-efficient legume options

Recent benchmarking of the critical STP requirements of a range of the temperate pasture legumes now available in southern Australia, confirmed many legume-grass pastures should be fertilised using the current STP guidelines (e.g., Figs. 1 and 2) because they did not have a critical P requirement which differed consistently from that of sub-clover (Fig. 4). However, a few forage species (crimson, purple and arrowleaf clover) and two pasture species (yellow serradella and French [*aka* pink] serradella) had lower critical STP requirements (Fig. 4; Sandral *et al*. 2019).

Average critical STP concentrations for the low critical-P legumes when grown in soils with a PBI range from 40-80 was:

- 20–21 mg Colwell P/kg soil (8 mg Olsen P/kg), for **serradellas, purple clover and arrowleaf clover**
- 25 mg Colwell P/kg (10 mg Olsen P/kg), for **crimson clover**.

(NB: There is no data which indicates what the critical Colwell P values are for these legumes when gown in soils that have PBI outside of this range.)

Lucerne

This series of experiments (Sandral *et al*. 2019) and one other report (Helyar and Anderson 1970) indicate **lucerne** (*Medicago sativa*) has a substantially higher P requirement than sub-clover. It may have a critical STP requirement ~1.5-fold or more, larger than that of the clover. However, there is insufficient data to prescribe a critical STP requirement for lucerne.

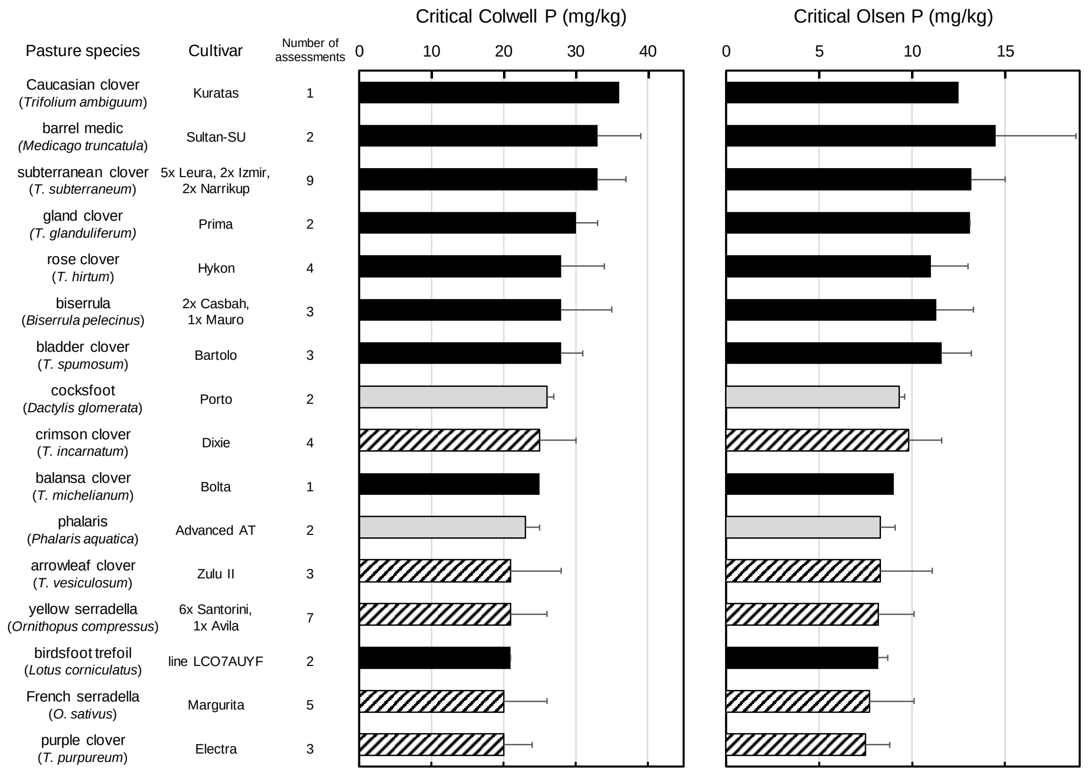
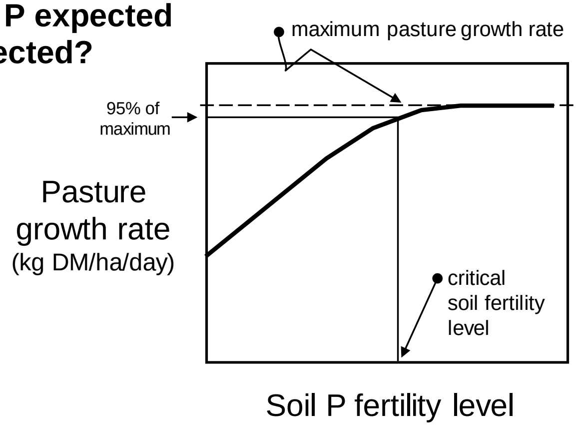


Figure 4: Average critical Colwell and Olsen soil test P (STP) values for 14 pasture legumes (solid black and hatched black bars) and 2 grasses (grey bars) from assessments made over three years and four field sites (soil PBI range: 40-80). Critical STP values support 95% of maximum yield in spring. Lucerne was also included in these experiments, but its critical P requirement could not be determined reliably because it often exceeded the STP levels in the highest P treatments. Error bars represent 1x standard deviation and are shown as a measure of the repeatability of the critical P determinations. Hatching indicates species had been grown on three or more occasions and were considered to have a significant (*P*=0.05) and consistently lower critical STP requirement than sub-clover. Different cultivars of some species were grown in the experiments but no significant differences in critical STP among cultivars of a legume species were observed. Data are derived from Sandral *et al*. (2019).

Further information

When is a response to P expected and when is it not expected?



Pasture grows relatively slowly when a soil is P-deficient. The growth rate is governed by the soil's ability to supply P to the pasture plants. Slow pasture growth means water-use efficiency (pasture grown per mm rainfall) will be relatively poor and productivity per hectare of land will be low. When P is applied, plant growth rate increases, more pasture is grown, and more animals can be sustained per hectare. With fertiliser additions that lift soil P fertility, a point will be reached where the soil can supply enough P for maximum pasture growth rates to be achieved. This is known as the "critical" soil fertility level. Increasing soil P fertility above this point does not result in a significant increase in yield. In southern Australia, the critical P level is defined as the STP concentration of topsoil (0-10 cm depth) that can support 95% of maximum yield in spring (Gourley et al. 2019). Producers sometimes observe their pastures are no longer responding to P. There are various reasons why this might occur.

A good reason is soil fertility has been built to the point where maximum pasture yield is being achieved and no further pasture response can be expected. It is then usually possible to shift down to a lower fertiliser application rate that is sufficient to maintain high pasture production without excessive fertiliser use.

However, a common reason for a poor response to P fertiliser is the existence of another nutrient deficiency. The most deficient nutrient in the soil defines the pasture growth rate. So, if another nutrient is "more" deficient than P, it will constrain the response to P-fertiliser. The "other" nutrients likely to cause such a problem for legume-based pastures in southern Australia are sulfur, potassium, and some micronutrients. The prevalence of these nutrient problems depends on your soil type and paddock history (see Step 4: *Other things that may constrain your pasture response to P fertiliser*).

What is the Phosphorus Buffering Index test?

The Phosphorus Buffering Index (PBI) test is a one-step soil test which has been adopted as the national standard method for measuring the P-buffering capacity of soil. When water-soluble P is applied to soil a large proportion becomes adsorbed to clay minerals; this determines the partitioning of P between the solid and solution phases of the soil. As plants take up phosphate from the soil solution, the adsorbed P is released to replenish the soil solution. Consequently, this characteristic of the soil influences the availability of P to plants and is helpful for interpreting some soil tests for plant-available P. In particular, it allows prediction of the critical Colwell extractable-P value of a soil.

PBI is determined after measuring the amount of P that adsorbs to 4 g of soil shaken gently for 17 hours at 25°C in 40 mls of 0.01M $CaCl_2$ solution which contains 4 mg of P in the form of KH_2PO_4 (Burkitt *et al.* 2002; Burkitt *et al.* 2008).

What are the Olsen P and Colwell P tests?

Colwell P and Olsen P soil tests both extract phosphate from soil using a bicarbonate solution (0.5 M NaHCO3; pH 8.5), but they differ in the time of extraction (Olsen: 30 min vs Colwell: 16h), and in the ratio of soil to extraction solution (Olsen: 2g soil/40 mls solution vs Colwell 0.5g soil/50 mls solution) (Rayment and Lyons 2011). Both are reported as mg (extractable-P) per kg of dry soil. For any particular soil, the amount of phosphate extracted by each test differs, and the critical soil P value also differs for each test. It is necessary to use the PBI test result for your soil to predict its critical Colwell P value (see Fig. 2).

Which extractable-P test should I be using?

There are many soil tests for extractable P. All of them aim to be "dip-stick" type measures of the P that is available for plant growth. As such they can be used to predict the likely response of pasture to P fertiliser. However, soil P tests can only be interpreted if you know the critical extractable-P value for the soil test you are using and for your particular soil (i.e., the value above which further responses to fertiliser P are unlikely). Some tests are not as reliable as others. Some extract particular forms of P better than other forms and may give differing results with different P fertilisers. Some soil tests vary with the soil being tested and this requires specific calibration for correct interpretation.

Most importantly, different soil tests return different STP values and this is why you must know the critical STP value of the test you are using. If you are already using a particular soil test, it may not be a good idea to shift to a different test unless you have good evidence that it is a better measure of plant-available P. You must also know the critical STP value for your soil with the new test.

Fertilising native grass pastures

Pastures containing native perennial grasses are often used in landscapes where the native grass(es) are the best-adapted species, on inaccessible or non-arable sites, or where it is not considered economic to introduce sown perennial grasses. Although they often occur on low P soils, it is not correct to assume that they will not respond to P fertiliser, or that they will be unproductive and a poor fertiliser investment option. Mitchell *et a*l. (2019) have reviewed experiment and demonstration trial data covering management of native grass pastures in south-eastern Australia. They concluded most pastures based on native grasses will respond to P fertiliser, leading to increased pasture and animal production. Native grass pastures have often been invaded by or may have been oversown with sub-clover. With a few qualifications, the principles for fertilising and managing these pastures are similar to those for sown pastures.

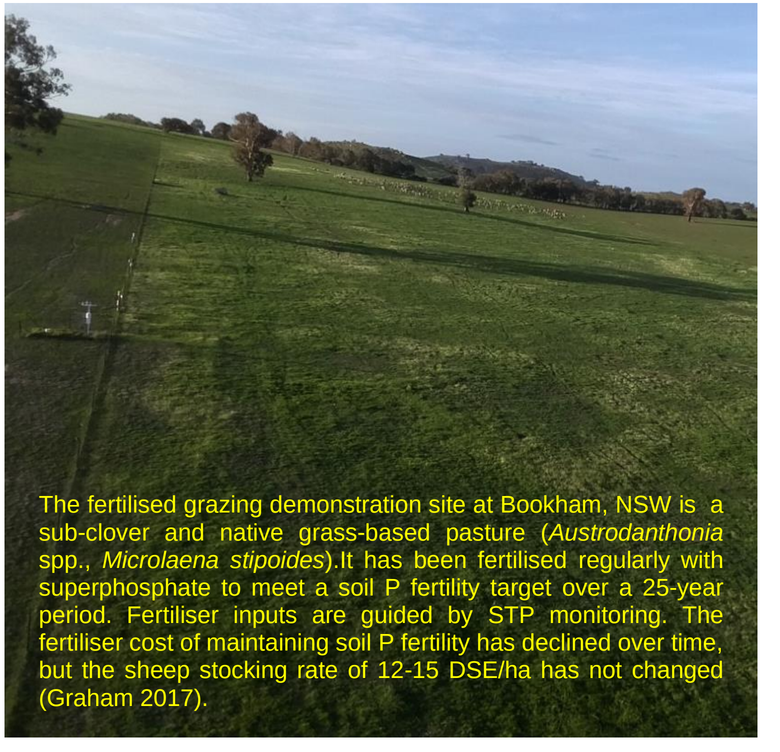
Important points of difference are: some native grasses are more "tolerant" of improved soil fertility and higher grazing pressures than others, and grazing management to support persistence of the native grass component of the pasture is likely to be required.

General recommendations (Mitchell *et al*. 2019)

1. Identify the native grasses and invasive annual species in your pasture; choose a P fertiliser strategy that is appropriate for the native grass species (see: *Targets for soil P management*, next page).
2. Use rotational grazing (*a common recommendation for promoting the persistence of perennial species*).
3. Aim for minimum herbage mass (800 kg DM/ha) and groundcover (80%).
4. In spring, apply extra grazing pressure to ensure sub-clover does not smother native grasses.
5. Reduce grazing pressure in summer to allow seed set.
6. In late summer, retain enough plant litter to minimise bare ground.

These recommendations, in the most part, are similar to those recommended for a sown (introduced) perennial grass pasture and are essentially focussed on protecting groundcover and perennial plants in a productive grazing system.

A unique aspect of the recommendations is the importance of using grazing during spring to ensure the native grass species are not displaced by competition from other fertility-responsive grasses and legumes. Grazing management is focused on protecting the perennial native grass component of the pasture. This contrasts with management of pastures based on introduced perennial grasses (e.g., phalaris etc.) where grazing management also focuses on maintenance of desirable levels of clover.



The fertilised grazing demonstration site at Bookham, NSW is a sub-clover and native grass-based pasture (*Austrodanthonia* spp., *Microlaena stipoides*).It has been fertilised regularly with superphosphate to meet a soil P fertility target over a 25-year period. Fertiliser inputs are guided by STP monitoring. The fertiliser cost of maintaining soil P fertility has declined over time, but the sheep stocking rate of 12-15 DSE/ha has not changed (Graham 2017).

Targets for soil P management of native grass-based pastures

Survey data and long-term paired-paddock trials indicate the productivity and persistence of native pastures can be increased with P fertiliser use. However, target STP concentrations depend on the dominant native grass species. Soil fertility-tolerant grasses will respond and be competitive against other sward components when the pasture is fertilised to the higher fertility level, whereas the fertility-intolerant, slow-growing species will be outcompeted by responsive species and can, therefore, tolerate only a much lower level of soil P fertility.

Pastures comprising the 'fertility-tolerant' native grasses

Olsen P target *: 10-13 mg/kg soil

e.g., *Microlaena stipoides (weeping grass)*, *Bothriochloa macra* (red grass) and some *Rytidosperma* spp. (wallaby grasses**: *R. caespitosum*, *R. fulvum*, *R. richardsonii*, *R. duttonianum* and *R. racemosum*)

Pastures that are based on the "fertility-intolerant" native grasses

Olsen P target *: <6 mg/kg

e.g., *Themeda triandra* (kangaroo grass); *R. carphoides*, *R. auriculatum* and *R. erianthum* (other wallaby grasses **).

Important footnotes:

* Colwell P targets were not provided by Mitchell *et al*. (2019). Because Olsen P and Colwell P results for any particular soil are highly correlated, it is reasonable to expect that an equivalent Colwell P target for your soil can be estimated by reference to the critical Olsen P concentration for clover-based pastures (i.e., 15 mg/kg): 10/15 = 0.66 and 13/15 = 0.87. Therefore, the likely target Colwell P value for a fertility-tolerant native grass pasture will be 66-87% of the critical Colwell P which applies to your soil. The critical Colwell P is estimated using the PBI value for your soil and the relationship in Figure 3. By this reasoning, the target Colwell P for fertility-intolerant native grass pasture will be about a third of the critical Colwell P for clover-based pasture.

NB: The targets recommended by Mitchell *et al*. (2019) are based on experience in experiments. They are very close to the critical values determined in other experiments using clover-based pastures and may not really differ significantly from the rates recommended for sown clover-based pastures. However, it is important to recognise application of P fertiliser may have a destabilising effect on the composition of a native pasture. If the growth of annual legumes and grasses is stimulated by P application without sufficient additional grazing pressure in spring, annuals may outcompete the native perennial grasses.

Consequently, it is recommended soil fertility improvements be made gradually. Proactively assess whether you are satisfied with the changes in your pasture. Best practice is to know your starting soil P fertility, set an appropriate target for soil P management, and work towards it over a number of years. Plan to increase livestock numbers as feed supply increases so plant competition can be managed adequately. This approach, using a target soil P fertility level with soil P monitoring and stocking rate adjustments, has been used successfully in the Bookham Grazing Demonstration on a wallaby grass (mainly *R. duttonianum)*, weeping grass (*M. stipoides*) and sub-clover pasture over a 25-year period (e.g., Fig. 13c; Graham 2017).

** Although the wallaby grass group of species is easily recognised as wallaby grass, it is difficult to identify the various species of wallaby grass because they have similar leaf and flower characteristics. This is obviously problematic when trying to manage species which may differ in their responses to soil fertility improvement. It is possible that applying P fertiliser to a pasture containing more than one wallaby grass species, may cause a shift in botanical composition towards the more responsive species.

STEP I

How to take soil samples

It is important to collect soil samples correctly to ensure a meaningful test result.
A detailed set of guidelines is found in: Gourley and Weaver (2019) *A guide for fit for purpose soil sampling*. Fertilizer Australia, Canberra, Australia.
https://www.hort360.com.au/wordpress/wp-content/uploads/2019/11/Fertcare-Soil-Sampling-Guide.pdf

(1) Sampling strategy – The strategies used for sampling soil fertility at a farm scale vary widely. Because soil types and soil fertility can be very different among paddocks on a farm (Figure 5), it is best to sample paddocks individually. The deviations in STP between paddocks on individual farms can be large and this information can help you to redirect fertiliser to areas where it is most needed. However, if you are just getting started and are concerned about the costs of sampling AND you are confident that you can group paddocks with similar land class, soil type and management histories, it is also possible to establish monitor areas or transects which represent each of the major classes of land (land management units) across the farm (Figure 6). Either way, the objective is to adequately represent the differing areas of the farm which are to be fertilised whilst ensuring a reasonable soil testing load and expense.

(2) Take representative samples – Using a soil corer (below left), sample in your monitor area or along a transect in a systematic way, noting the sampling interval and pattern used. To ensure samples reflect the paddock as a whole, avoid stock camps, fence lines, water troughs, fertiliser dumps, burnt timber rows, wet gullies, gateways, tracks or dung patches and sample from different soil types separately. If sampling a paddock where there are obvious clumps of more vigorous pasture associated with animal excreta, sample the soil between the clumpy material.

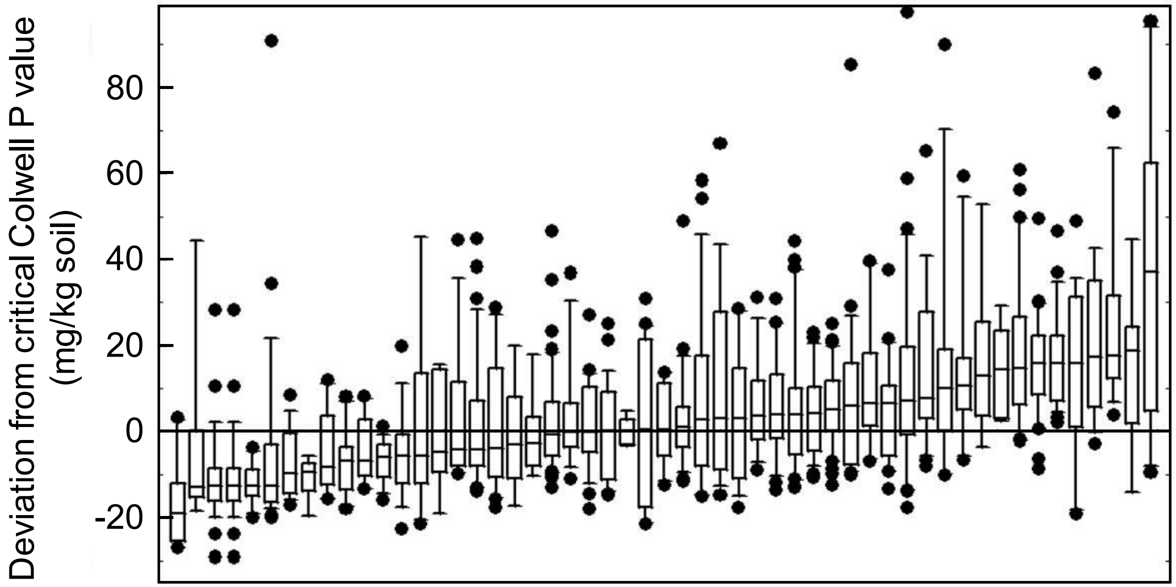


Figure 5: Box plots show how widely the soil test P (STP) values for individual paddocks on farms can deviate from the critical Colwell P concentration. The graph shows results for 53 farms on the NSW southern and central tablelands which were sampled (0-10 cm depth) in spring 2016. Positive values indicate soil P fertility in the supraoptimal range; negative values indicate paddocks which were P-deficient. The box contains results from the middle 50% of paddocks, 80% of values occur inside the 'whiskers', and closed circles indicate fields with very high or very low STP concentrations. Bars show the median STP concentration. Redrawn from Simpson *et al*. (2017).

The results indicate many farms can optimise their use of P fertiliser by redirecting its use from paddocks where P fertility exceeds the critical P level to paddocks which are below the critical P level. Some farms can potentially take a 'P-holiday' (e.g., farms on right-hand side of graph), whilst others (left-hand side of graph) can potentially improve production by fertilising to achieve soil P levels closer to the critical P level.

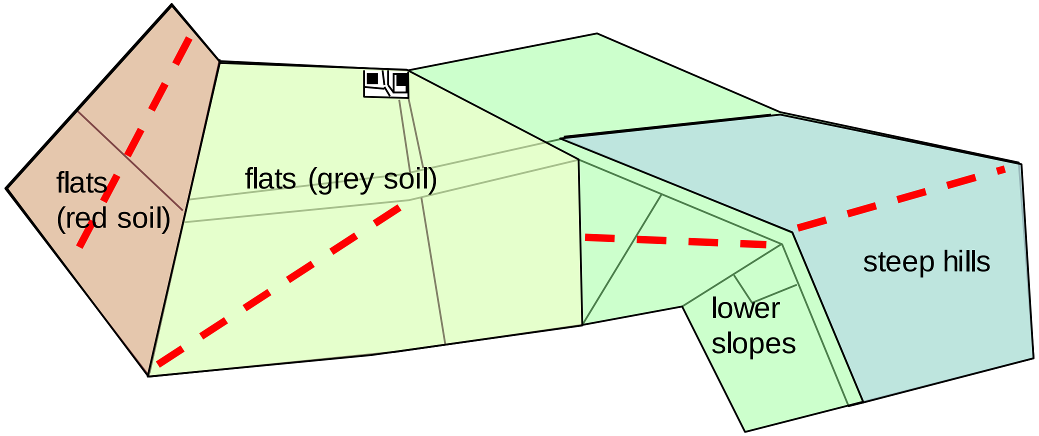


Figure 6: Hypothetical example of soil sample transects on monitor paddocks (areas) of a farm.
The aim is to establish transects (– –) which represent the major classes of land. Areas must have similar soil types, topography, and similar fertiliser histories for this to be a sensible option. Retest the monitor areas annually. Over time you will be able to make decisions based on the soil fertility trends that the data will reveal.

STEP I

(3) Mark the site – Keep a record of the monitor area or transect and your sampling pattern so can be repeated when testing in the future. You may do this by noting where you started and finished and the route taken, by taking a series of GPS readings, etc.

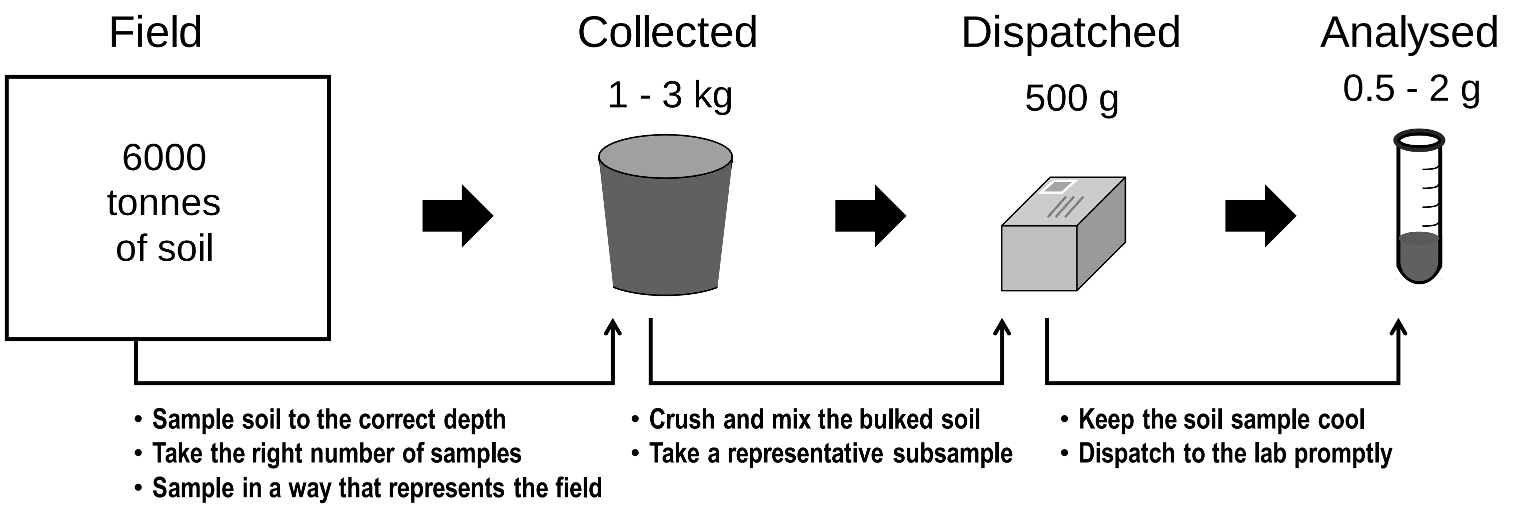
(4) Sampling depth – Extractable P is measured in topsoil samples using a soil sample depth of 10cm. P is typically more concentrated in the top few centimetres of soil so it is important to obtain the full volume of soil to 10 cm depth to avoid biasing the concentration of P in the soil sample.

(5) Sample number and handling – Take a minimum of 30-50 soil cores (19 mm diameter cores or larger) along the transect or monitor area and combine to give a sample representative of the paddock. Taking fewer soil cores will reduce the accuracy of your test and will increase the likelihood of greater year-to-year variability in your soil test results. Send the sample to the test laboratory promptly. Use an ASPAC (Australasian Soil and Plant Analysis Council) accredited laboratory.

Figure 7: Techniques to minimise soil sampling error.

Remember the sample you dispatch is probably only about 0.00001% of the field soil you are sampling.

Figure adapted from Gourley and Weaver (2019).



(6) Timing – Always sample at the same time every year to minimise variability in soil test results due to environmental effects (this is discussed in more detail later). It is potentially feasible to take annual samples at any time of the year, but soil samples for pasture production are most commonly taken in late spring. At this time soil is usually moist, but not wet, allowing soil cores to be taken quickly and easily. Moist soil holds together in soil coring tools and this helps to ensure the sample is the full 10 cm depth. Never sample within the first few months after fertiliser application.

Step 2: What stocking rate?

The main reasons for applying P to pasture are to either increase, or to maintain stocking rate. Applying P without having extra stock to use the extra pasture grown may not be profitable. The extra stock that are needed may cost more than the fertiliser itself.

Predicting how many livestock may be carried as soil fertility is lifted is often the most difficult task. Potential carrying capacity of a well-fertilised, temperate pasture is determined by the local climate, pasture type and soil conditions (particularly the water-holding capacity of the root zone). However, a dominant influence is the length of growing season.

Figure 8 shows relationships between potential carrying capacity (dry sheep equivalents (DSE)/ha) and estimated average length of growing season from grazing trials run in south-eastern Australia (Saul and Kearney 2002). Upper and lower boundaries for potential carrying capacity were determined because smaller paddocks tended to carry more stock (most likely due to uneven pasture utilisation in larger paddocks).

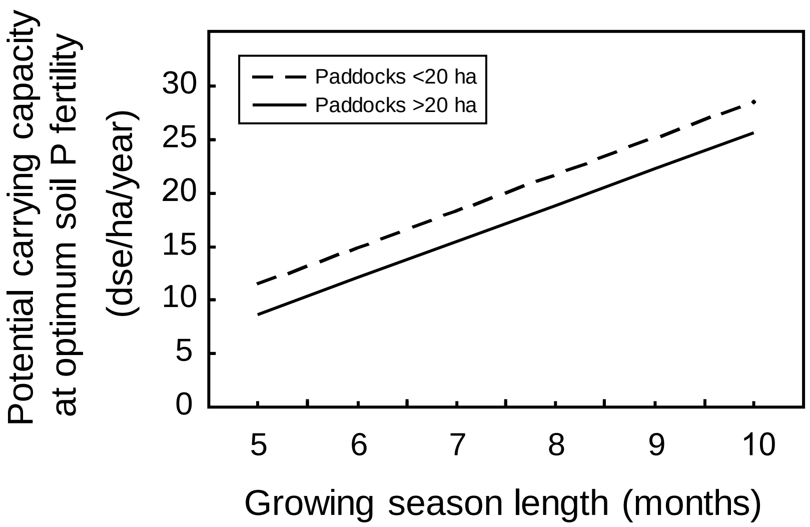


Figure 8: The relationship between potential carrying capacity of paddocks optimally fertilised with P (Olsen P = 15 mg/kg) and growing season length (from Saul and Kearney 2002). Variation in growing season length alone was found to explain about 67% of the variation in carrying capacity of well-fertilised paddocks from various locations across south-eastern Australia.

How to use this information:

We will use the results of a grazing demonstration trial at Bookham, NSW (Graham 2006; 2017) to illustrate how it is now possible to estimate the soil fertility level to give near maximum pasture production, and the potential carrying capacity of the site when operating at this level of soil fertility. The PBI of the soil at Bookham is 80. This indicates (using Fig. 2) the critical Colwell P soil test value is about 32 mg P/kg soil. We have already seen in Figure 3 that a pasture growth experiment at this site confirms this is correct. Average growing season length is estimated to be 7.5 months (opening rains about last week of April, pasture browning off first week of December). Figure 8 indicates 17-20 DSE/ha may potentially be carried. The paddocks in the demonstration trial were under 20 ha in size so the upper estimate (20 DSE/ha) should apply. Unfertilised pasture at this site had a Colwell P concentration of about 10 mg P/kg soil and carried 6 DSE/ha. These data provide upper and lower boundaries for soil fertility and stocking rate management and Figure 9 illustrates how to estimate the stock numbers which may be supported at intermediate levels of soil P fertility. The pasture growth response curve is taken from Figure 3a. In fact, the fertilised paddock in the demonstration trial carried 12-15 wethers/ha in good to average seasons with soil fertility maintained just below 20 mg Colwell P/kg soil.

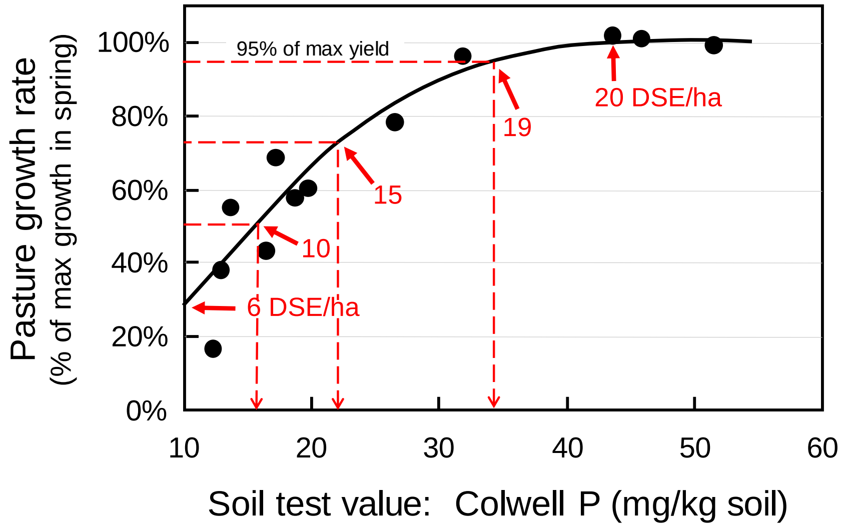


Figure 9: Pasture growth response to increasing soil P fertility at Bookham, NSW and the estimated stock carrying capacity of the pasture. Combining information about the critical soil P level for near-maximum (95%) pasture growth with potential carrying capacity sets an upper estimate for soil fertility and stocking rate (i.e., at ~95% of 20 DSE/ha). Knowledge of current soil fertility (10 mg P/kg soil) and stocking rate (6 DSE/ha) indicates the present position and together these pieces of information enable intermediate stocking rate and soil fertility positions to be estimated by assuming that equal increments in pasture growth rate will support equal increments in stocking rate.

What to do if you do not have access to local fertiliser trial information

Soil fertility and potential carrying capacity estimates can still be used in much the same way as in Figure 9 when you do not have access to pasture growth response information.

This is done by:
(1) determining the stocking rate that can be sustained at your current soil test P (STP) concentration,

(2) using the soil PBI to predict the critical STP concentration (Figure 2). Remember this corresponds with 95% of maximum pasture yield,

(3) estimating the carrying capacity of the paddock when fertilised for maximum pasture yield (e.g., by using growing season length and Figure 8),

(4) drawing a straight line from the current STP and stocking rate position to the predicted critical STP and carrying capacity position to represent the pasture response function (see Figure 10).

(5) The carrying capacity of the pasture at intermediate soil fertility levels is estimated by assuming stocking rate and pasture production are interchangeable on the left axis of the graph.

NB: Because pasture response relationships are often curvilinear (e.g., Figure 9), this exercise is likely to give a conservative estimate of the stock numbers which may be carried at each intermediate soil P fertility level (compare Colwell P levels predicted for each stocking rate from the actual pasture response function (Fig. 9) with those when the relationship between stocking rate and soil fertility is assumed to be linear (Fig. 10)).

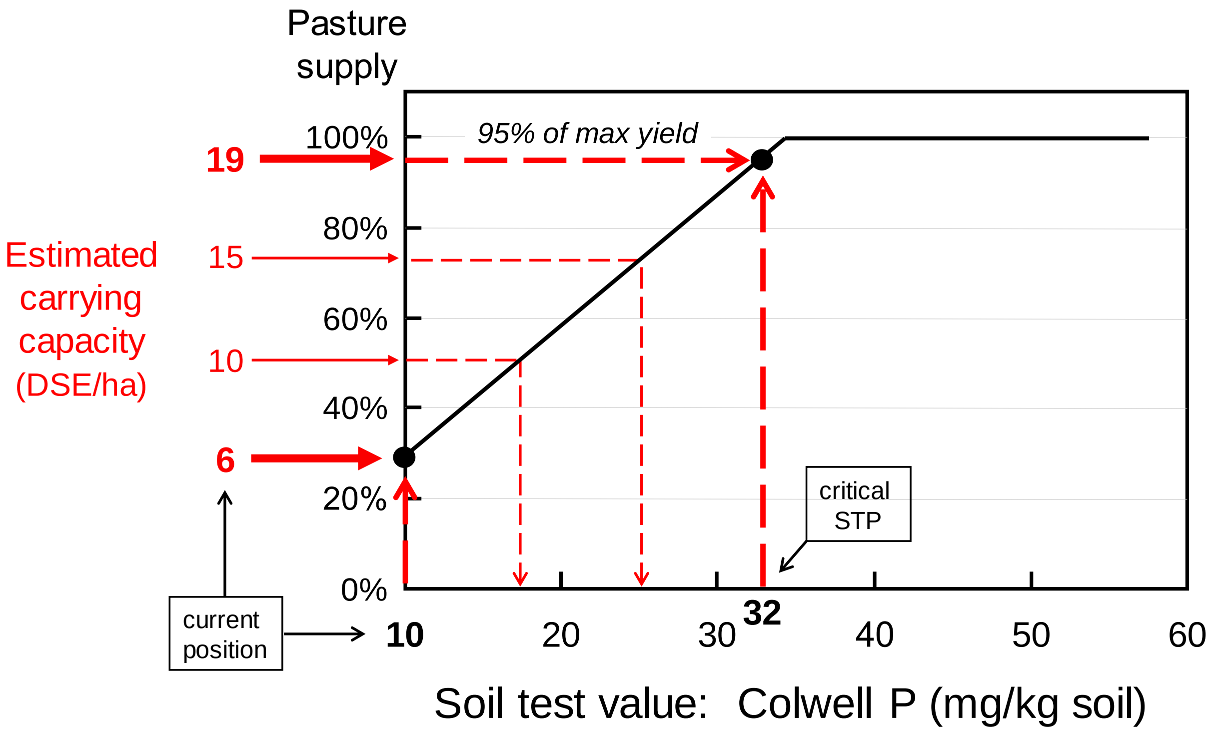


Figure 10: In many cases, the nature of the pasture-soil fertility response function for a site will not be known. However, it is still possible to estimate the critical soil P level and potential carrying capacity for the site. The current soil fertility and stocking rate can also be determined. This allows intermediate stocking rate and soil fertility positions to be estimated. Until better information is available, a linear increase in stocking rate with increase in soil P fertility level is assumed.

STEP 2

Further information

STEP 2

How robust are estimates of carrying capacity for adequately fertilised pastures?

Estimating the carrying capacity of paddocks is the most difficult and least defined step in the process of planning a fertiliser investment. It is important to understand the reliability and limitations of the estimates you make. Pitching too high will result in overstocked and degraded pastures and excessive supplementary feeding; too low will sacrifice income unnecessarily and may cause you to decide incorrectly against investing in fertiliser.

Other ways to estimate potential livestock carrying capacity

Estimates based on average length of growing season

The method adopted for use in this booklet is based on the relationship measured between stocking rates achieved on fertilised pastures and growing season length at a number of locations throughout south-eastern Australia (Saul and Kearney 2002). In that study, variance in growing season length explained about 67% of the variance in the stocking rate. The association between growing season length and stocking rate is high but it should be remembered that about a third of the variance was associated with other undefined factors. The sorts of things likely to influence potential carrying capacity for a given length of growing season are pasture species, joining dates and other management actions, prevailing climate, soil type, soil condition etc. Potential carrying capacity estimates based on growing season length should, therefore, be treated as a starting point which can be adjusted as better information about the sustainable carrying capacity of your paddocks becomes known.

Estimates based on average annual rainfall

There have been a number of attempts to relate potential stocking rate or pasture growth to either in-season or average annual rainfall. The most well-known being French (1987), who found a linear relationship between potential stocking rate and annual rainfall (range 350-650 mm/year) for sites in South Australia:

sheep/ha = 1.3*(mm of annual rainfall – 250)/25

It is likely this relationship holds for the environment in which it was formulated and in similar Mediterranean type climates (mild wet winters and springs followed by hot, dry summers), but the estimates may not be applicable in other regions. For example, Saul and Kearney (2002) found that annual rainfall explained only about 48% of the variance in stocking rate in their study of sites across south-eastern Australia. Growing season length was thought to be a better predictor of carrying capacity than annual rainfall presumably because factors such as soil water-holding capacity, pasture type, topography and rainfall distribution are accounted for indirectly in the estimate of growing season length.

Local experience

In many districts either departmental or producer-initiated stocking rate trials have been conducted. These can be used to compare or 'ground truth' other estimators. Critical factors to consider are the length of the trial, soil fertility management and the seasonal conditions that applied during the years that the trial was run. For example, a three-year trial may give misleading information if the seasonal conditions were unusual. Also, the enterprise type and the timing of reproduction need to be considered. If the time of lambing is radically different to your operation, this will have an impact on the number of ewes run and allowances for the differences will need to be made.

Paddock records on your own property can also give you a guide. Examine the performance of paddocks that have had a good history of fertiliser use; your records will enable you to compare the stocking rates achieved with potential stocking rate estimations made by the other methods. It is not uncommon for the carrying capacity of paddocks to vary by up to threefold across a property. The aim is to increase the number of paddocks able to carry higher stock numbers sustainably.

Computer-based simulation models

Computer-based models of grazing systems are used to estimate potential stocking rates for districts and production systems. Discussing your plans with an advisor using this technology may also help you test your ideas.

Step 3: Determining how much P to apply

Firstly, you must decide if your objective is to ***maintain*** the current level of soil P fertility by holding the paddock at about the same STP value, or to ***build*** soil P fertility to a higher STP value in the coming year(s).

To maintain soil P fertility

Enough P must be applied to cover export and loss of P from the paddock (see Figure 11 and Eqn 1).

- P is exported in animal products or when herbage (e.g., hay) is removed.
- P is lost when faeces are accumulated in animal camps, if P is moved in run off, water leaching to depth or by soil erosion, and when P accumulates in soil because it has become tightly bound to soil particles or is contained in organic matter that resists degradation (P accumulation in soil is sometimes referred to as P fixation).

Fertiliser P to maintain STP concentration = **P exported in animal products** + **P accumulated in the paddock** + **P losses (erosion, runoff, or leaching)**

……Eqn 1

To build soil P fertility

The amount of P needed to build soil P levels is the amount of P required for STP maintenance ***plus*** an extra amount of P to achieve an increase in the soil test value (Eqn 2).

Fertiliser P to increase STP concentration = **Fertiliser P to maintain STP** + **Additional P to increase the STP level**

……Eqn 2

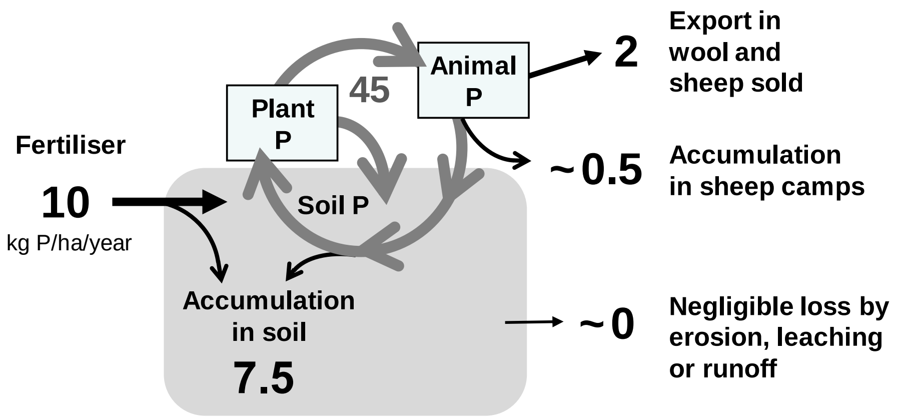


Figure 11: Average annual inputs, removals and accumulations of P in a pasture system grazed continuously by sheep near Canberra. Soil P fertility was maintained close to the critical soil test P (STP) concentration for near maximum production (Simpson *et al*. 2015b). It was estimated that about 45 kg P was cycling through the soil-plant-animal system each year and high productivity of the grazing system was only possible because of the natural cycling of P (Simpson *et al*. 2015a). The amount of fertiliser needed to maintain soil P fertility and production was less than a quarter of the P cycling in the grazing system. The maintenance rate of P fertiliser covered only the P removed in animal products and the P accumulated in soil and sheep camps. Losses by erosion, leaching and run off were negligible. Regular P fertiliser inputs were essential to maintain production; if fertiliser was with held the STP concentration of the soil, and pasture production, declined rapidly.

NB: The calculations of fertiliser amounts needed to maintain or build soil P fertility that are presented in this booklet apply to the use of P fertilisers which contain mainly soluble phosphate (e.g., superphosphate, etc.) and are most relevant for soils that are not subject to excessive P loss by leaching (e.g., not for very sandy soils with a very low PBI).

Any amount of P loss to the wider environment in run off or through leaching is undesirable.

When the PBI of your soil is <35 there is an increased risk P may be lost in run off and/or leaching. When this is the case, do not use this booklet alone to support your fertiliser decisions. Seek further local advice; check whether P from previous fertiliser applications has moved to depth in your soil profile; consider the merits of using a less soluble form of P fertiliser.

STEP 3

Calculating the amount of P required to *maintain* soil P fertility

A P-budgeting approach developed first for New Zealand pasture systems (Cornforth and Sinclair 1982) and adapted to Australian pastures (Cayley and Kearney 2000, Cayley and Quigley 2005) may be used. The budget recognises loss of P from the main grazing area of paddocks due to **soil** (P which is fixed, adsorbed, or leached) and **animals** (P transferred to camps and removed in products). Select the soil and animal loss factors appropriate to your paddock(s) from Table 1 and proceed to Table 2 to calculate the estimate of **kg P/DSE** required to maintain your current soil fertility level.

The amount of maintenance P to apply per hectare is calculated as: **kg P/ha = P/DSE x [average annual stocking rate (DSE/ha)]**

Table 1: Loss factors for sheep or beef cattle (for calculating maintenance P applications)

(a) Soil loss factors		
Recent alluvial soils, low rainfall loams		low
Podzols, clay-loams (rainfall less than 900 mm), rendzinas		medium
Acid sands, krasnozems and other clays, organic soils		high
(b) Animal loss factors		
Intensive rotational grazing	Flat and rolling country (mostly less than 10°)	Very low
	Easy hills (mostly less than 25°)	low
	Steep hills (one third of paddock >35°)	medium
Set stocked or intermittent grazing	Flat and rolling country	low
	Easy hills	medium
	Steep hills	high

Table 2: Predicted kg P/DSE (*for calculating maintenance P applications*)

Soil Loss factor	Animal Loss factor	Poor pasture Annual rainfall (mm)			Improved pasture (Annual rainfall mm)		
		400	600	800	400	600	800
low	very low	0.42	0.45	0.48	0.43	0.48	0.53
	low	0.54	0.58	0.62	0.55	0.62	0.68
	medium	0.65	0.70	0.75	0.67	0.75	0.83
	high	0.77	0.83	0.89	0.80	0.89	0.98
medium	very low	0.61	0.65	0.70	0.63	0.70	0.77
	low	0.72	0.78	0.84	0.75	0.83	0.92
	medium	0.84	0.91	0.97	0.87	0.97	1.07
	high	0.96	1.03	1.11	0.99	1.11	1.22
high	very low	0.80	0.86	0.92	0.82	0.92	1.01
	low	0.91	0.98	1.05	0.94	1.05	1.16
	medium	1.01	1.11	1.19	1.06	1.19	1.31
	high	1.15	1.24	1.32	1.18	1.32	1.46

Soil definitions:

Alluvial soils: derived from river activity, usually well drained, more fertile than soils derived *in situ* from underlying rock

Loam: both friable and cohesive; when moist can be rolled into a ball but cannot be rolled out into a ribbon. Sand grains cannot be felt.

Clay loam: like a loam but can be rolled into a ribbon that soon breaks up. Sand grains cannot be felt.

Clay: tough, plastic soil that can be rolled into a long ribbon when just dry enough not to be sticky.

Podzol: acidic sandy to clay loam topsoil with a change in texture (more clay) down the profile.

Rendzina: black to grey friable clay overlying soft limestone; neutral to alkaline reaction and a uniform profile.

Krasnozem: dark red-brown clay with very friable and stable crumb structure. The subsoil is a red clay, friable and very porous.

Organic soils: reclaimed swamps with mixed inorganic (clay) and organic materials.

Acid sands: sands are not cohesive and are coarse to touch, often high in organic matter with no change in texture to depth.

Other definitions and qualifications:

1 DSE is equivalent to a 50 kg wether.

Poor pasture is defined as pasture dominated by weedy species or native grasses as they are expected to have a lower yield and a lower carrying capacity than *improved pasture*.

The effectiveness of rainfall will be less in soils with poor water-holding capacity. Cayley and Saul (2001) recommended considering using 100-200 mm less rainfall than average rainfall for shallow, sandy, stony, or badly structured soils.

This maintenance P calculation (Tables 2 and 3) is reproduced from Cayley and Quigley (2005) ‘Phosphorus for sheep and beef pastures’.

Calculating the amount of P needed to *build* soil P fertility

If you are planning to increase the soil P fertility of your paddock, you will need to apply the amount of P required for 'maintenance' plus an additional amount to achieve the planned increase in STP concentration. A guide to the amounts of P per hectare needed to increase the Olsen or Colwell soil tests by one unit is provided in Table 3.

The amounts of P required are influenced by the PBI value of the soil (Table 3). For example, if the soil has a PBI=80 and the aim is to raise the Colwell STP concentration by 2 mg P/kg soil over one year, it would be necessary to apply the amount needed for maintenance plus an extra: 2 x 2.7 = 5.4 kg P/ha.

It is usual to build soil P fertility incrementally (over a number of years). Because of this, the calculation of P inputs is a dynamic process. Each year the STP concentration will increase allowing increase in stock numbers; this in turn means the maintenance P requirement will also increase annually. The worked example (see following page) shows how a dynamic calculation is done. The online computer tool that accompanies this booklet (https://www.mla.com.au//extension-training-and-tools/tools-calculators/phosphorus-tool) uses a similar procedure to calculate the P inputs needed for building soil P fertility.

Table 3. Estimates of the amounts of P per hectare (kg P/ha) which needs to be applied in excess of the maintenance P application to raise soil test values by one unit (mg P/kg soil) over the coming year.

Note: There are wide confidence intervals associated with these estimates. A 95% confidence interval means there is a 95% probability the correct rate of P application will occur within the specified range of values.

These data are derived from Burkitt *et al.* (2001); Burkitt *et al.* (2002).

PBI value of topsoil (0-10 cm depth)	50	100	200	300	400	500	600
Approximate amount of extra P* (in kg P/ha) needed to raise an Olsen soil test by about 1 unit (mg P/kg soil). (95% confidence interval)	8.6 (6.8-10.4)	9.0 (7.3-10.7)	9.8 (8.3-11.3)	10.6 (9.2-12.0)	11.5 (10.1-12.9)	12.3 (10.7-13.9)	13.1 (11.3-14.9)
Approximate amount of extra P* (in kg P/ha) needed to raise a Colwell soil test by about 1 unit (mg P/kg soil). (95% confidence interval)	2.7 (2.5-2.9)	2.7 (2.5-2.9)	2.9 (2.7-3.0)	3.0 (2.8-3.1)	3.1 (2.9-3.3)	3.2 (3.0-3.4)	3.4 (3.2-3.6)

An important note about how to use these calculations

The calculations of *maintenance* and *build-up* rates for P-fertiliser applications are based on data from published field experiments and can be used to estimate P application rates when you have no better information. However, the calculations should always be regarded as 'ball-park' estimates because they may not precisely reflect your soil or soil conditions. We know STP responses to P application can vary considerably among different soils even when the PBI value is the same (note the wide confidence intervals for P application rates specified in Table 3).

In many instances (e.g., worked example in this booklet), the calculations have proven to be reasonably accurate. In other instances, however, it has been necessary to amend the calculated fertiliser rate to achieve the planned soil fertility outcome.

Always follow your fertiliser planning with a STP monitoring regime (more details later in this booklet) as this will allow you to check if your fertiliser rate is appropriate. The results from monitoring STP can also be used to fine tune your fertiliser rate.

Worked example

Background information

Location: "Kia-Ora", Bookham, NSW: Grazing System Demonstration Site.

Pasture: 40% native perennial grasses, 60% annual grasses and sub- clover (Hill *et al.* 2004)

Soil: yellow kurosol (Isbell 1996) or yellow podzolic (Stace *et al.* 1968); soil derived from granite

Colwell extractable P before fertiliser application: 10 mg P/kg soil (*see Fig. 9*)

Stocking rate when Colwell P is 10 mg P/kg soil: 6 DSE/ha (6 Merino wethers/ha)

PBI: 80.
→ therefore, predicted critical Colwell P is 32 mg P/kg soil.

Average annual rainfall: 700 mm; typical growing season length is ~7.5 months
→ predicted carrying capacity for well-fertilised pasture is ~20 DSE/ha (*Fig. 8*). At critical P this is equivalent to ~19 DSE/ha (i.e., 95% of maximum production; *Fig. 9*).

Soil P management plan

Soil P management objective: raise Colwell P to ~20 mg P/kg over 5 years.
→ raise Colwell P by 2 mg P/kg each year

Stock management objective: the potential carrying capacity is predicted to be 20 DSE/ha. However, our current objective is to lift stocking rate to 13 DSE/ha over five years, in step with the improving level of soil P fertility (e.g., *see Figs. 9 & 10*).
→ this is an increase of 1.4 DSE/ha/yr (e.g., 1.4 wethers/ha/yr)

STEP 3

Calculations

Maintenance P calculation (using Tables 1 and 2)

Maintenance P (kg P/ha) = P/DSE x [average annual stocking rate (DSE/ha)]

- *Average annual rainfall: **700 mm***
- Pasture *type:* ***unimproved***
- *Soil loss factor:* ***medium***
- *Animal loss factor:* set stocked but small paddock with good pasture utilisation, therefore most like intensive rotational grazing, with rolling country = ***very low***

Maintenance P requirement in year one: 0.81 x 7.4 DSE/ha = 6.0 kg P/ha
Maintenance P for year 5 of program: 0.81 x 13 DSE/ha = 10.5 kg P/ha

Building P calculation (using Table 3)

To raise Colwell P by 2 mg P/kg each year, this soil (PBI = 80) will require application of:
2.7 x 2 = 5.4 extra kg P/ha

Predicted P application rate: P application rate = maintenance rate + build-up rate

The amount of P to be applied increases each year as shown in Table 4; for reasons of convenience and practicality we determine the average P application rate and apply it each year of the program

For single superphosphate which contains 9% P, the average P-application rate of 13.7 kg P/ha/year equates to annual applications of 152 kg superphosphate/ha over the five-year period.

The soil P and livestock management objectives are achieved in year five. From year six, the rate of P application will reduce to a maintenance rate (i.e., 10.5 kg P/ha/year; or ~117 kg superphosphate/ha/ year). This is the same amount as the maintenance P component of the fertiliser rate for year five.

Table 4: Calculation of the predicted rates of P-fertiliser application to raise Colwell extractable P from 10 to 20 mg P/kg and stocking rate from 6 to 13 DSE/ha over five years at Bookham, NSW.

Year	1	2	3	4	5	average
Planned stocking rate (DSE/ha)	7.4	8.8	10.2	11.6	13.0	
Maintenance P application rate assuming 1.4 DSE/ha increase each year (kg P/ha)	6.0	7.1	8.3	9.4	10.5	
P building rate to raise Colwell P by 2 units per year (kg P/ha)	5.4	5.4	5.4	5.4	5.4	
Predicted rate of P application (kg P/ha)	11.4	12.5	13.7	14.8	15.9	**13.7 kg P/ha/year**

What actually happened at the site featured in the worked example?

The Bookham Grazing Demonstration site was managed without the benefit of these calculations.

A total of 750 kg superphosphate was applied over a five-year period from 1993 to 1998 to build up the soil P fertility level as shown in Figure 12.

The average rate of fertiliser application was 150 kg superphosphate/ha/year. This is very close to the amount calculated as necessary to achieve a Colwell P concentration of 20 after five years (i.e., page 18; 152 kg superphosphate/ha/year).

The soil test results were typically "noisy", but regular soil testing revealed soil fertility was moving in the right direction and in 1998 a decision was made to maintain soil fertility, ideally in the range: Colwell P = 20 - 25 mg/kg soil.

This was not quite achieved, but soil fertility was successfully held just below Colwell P = 20 mg P/kg from 1999 to 2002 by applying an average of 85 kg superphosphate/ha/year.

The estimate for maintenance P applications to hold soil P fertility at the target soil P level was 10.5 kg P/ha (117 kg single superphosphate/ha/year). So, in practice, less fertiliser was required to maintain soil P fertility than was calculated.

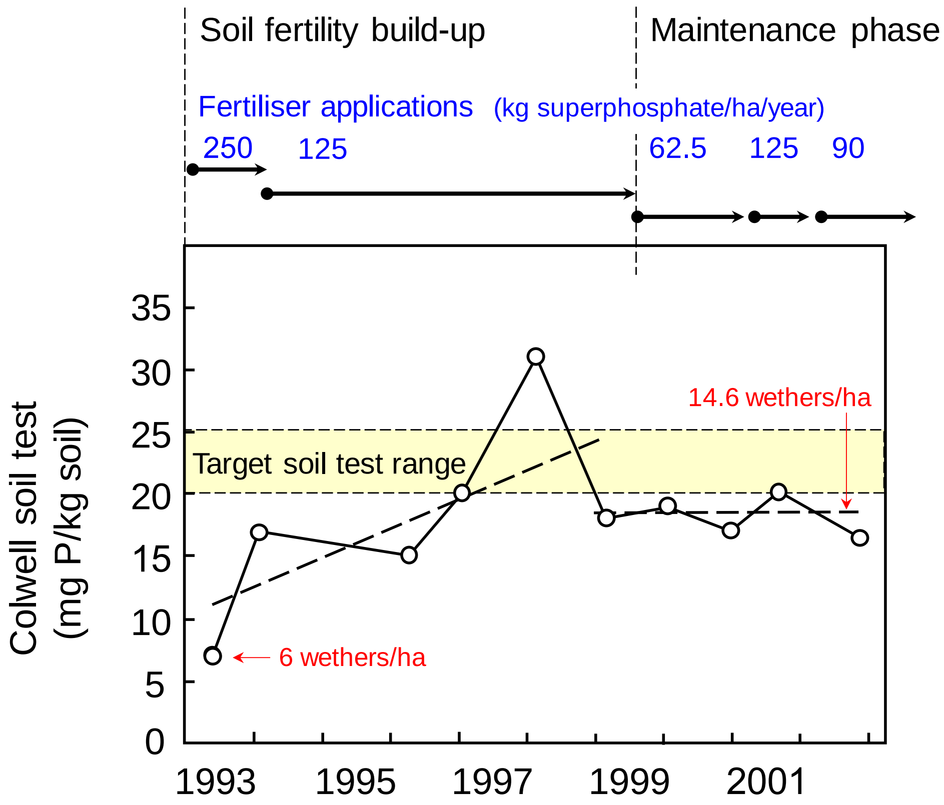


Figure 12: Superphosphate application rates and results of annual soil P testing in a Grazing Systems Demonstration at "Kia-Ora", Bookham, NSW. Dashed lines show trends in the data used when making fertiliser decisions.

STEP 3

STEP 3

Further information

The importance of regular (annual) soil testing

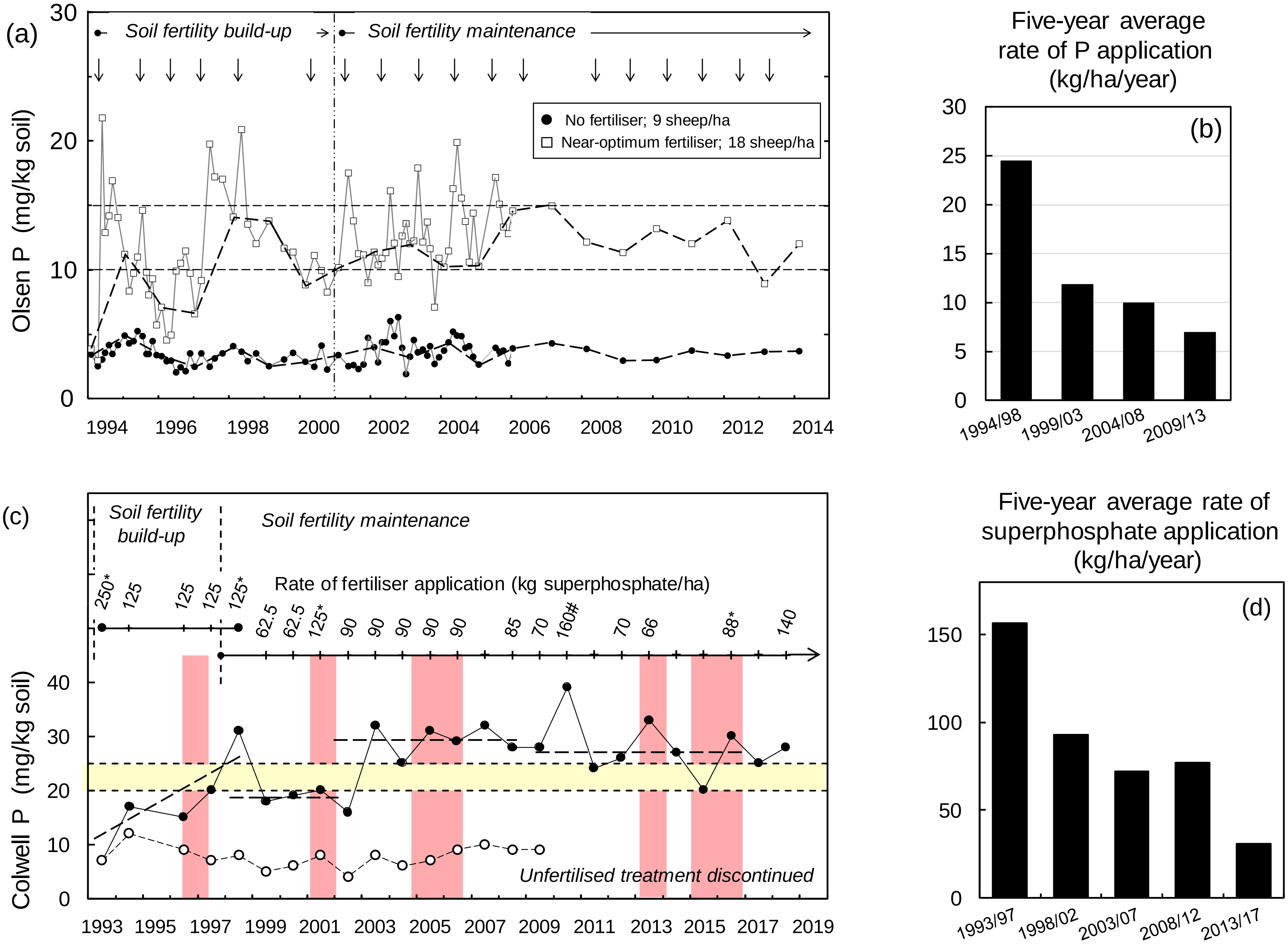
There is always considerable seasonal variation in STP results. This is due to the effects of fertiliser applications, seasonal changes in soil moisture and temperature conditions which stimulate bursts of P release from the microbial biomass, and P mineralisation or immobilisation when soils wet and dry. In addition, it is inevitable that sampling error, lack of replication in farm testing regimes, and laboratory error will contribute to variability in soil test results.

The Olsen P results from testing at 6-weekly intervals shown in Figure 13a, illustrate just how dynamic STP results can be. The figure also shows how sampling the soil at the same time each year helps to smooth out the seasonal variability in STP results. Regular STP monitoring reveals trends in STP results that indicate how fertiliser use is influencing soil P fertility.

Take sensible precautions when using soil tests to reduce unnecessary 'noise' in the results and to ensure reliable interpretation of soil test information. You should:

1. Take accurate soil samples (see: *How to take soil tests properly*).
2. Test your paddocks at the same time each year to minimise seasonal variability in test results. Do not take your soil samples within the first two months after fertiliser application.
3. Set a pragmatic target range for soil P management that is guided by the critical P requirement of your soil-pasture-animal system.
4. Start an annual soil-fertility monitoring program which will reveal trends through time in soil P fertility (e.g., Figs 13c & 14). As much as possible, make fertiliser decisions based on trends in the data rather than one-off soil test results which may provide an unrealistic fertility assessment due to sampling or seasonal variability.

Figure 13: (a) The Olsen P concentration of topsoil (0–10 cm) in selected grazing system treatments from a long-term grazing experiment at Hall, ACT (adapted from Simpson *et al.,* 2015b). Three phases of the experiment are shown: 1994–2000, a soil fertility building phase, and 2001–2006, a soil fertility maintenance phase during which pasture was grazed continuously and soil test P (STP) was monitored at approximately six-week intervals; and 2007–2014, a phase in which soil P fertility continued to be maintained, but with changed grazing management and only annual monitoring of the STP concentration. The fields which received no P fertiliser (closed circles) were stocked with nine sheep/ha. P was applied to the fertilised fields (open squares) with the intention of entering the spring period of pasture growth with a STP level within an Olsen P target band of 10-15 mg P/kg soil. These fields were stocked with 18 sheep/ha. Dashed horizontal lines delineate the target range for STP management. Arrows indicate when P fertiliser was applied (typically in autumn close to the break of each season). Each symbol represents the average STP concentration of three replicate fields. Soil test P monitoring points are joined by a solid grey line to illustrate seasonal variability in soil test results. The dashed black line joins soil tests taken in Jan/Feb and illustrates the variation in STP results which would be typical of annual monitoring at the same time each year. These STP values were used to estimate the amount of P to apply each year. P fertiliser was typically applied in autumn close to the break of each season. (b) Five-year average rates of P application for the duration of the experiment at Hall, ACT. (c) Fertiliser application history and results of annual Colwell P (mostly during spring) in a Grazing Systems Demonstration at, Bookham, NSW (* indicates years when molybdenum was also applied; # a year in which the fertiliser spreader applied twice the requested fertiliser rate). Shaded vertical panels indicate years in which spring droughts occurred. The fertilised field carried 12-15 sheep/ha once the target STP concentration was achieved (zone delineated by dashed horizontal lines). Soil test results from an adjacent unfertilised paddock grazed continuously by six sheep/ha are also shown. The dashed lines show trends in the data used at intervals to gauge progress in STP management. Source: Graham, (2006; 2017) and R.P. Graham *unpublished data*. (d) Five-year average rates of superphosphate (9% P) application for the duration of the Bookham demonstration trial.


(a)
Soil fertility build-up
Soil fertility maintenance
No fertiliser; 9 sheep/ha
Near-optimum fertiliser; 18 sheep/ha
Olsen P (mg/kg soil)
Five-year average rate of P application (kg/ha/year)
(b)
1994/98
1999/03
2004/08
2009/13
(c)
Soil fertility build-up
Soil fertility maintenance
Rate of fertiliser application (kg superphosphate/ha)
250* 125 125 125 125* 62.5 62.5 125* 90 90 90 90 90 85 70 160# 70 66 88* 140
Colwell P (mg/kg soil)
Unfertilised treatment discontinued
Five-year average rate of superphosphate application (kg/ha/year)
(d)
1993/97
1998/02
2003/07
2008/12
2013/17

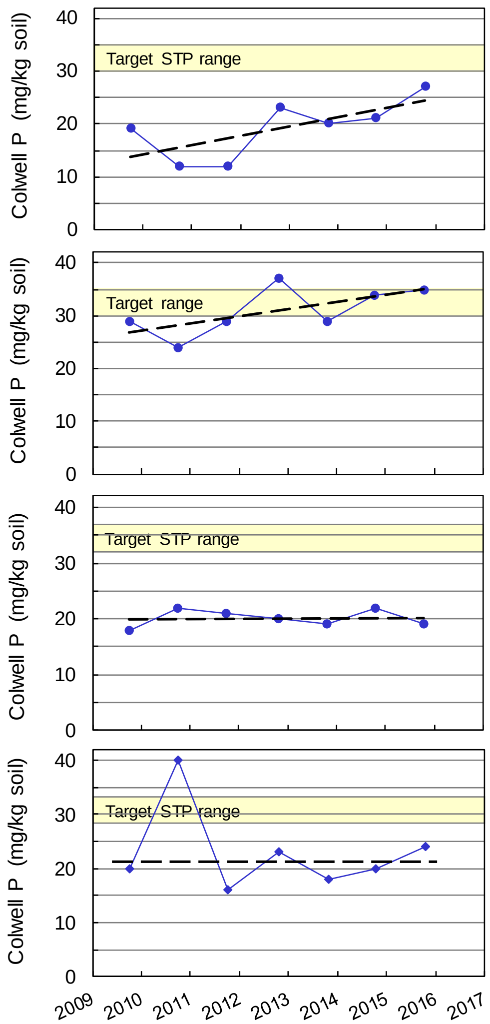
STEP 3

Using soil test P results to adjust fertiliser rates

While testing paddocks every three or so years has been promoted in the past, this is not logical or reliable enough for fertiliser decision making given the intrinsic seasonal and interannual variability in P availability. Monitoring soil P fertility with annual testing helps to overcome this problem because outlier values can often be recognised, and decisions can be based on the trends in the STP results.

The data presented in Figure 14 are examples of STP monitoring results from a farm business near Bombala, NSW. They illustrate how STP data can be used to fine-tune your fertiliser management plans and to check the appropriateness of fertiliser application rate calculations.

STEP 3



Paddock name: "China wall"
PBI: 63
Predicted critical Colwell P: 30 mg/kg
Ave. fertiliser rate: 100 kg superphosphate/ha/year
Decision for 2017: Progress towards the STP target is good; no change to fertiliser.

Paddock name: "Jimmy's Road"
PBI: 54
Predicted critical Colwell P: 29 mg/kg
Ave. fertiliser rate: 100 kg superphosphate/ha/year
Decision for 2017: Soil P now reliably within STP target range; reduce P fertiliser to maintenance rate; continue monitoring STP trend.

Paddock name: "Ring-a-bells"
PBI: 84
Predicted critical Colwell P: 32 mg/kg
Ave. fertiliser rate: 128 kg superphosphate/ha/year
Decision for 2017: Achieving only maintenance of suboptimal STP at current fertiliser rate; increase fertiliser to build STP towards target.

Paddock name: "Sunnyside"
PBI: 34
Predicted critical Colwell P: 27 mg/kg
Ave. fertiliser rate: 100 kg superphosphate/ha/year
Decision for 2017: Farmer chooses to ignore very high STP result. Current fertiliser rate is maintaining STP below target; increase fertiliser.

Figure 14: Soil test P monitoring results for four paddocks fertilised annually on a farm near Bombala, NSW and their interpretation for fertiliser decision making. Dashed lines indicate the soil fertility trends on which decisions were based.

Setting a pragmatic STP target range for soil P management

The critical STP value represents a sensible upper boundary for the P management of your soil. It is not sensible to exceed it excessively because:

(i) Overuse of fertiliser does not grow more pasture
(ii) High STP concentrations drive faster rates of P accumulation in the soil (i.e., P-fixation)
(iii) The risk of P loss to streams (where P is a pollutant) is increased
(iv) You will be wasting money.

The target you set for soil P management should be guided by the critical STP level, after taking pragmatic and business considerations into account.

Pragmatic considerations: Soil test results are always quite variable due to seasonal fluctuations in P availability; this dictates a hard STP target will be unattainable. Set a target range which recognises the practicality of maintaining your soil P target level. For example, a target range of ~5 mg Colwell P/kg soil would be sensible or ~3 mg Olsen P/kg soil (see Fig. 13 for examples).

Business objectives: The purpose of applying fertiliser to a low-P soil is to increase pasture growth and, consequently, animal production per hectare. Pastures grown at their maximum growth rate ensure water (rainfall) and land resources are used most efficiently. However, it is not mandatory to manage soil at its optimum fertility level. This is primarily a business decision. If you opt to maintain a sub-optimal P fertility level you will grow less pasture and run less stock.

Why test pasture soils in spring?

It is feasible to test soils at any time of the year except soon after P fertiliser has been applied. However, it is usually recommended to test soil when the pasture growth rate is at its maximum for the year (i.e., typically during spring). This is when the demand for soil nutrients by a rapidly growing pasture is at its greatest.

A myriad of reasons support this practice, including the soils are moist and sampling is easy, soil cores remain intact and sampling accuracy is improved; results are obtained in time to order fertiliser for the next season and it is wise to separate the timing of buying fertiliser from the application date so deals can be made.

However, the most important agronomic reason is the soil test is timed appropriately to assess whether nutrient levels can support maximum pasture growth. Fertiliser is usually then ordered and applied close to the opening of the following growing season. A spike in nutrient availability follows fertiliser spreading, but available nutrient concentrations typically fall as the growing season progresses (e.g., see the seasonal fluctuations in STP concentrations shown by six-weekly soil tests (Fig. 13a).

Soil P Levels will be maintained at or above the fertility target over the growing season when soil testing coincides with maximum pasture growth and fertiliser is applied close to the start of the growing season.

Some longer-term benefits of sticking with your soil P management plan

Long-term assessments of using a targeted approach to soil P management backed by STP monitoring indicate that this approach sustains high pasture and animal production while also delivering a steady reduction in the fertiliser-cost of production over time (Figures 13b and 13d).

The reduction in fertiliser costs can be attributed to at least two factors: (i) once the critical P fertility level is achieved, a lower fertiliser rate is required to maintain the target soil fertility than that required to build soil P fertility and this delivers an obvious cost saving, and (ii) application of P to soils with moderate to high P buffering and sorption capacities most probably has a ‘P-sparing effect’ because P slowly penetrates the soil particle and this changes the nature of the P-reactive surfaces in the soil (Barrow, 2015; Barrow and Debnath, 2018). Put simply, each application of P is expected to slowly improve the effectiveness of subsequent P applications.

In the examples provided (Figure. 13), the initial step-change in P application rates was associated with the shift from building to maintenance of soil P fertility. Thereafter, it is anticipated that P-sparing has contributed to the declining rate of maintenance P. However, it is difficult to determine the extent to which this was so because P fertiliser rates were also being adjusted in response to STP results and trends. This is seen in Figure 13c where STP monitoring improved confidence in P fertiliser decisions and, increasingly, the decision was taken to skip fertiliser applications after dry spring conditions because the STP data often indicated soil P-fertility had been conserved.

P fertiliser decisions

If the target for soil P management has been reached and the paddock is sustainably supporting the stock numbers you expected then a maintenance rate of P-fertiliser is required.

If paddocks are well above their target P level then it is possible:

a) to apply P-fertiliser at the maintenance rate to hold soil fertility, or

b) to apply a sub-maintenance rate of fertiliser or to withhold fertiliser to allow soil fertility to decline to the target level.

If soil fertility levels of paddocks across a farm are insufficient to support the livestock numbers held or planned, it is necessary to assess which paddocks are at or above their critical P level and at maximum production, and which paddocks may be fertilised to raise their productivity. Assess factors such as soil depth, shelter, pasture species and aspect in deciding which paddocks are selected for increased rates of fertiliser.

Under difficult financial circumstances, it may be necessary to fine tune the use of fertiliser across the farm. Within paddock assessments may allow less productive areas (e.g., westerly aspects, rocky and shallow soil depth areas) to be excluded from fertiliser applications, hence improving the efficiency of the fertiliser that is to be applied. However, this action will cause these parts of the paddock to become less productive and so it cannot be a long-term strategy unless the areas are to be withdrawn from the grazing area.

Droughts

In the absence of a paddock's soil fertility history, decisions must be made using whatever soil test data is available. However, it is generally far better to be making decisions based on the soil fertility trends that are revealed by monitoring STP. Droughts present a potential 'exception-to-this-rule'.

Droughts are rarely predicted and the year's fertiliser application has often been spread by the time a dry season is apparent. In a drought, pasture does not grow to its full potential and dry soil conditions mean soil chemical reactions are also not likely to proceed at the usual pace.

Under these conditions it is common to see higher than normal subsequent soil test results because plant-available P has been conserved in the dry seasonal conditions (e.g., Figure 13c).

Elevated soil test numbers after drought can be indicative of P conservation and may allow moderation of P-inputs without sacrificing the soil fertility plan and target. This can provide welcome cashflow relief after a difficult period. After prolonged drought periods, stock numbers may also be well down and a complete revision of the soil fertility plan may be necessary.

When to review soil fertility management plans: about every three years and after drought.

Step 4: *Other things that may constrain your pasture response to P fertiliser*

Other soil nutrients

This booklet deals primarily with managing the P-fertility of soils used for temperate, legume-based pastures. It has been assumed so far the soils are only deficient in P and N. If a soil has an additional nutrient limitation for plant growth, the most deficient nutrient will be the primary limiting factor.

In such cases it is possible the expected pasture growth response to P-fertiliser will not be realised (see Fig. 15). Money invested in P-fertiliser will not be entirely wasted, but it will be used inefficiently. The expected carrying capacity will not be realised and profitability of the investment will be compromised.

It is important to be vigilant so limiting nutrient situations are identified early. Common nutrient deficiencies are Mo (molybdenum) in acid soils, S (sulfur) and K (potassium). However, deficiencies of copper, boron, zinc and magnesium are also known to occur in particular soils across southern Australia.

Check local conditions with local advisors. Use soil testing to detect potential macronutrient deficiencies and plant testing to investigate potential micronutrient problems.

Critical soil test benchmarks for S and K are provided in Tables 5 and 6.

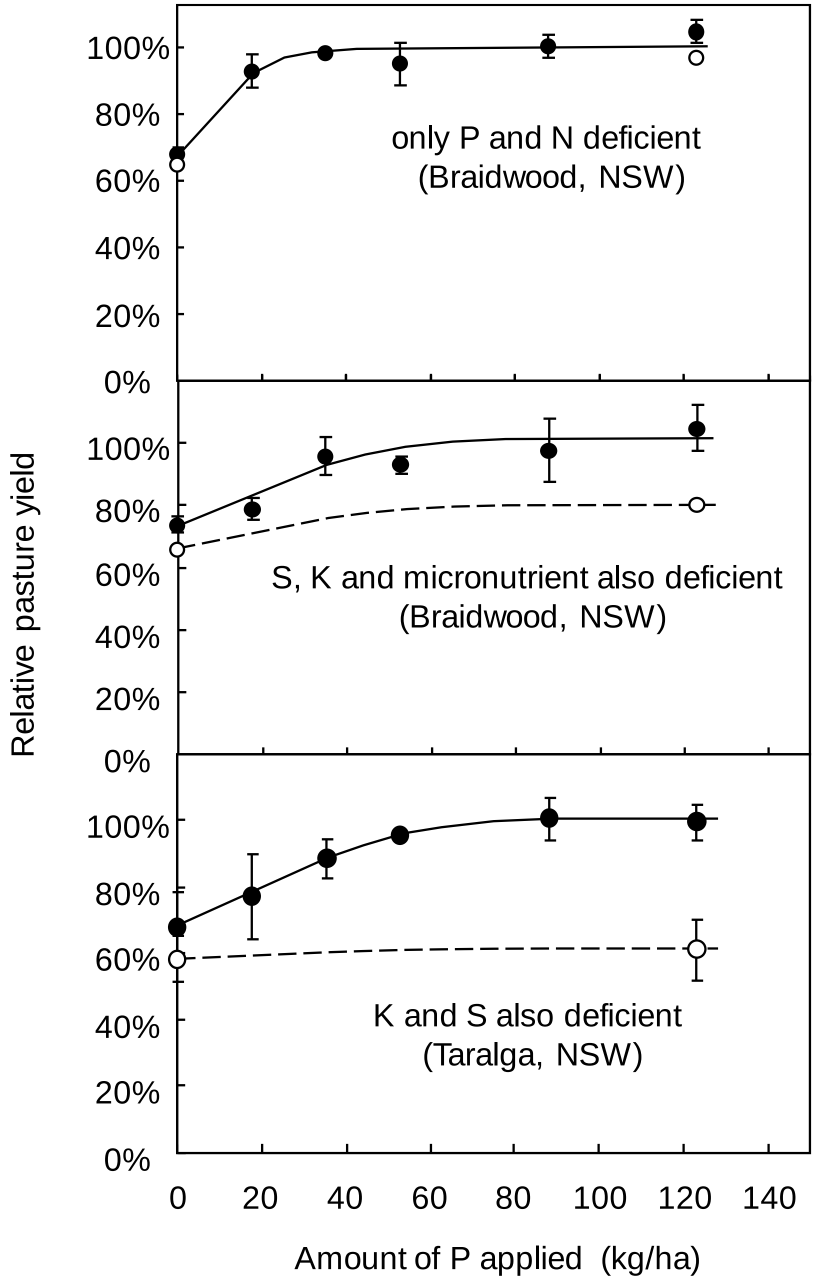


Figure 15: Response of sub-clover-based pastures to increasing amounts of P applied along with a blanket application of other potentially deficient nutrients other than N (closed circles) at three sites on the southern tablelands, NSW. The relative yield of unfertilised pasture without the other nutrients, and pasture to which P was also applied at the highest rate in the absence of the other nutrients are also shown (open circles). These data show nutrient deficiencies other than P were constraining the response to P-fertiliser at two sites. Other nutrient deficiencies will substantially reduce the value of investing in P fertiliser unless corrected.

STEP
4

Table 5 - Critical potassium

Colwell K soil test values (mg K/kg soil) for four soil texture classes derived from a national data set by Gourley *et al.* (2007; 2019).

(NB: *there was insufficient data available to define a response relationship for clay soils*.)

More details can be found in the "Making better fertiliser decisions for grazed pastures in

Soil texture	Critical Colwell K value[1]	Confidence interval[2]
Sand	126	109-142
Sandy loam	139	126-157
Sandy clay loam	143	127-173
Clay loam	161	151-182

[1] Soil test value (mg/kg soil) for 95% of maximum pasture yield.
[2] 95% chance that the critical soil test value falls within this range.

Table 6 - Critical sulfur

CPC (calcium phosphate plus charcoal) and KCl-40 (potassium chloride extract at 40°C for 3h) soil test values (mg S/kg soil) as derived from a national data set by Gourley *et al.* (2007; 2019).

(NB: *most soil S test data were from clay loam or sandy loam soils. There was insufficient data to test whether S test–pasture response relationships differed among soil textures, states or regions.*)

More details can be found in the *Making better fertiliser decisions for grazed pastures in Australia* technical booklet at: www.asris.csiro.au and Gourley *et al.* (2019).

Soil S test	Critical S value[1]	Confidence interval[2]
CPC	3	2-4
KCl-40	8	6-10

[1] Soil test value (mg/kg soil) for 95% of maximum pasture yield.
[2] 95% chance that the critical soil test value falls within this range.

Use soil testing to develop and maintain balanced soil fertility

When a nutrient other than P is also deficient for pasture growth, it is either necessary to fully correct the second deficiency and then continue with your soil P management plan, or to apply the second nutrient concurrently at a rate that ensures it is no more limiting for pasture growth than P.

For example, micronutrient deficiencies [e.g., molybdenum] are usually fully corrected because the quantity of nutrient required is small and the cost of correction is relatively low. On acid soils, a molybdenum deficiency is usually addressed by reapplication every five to six years. In contrast, macronutrient fertility is more costly to address, and usually builds soil fertility slowly.

Figure 16 shows how soil test P and S monitoring results from paddocks on a similar soil were graphed to assess whether use of superphosphate (9% P, 11% S) was providing a balanced solution to concurrent soil P and S deficiencies. Despite substantial temporal variability in both S and P test results, the data clearly indicated that use of superphosphate was improving both nutrient deficiencies and would achieve near-optimum S and P levels within similar timeframes. Note the use of a P fertility index: i.e. ($\frac{current\ Colwell\ P}{critical\ Colwell\ P}$), to allow comparison of paddocks with small differences in PBI. A P fertility index of one equates to the critical P requirement.

STEP
4

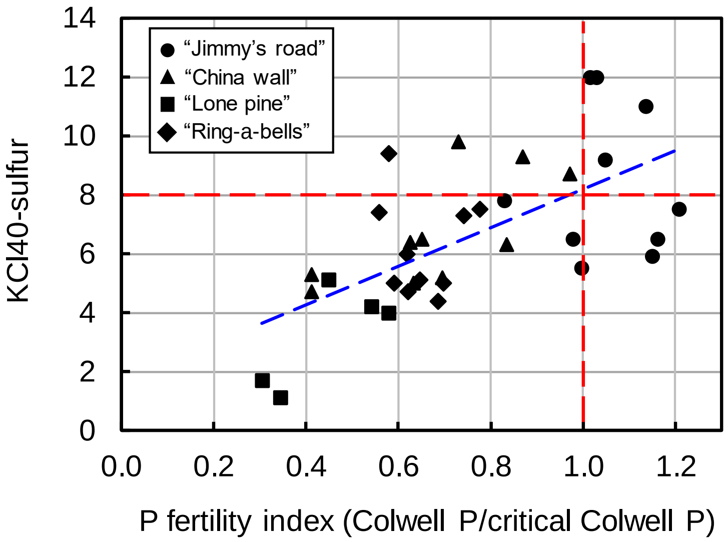


Figure 16: P and S soil test data from monitoring fields on a similar soil over several years. Dashed red lines show critical S and P levels. The dashed blue line is a "best-fit" trend line.

Pasture composition and stability

When P-fertiliser is first applied to pasture growing in P-deficient soil, is it usual to see changes in the botanical composition over a couple of seasons. The grassland often shifts from being relatively botanically diverse and slow-growing to a less diverse but more productive pasture. The nature of the changes varies between grassland systems, environments and with previous interventions such as the sowing of exotic species. However, it is common to see an increase in productive annual and perennial species (including legumes which bring biologically-fixed N into the system) and a decrease in less productive, less competitive, diminutive and/or prostrate species. Feeding value of the pasture for livestock also improves. Changes in botanical composition are driven by the changing P and N status of the soil, but also by grazing pressure exerted by livestock (e.g., Figure 17).

In many cases, pastures fertilised to achieve near-maximum productivity and livestock carrying capacity, approach botanical sustainability limits which are still relatively poorly understood. It is likely the resilience of intensively managed pasture systems depends on which plant species are present, on the presence of underlying problems such as soil acidity, salinity and drought, and is likely to also be influenced by paddock aspect and grazing management.

In some cases, the loss of key species can be very significant and may threaten the ability of the pasture system to maintain a high carrying capacity or to withstand droughts and other stresses. The costs of pasture renovation are high and payback periods so long that significant loss of pasture composition and quality is generally unacceptable. Loss of key species, such as deep-rooted perennials, also has substantial potential costs for grazing system sustainability as they contribute significantly to high pasture yield, feedbase stability, pasture water balance (reduced leakiness), reduced nutrient leaching and reduced soil acidification.

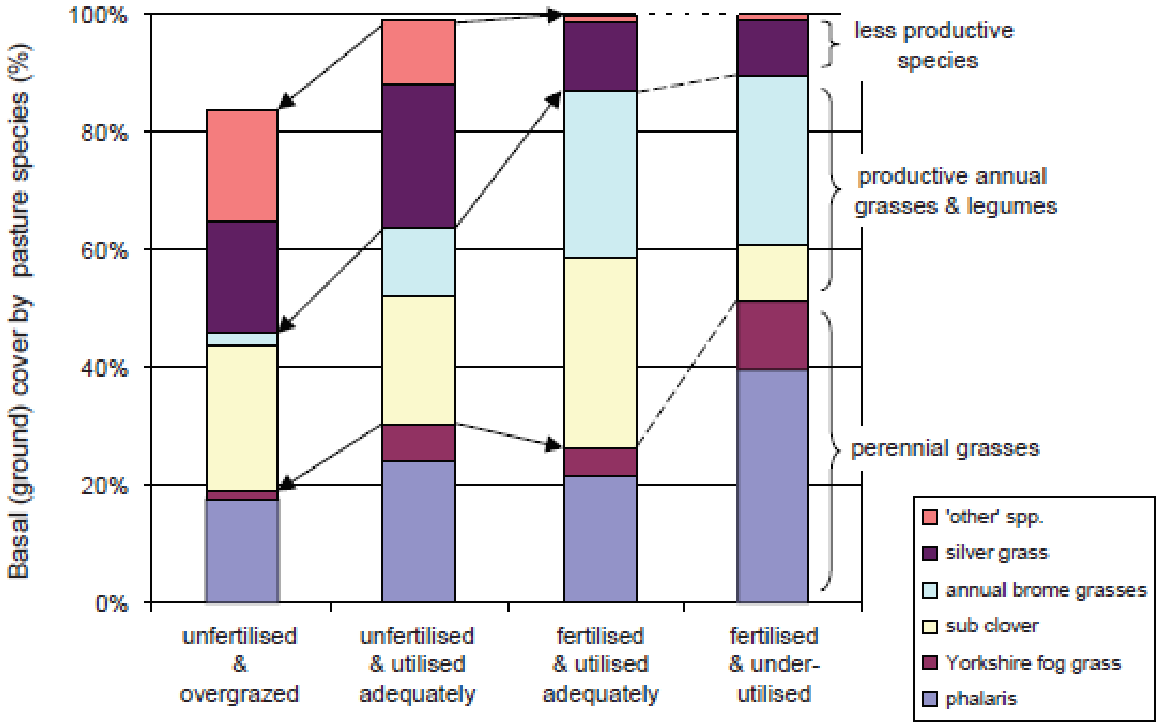


Figure 17: Changes in basal cover (effectively coverage of the ground surface; average for 1999-2001) by pasture species in an initially degraded phalaris and sub- clover-based pasture on P-deficient soil (Olsen P = 4 mg P/kg; Colwell P equivalent = 8 mg P/kg) near Hall, ACT after annual applications of P-fertiliser and changed sheep grazing rates from 1994. Applications of P raised the soil P fertility to an Olsen P = 10-12 mg P/kg soil (Colwell equivalent about 20-24 mg P/kg). The 'unfertilised-overgrazed' and 'fertilised-adequately utilised' pasture systems were grazed continuously by 18 yearling Merino wethers/ha, whilst the 'unfertilised-adequately utilised' and 'fertilised-under utilised' systems were grazed by nine wethers/ha. Increase in bare ground was associated with low soil fertility and overgrazing, decline in the presence of less-productive species and increase in the more-productive species was associated with increased soil P fertility, and changes in perennial grass cover were associated mainly with grazing pressure (i.e., the combination of soil fertility and stocking rate). (Redrawn from Hill *et al.* 2004)

STEP 4

Figure 18 shows a substantial change in the botanical composition of a wallaby grass pasture near Yass, NSW after application of superphosphate to lift production and stocking rate. The botanical changes observed in the intermediate fertiliser-stocking rate treatments are to be expected and are not dissimilar to the sorts of botanical change also observed in intensively-managed, improved pastures. However, the concern for the native grass pasture system is potential loss of a perennial grass that cannot be re-sown at an affordable cost. Wallaby grass composition in the highest fertiliser and stocking rate treatment in this experiment appeared to be even further compromised, but this treatment started with poorer wallaby grass cover and it is unclear whether intensive management was the real cause of the much lower final wallaby grass cover.

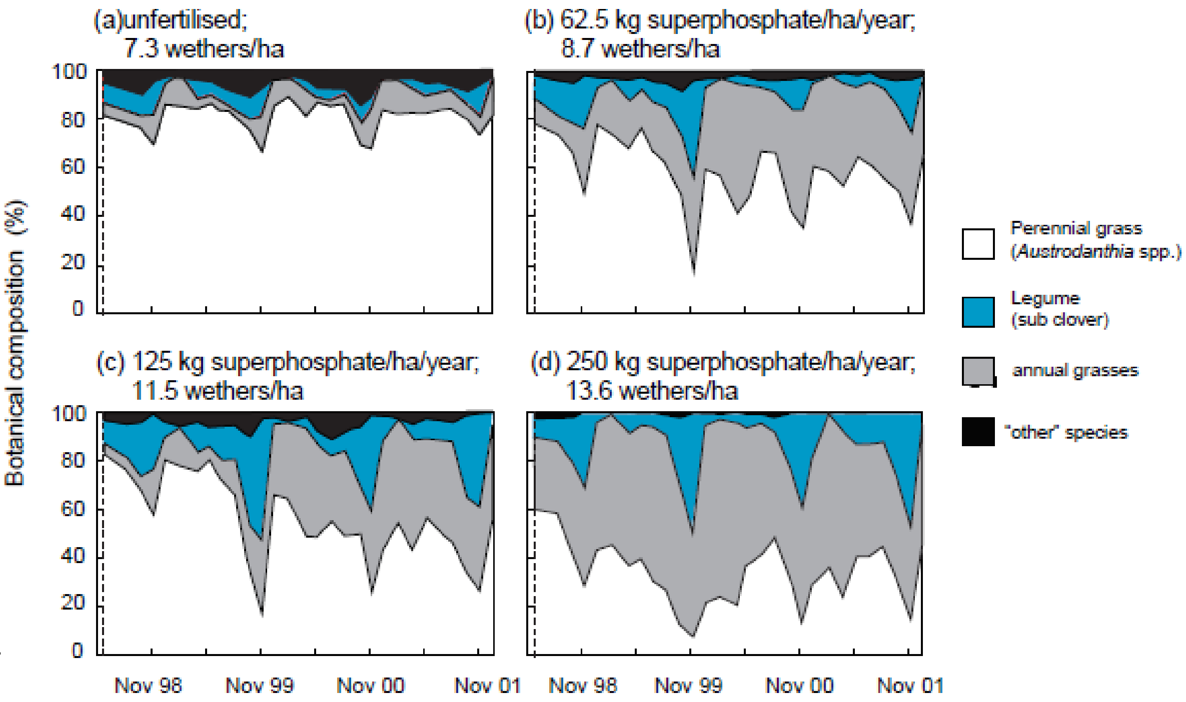


Figure 18: Changes in botanical composition of a wallaby grass pasture near Yass, NSW after annual applications of P-fertiliser and changed sheep grazing rates commencing 1998. High wallaby grass cover and low sub-clover content was associated with low soil fertility. Declines in wallaby grass cover occurred over the first few years at the same time that annual grasses and clover species were increasing. Thereafter, pasture composition was relatively stable. (Bolger and Garden 2002)

Techniques to protect the pasture resource base from degradation

STEP 4

Grazing management: Rotational, as opposed to continuous grazing, can help manage pasture persistence. Perennial species benefit from rotational grazing. Strategic resting (e.g., four weeks after opening rains within a set stocked system) can also be beneficial for persistence, as can light stock pressure during a period of stress. However, resting strategies mean livestock pressures elsewhere may be higher, supplementary feeding may be needed, or you have destocked. They all incur a cost. Understocking is costly and can also cause problems with pasture composition. The greatest pressure comes from stock numbers which exceed the pasture's carrying capacity, regardless of the grazing method used.

Consider your pasture type and whether pushing to maximum soil fertility is desirable: Native pastures are often in parts of the landscape which cannot be resown and seed is relatively expensive and hard to obtain. Consequently, it is more critical to ensure native pasture species persistence is maintained. For example, at the Bookham Grazing Demonstration site (Figure 13c) it was decided to aim at a soil P fertility target which was below the critical P level for maximum pasture growth to decrease the risk of annual grasses becoming dominant; i.e., as a risk management strategy.

Dry periods: The higher your stocking rate the more critical it is to have a strategy in place to manage dry times. Increased P improves pasture growth when we have moisture, during extended dry periods the extra P is of less help. It is critical to manage the increased livestock pressure so as to avoid permanent damage to the pasture base.

Be vigilant, back-off the grazing pressure if necessary: Ground cover is your guide for action regarding the need for rest or a reduction in livestock numbers. Strategies could include the use of drought lots, the sale of stock, agistment or supplementary feeding.

Step 5: Budget to check you will make money from your investment.

When soil test information indicates that you will be able to increase pasture production by applying P-fertiliser, it does not automatically follow that you will generate a profit. The extra pasture grown must be converted into a product that can be sold profitably. Cash flow budgeting allows you to look at the potential return on your proposed investment in fertiliser. It can also be used to show the year-to-year consequences of a fertiliser investment plan.

Cash flow budgeting

A Cash Flow Budgeting Tool is provided online (i.e., Step 5 of the on-line 'Five Easy Steps" Soil Phosphorus Tool that accompanies this booklet; (https://www.mla.com.au//extension-training-and-tools/tools-calculators/phosphorus-tool). Here, use of the Cash Flow Budgeting Tool is illustrated by assessing the likely value of increasing the application of superphosphate to a native grass and sub-clover-based pasture grazed by Merino wethers at Bookham, NSW. This is the grazing system which was the subject of the worked example on page 18.

This example is provided to illustrate: (i) how the budgeting tool is used, (ii) how its use can help you to evaluate the likely returns from fertiliser investments, and (iii) how the tool can also be used to examine the impacts of commodity prices and livestock genetics on returns from fertiliser investments.

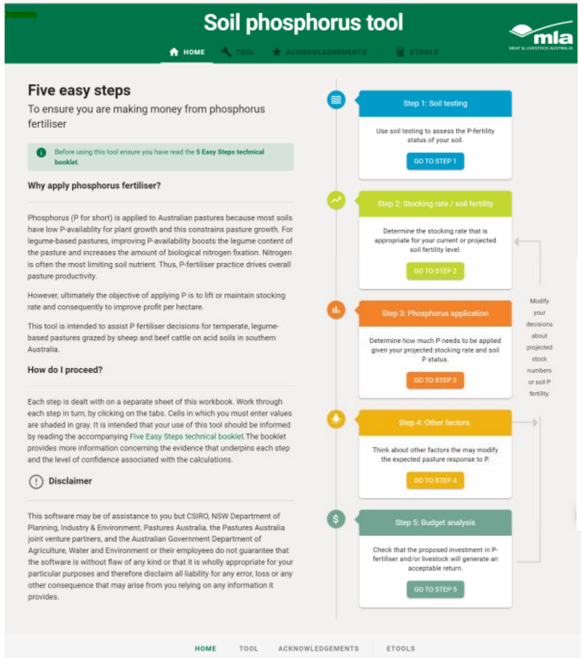


Figure 19: Home page from the online soil phosphorus tool.

Example

Figure 20 shows the expected response to soil P fertility improvement at the Bookham site. For this budgeting example, we assume that the pasture is being fertilised currently to maintain a Colwell P concentration of ~17 mg P/kg soil and is carrying 10 DSE/ha. This is being achieved by annual applications of 90 kg superphosphate/ha.

The cash flow budget is developed to test whether it would be worthwhile to increase soil P fertility over a two-year period so 13 DSE/ha may be carried. The pasture response model (Figure 20) predicts this will require soil P fertility to be increased to Colwell P = 21.6).

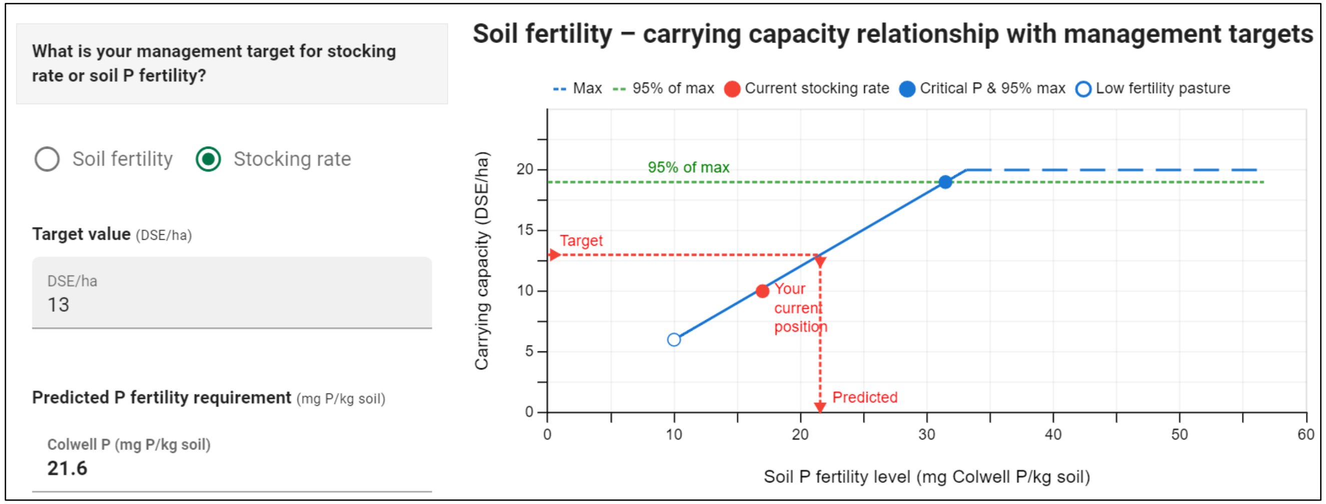


Figure 20: Predicted response to improvement in soil P fertility at the Bookham Grazing Demonstration site. This graph is from Step 2 of the "Five Easy Steps" tool. The current position (Colwell P = 17 mg/kg soil and carrying capacity = 10 DSE/ha) and target for the fertiliser investment (13 DSE/ha) are also shown.

At Step 5, the Cash Flow Budgeting Tool records automatically the key information that was generated by working through Steps 1 to 3 of the Five Easy Steps on-line tool (Fig. 21).

The operator is then required to enter the current rate of fertiliser use, appropriate information concerning fertiliser and livestock prices, and the expected livestock gross margin; i.e., the financial inputs to the Cash Flow tool.

The outputs from the Cash Flow Budgeting Tool are reported in graphical (Figure 22) and tabular formats (Table 7) which demonstrate the predicted profitability and pay-back period for the proposed change to soil fertility management.

In this example, the projected net cash flow is initially lower than the current value due to outlays for fertiliser and livestock. The cumulative cash flow position (which includes interest paid on debt) shows the time it takes to break even compared to doing nothing. Thereafter, in this example, the return on investment is favourable (Table 7, Fig. 22).

Scenario name: Grazing Demonstration | SAVE | Farm name: Bookham | Paddock name: Fertilised paddock | Load scenario: Grazing Demonstration

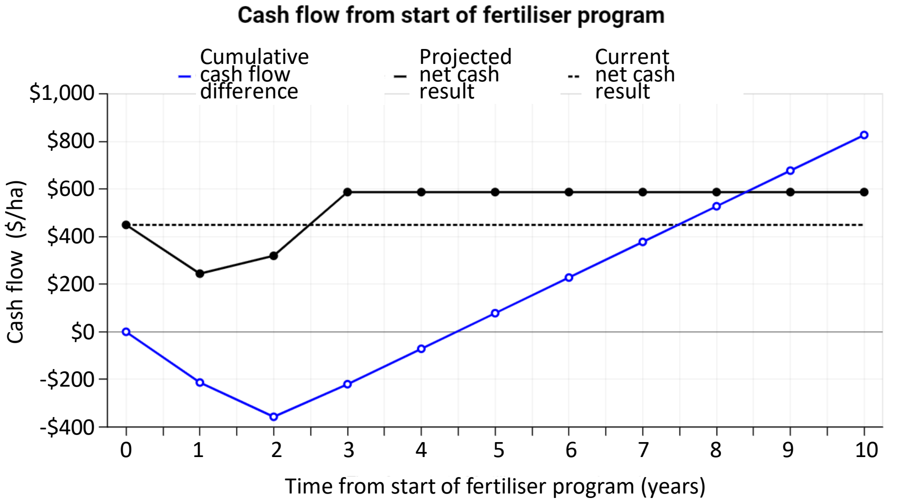
Soil phosphorus data (from previous steps)

Step #	Data type	Results you generated at previous steps
1	Current soil Colwell P (mg/kg)	17
1	Critical soil test level for near maximum pasture growth (mg/kg)	31
2	Current stocking rate (DSE/ha)	10.0
2	Potential carrying capacity with optimal soil fertility (DSE/ha)	20.0
2	Preferred target for soil P management (mg P/kg)	22
2	Stocking rate – at preferred target for soil fertility management (DSE/ha)	13.0
3	Timeframe – to achieve new soil fertility and stocking rate targets (years)	2
3	Stocking rate – yearly increase (DSE/ha)	1.5
3	Planned increase in soil P test (mg P/kg per year)	2.3
3	Fertiliser rate needed to increase soil P at required rate (kg/ha/year)	179
3	Maintenance fertiliser rate at target carrying capacity (kg/ha/year)	117

Budget data

Step #	Data type	Enter values
5	Current fertiliser rate (kg fertiliser/ha/year)	Enter value 90
5	Gross margin – current ($/DSE)	Enter value 50
5	Gross margin – projected ($/DSE)	Enter value 50
5	Capital cost of extra livestock ($/DSE)	Enter value 160
5	Fertiliser cost ($/tonne)	Enter value 450
5	Fertiliser spreading cost ($/ha)	Enter value 10
5	Interest on debt (%)	Enter value 8
5	Area of pasture (ha)	Enter value 100

Figure 21: Step 5 records key information generated at Steps 1 to 3 of the Five Easy Steps online tool. The example shown here is for an assessment of the opportunity to increase superphosphate applications to lift soil P fertility from 17 to 22 mg Colwell P/kg and stocking rate from 10 to 13 DSE/ha at Bookham, NSW. The results of the assessment are then combined with the current rate of fertiliser use, fertiliser and livestock prices, and the livestock gross margin to develop a cash flow budget for the proposed change in pasture management.



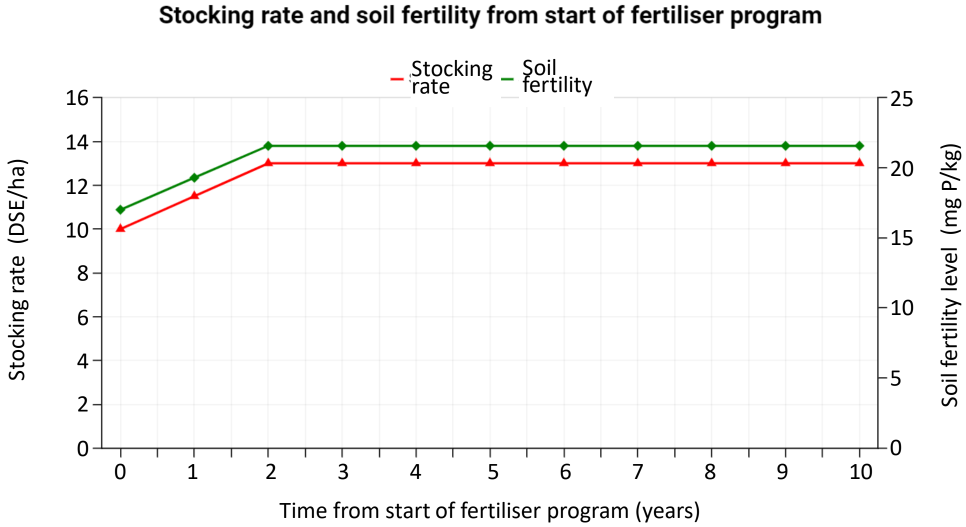


Figure 22: A graphical summary of cash flow, stocking rate and soil P fertility changes in the example scenario based on a Merino enterprise at Bookham, NSW. The graphs are generated by the online Five Easy Steps P tool at its Cash Flow Budgeting step (Step 5).

Table 7: Tabulated summary from the cash flow assessment generated by the cash flow budgeting tool. The objective was to increase carrying capacity from 10 to 13 DSE/ha over 2 years by increasing soil P-fertility from 17 to 22 mg Colwell P/kg in a Merino wether enterprise grazing native grass and subterranean clover-based pasture at Bookham, NSW. The livestock gross margin is $50/DSE). Sheep cost $160/DSE to purchase. The maintenance fertiliser rate for the base position (10 DSE/ha) is 90 kg superphosphate/ha. Fertiliser is to be spread at 179 kg/ha to achieve the planned increase in soil fertility. At the target stocking rate (year 3), the enterprise moves to a new maintenance phase with fertiliser inputs at 117 kg/ha superphosphate/ha.

Cash flow budget	**Current regime**	**Projected fertiliser option →**					
Year	0	1	2	3	4	5	6+
Stocking rate (DSE/ha)	10	11.5	13	13	13	13	13
Fertiliser rate (kg/ha)	90	179	179	117	117	117	117
Expected Soil P fertility (mg Colwell P/kg)	17	19	22	22	22	22	22
[(a)] Livestock gross margin income (S/ha)	$500	$575	$650	$650	$650	$650	$650
[(b)] Fertiliser cost [incl. spreading] ($/ha)	$50.50	$90.55	$90.55	$62.65	$62.65	$62.65	$6.65
[(c)] Livestock purchase cost ($/ha)	$0	$240	$240	$0	$0	$0	$0
[(d)] Net cash result ($/ha) ***(= a – b – c)***	$449.50 [(e)]	$244.45	$319.45	$587.35	$587.35	$587.35	$587.35
Annual difference in cash flow due to new fertiliser program ($/ha) ***(= d – e)***	$0	-$205.05	-$130.05	$137.85	$137.85	$137.85	$137.85
Cumulative cash flow position with interest ($/ha)	$0	-$213.25	-$357.36	-$220.32	-$71.51	$78.24	228.07+
Additional livestock capital ($/ha)	$0	$240	$480	$480	$480	$480	$480
Internal rate of return after 5 years						37%	

STEP 5

The cost of the livestock (required to convert extra pasture to income) is typically much larger than the fertiliser costs. It is important to separate fertiliser and livestock costs when making your fertiliser decision. Livestock costs, for instance, are offset by the fact that your farm's livestock capital is will be increased by the same amount. The internal rate of return figure looks at the investment decision with the livestock stock values removed. In this example, an attractive return on investment is predicted. However, there are always cash flow impacts of changes in pasture management which need to be managed.

Guide to the inputs and outputs from the cash flow budgeting tool

Inputs

Stocking rates and carrying capacity: measured as dry sheep equivalents (DSE/ha). See Appendix 1. The carrying capacity of the pasture at the target level of soil P fertility, and the yearly increase in carrying capacity are determined from the relationship between carrying capacity and soil fertility level which is developed as described in Steps 1 and 2 of this booklet.

Gross margins per DSE: are required for the current situation and for the situation after fertiliser and stocking rate adjustments have been made. These gross margins reflect production per head and are converted to per ha using the carrying capacity numbers. If carrying capacity is changing in line with change in pasture production (i.e., pasture utilisation is remaining about the same), differences in gross margin per head will be small (typical range: +$1 to -$2), most often a small decline in gross margin per DSE might be expected. A gross margin template is provided (Appendix 2) to help you calculate the gross margin that applies to your operation.

Livestock costs: the capital cost of extra livestock required to convert the extra pasture into a saleable product is often greater than the fertiliser cost. The figure required is in $/DSE: e.g., Merino ewe @$240/head equals $160/DSE because the DSE rating of a ewe is 1.5.

Fertiliser cost, application rates and spreading cost: the cost of fertiliser is not included in the gross margin per DSE because fertiliser cost is accounted for in these items of the budgeting tool. The current fertiliser rate is that being used to maintain the current stocking rate and soil P fertility level. It can be determined from current practice and should be roughly consistent with the maintenance P-fertiliser application rate calculated from the current stocking rate using Tables 2 and 3. If these estimates are not roughly consistent think through the reasons why this may be the case. Firstly, recognise the calculators provided in the tool provide only ballpark estimates and you may have better information. However, differences may also occur because your calculation of maintenance P is not appropriate for your situation and site, or because actual rates of usage have been influenced by seasonal considerations, stocking rates, etc.

Soil P test levels: are specified as mg P/kg soil and may be values derived from either the Colwell or Olsen extractable P tests provided the test method used is consistent with that used to specify the relationship between carrying capacity and soil P fertility (Figures 9 or 10), and fertiliser application rate and soil P fertility (Table 3). Rates of P-fertiliser application are determined using Tables 1-3 as outlined in Step 3 of this booklet.

Interest on debt: this interest rate is used to calculate the cumulative cash flow position.

Area of pasture: the area to be fertilised.

Outputs

Limitations: The tool is designed to assess applications of fertiliser for maintenance or increase soil fertility. Predictions arising from situations in which soil fertility is allowed to decline have not been tested adequately. All outputs are determined automatically from the input information. Predictions can only ever be as good as your input data. Key outputs are graphed. The graphs of stocking rate and soil fertility level are intended for checking the expected production outcomes in a fertiliser investment plan.

Potential profitability: can be determined from the projected net cash result.

Time for the investment plan to break even: can be determined from the cumulative cash flow difference, which includes interest paid on debt. It is the time it takes for the cumulative cash flow difference to equal $0.

Internal rate of return: is calculated after five years and again after 10 years in the Cash Flow Budgeting tool. The internal rate of return is the compound interest which could be charged on a project so it breaks even at the end of the development period. For example, if there is a 25% internal rate of return showing in year five, it would mean if you had borrowed for all of the development at an interest rate of 25%, you would be just able to pay back the financier at the end of year 5 after you sold the additional stock that you had bought. Because you can usually borrow for much less than 25%, it would indicate that the project was quite attractive. As a guide, in a low interest rate environment with a good outlook for the animal product you are producing, you might consider that an internal rate of return of 12% may be sufficient to cover your production risks. If the risk of a project is increased (e.g., because of factors such as climate variability, uncertainty of fertilizer or product prices etc.), you may require a higher return to justify the investment. Generally, returns over 15-18% would be considered attractive. Remember, in the financing of any project the loan principal needs to be paid back as well as the interest on the loan and this requires a return significantly higher than the current interest rate to ensure you can meet your commitments.

Further information

How do investment plans and input costs influence return from a fertiliser investment?

The following examples show data generated using the Cash Flow Budgeting Tool to illustrate some of the relationships between the key factors which affect the financial outcomes of a fertiliser investment.

These analyses are based on the Merino wether enterprise at Bookham, NSW used in the “worked example” to calculate P application rates (page 18) and are extensions of the financial budgeting example in which the value of increasing soil P fertility over two years to support an increase in pasture varying capacity from 10 to 13 DSE/ha was examined (pages 28-30). The financial assumptions used for this base scenario are outlined in Figure 21. Changing these assumptions will change the numbers, but not the trends revealed in the following examples.

Where do the dollars get spent in a fertiliser program?

Cash is required to buy fertiliser and extra livestock to consume the extra pasture that is grown. The livestock costs usually well exceed the fertiliser costs but you retain the livestock as an asset in the business. This will show up on your balance sheet under ‘current assets’.

What is the impact of fertiliser price on returns?

Increases in fertiliser cost reduce profitability. However, an increase in fertiliser prices is not usually be a good reason to abandon your soil fertility management plan.

Figure 23 displays the current yearly returns (dotted lines) against the projected yearly returns for the base scenario in which which the value of increasing soil P fertility over two years to support an increase in pasture carrying capacity from 10 to 13 DSE/ha was examined. Only the fertiliser price is changed. Increases in fertiliser reduce the financial return ($/ha). However, even if fertiliser prices were to reach $1,000/t, the financial return from increasing stocking rate by 3 DSE/ha is still positive on a gross margin basis and returns ~$150/ha in Year 1. By year 3, the projected financial return is greater than that achieved at the current stocking rate, regardless of the fertiliser price. The Internal Rates of Return (at five years) for these price levels were 37%, 32% and 24% for fertiliser costing $450, $650 and $1,000/tonne, respectively.

NB: The financial returns presented here are gross margins; they do not account for overhead or other financial costs in a business.

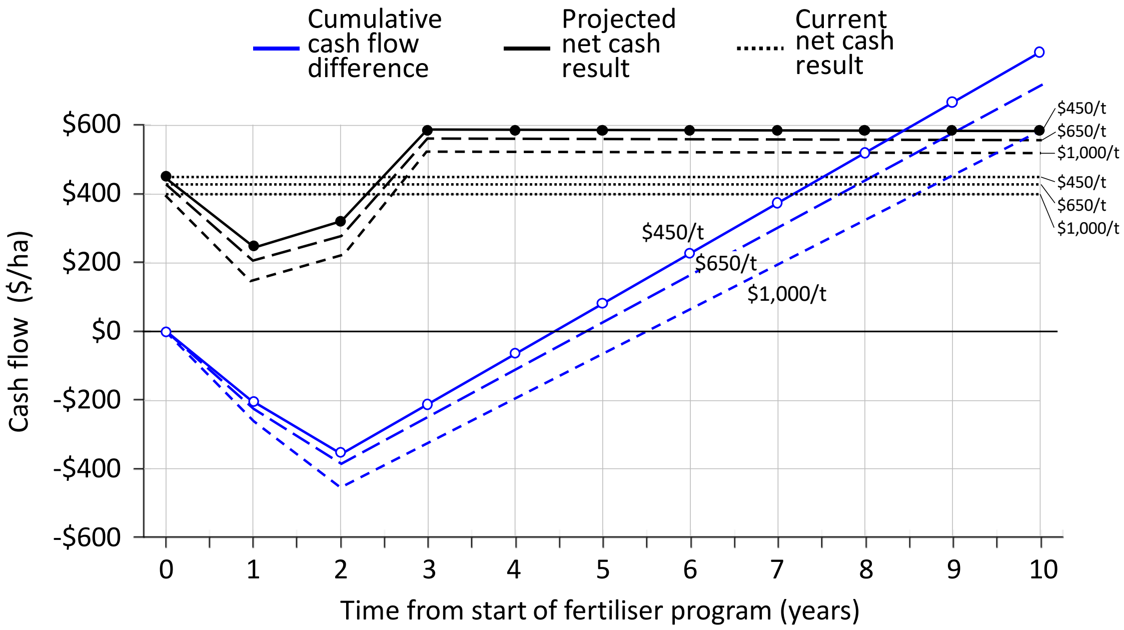


Figure 23: Impact of fertiliser prices ranging between $450/tonne and $1,000/tonne on additional profit per hectare (net cash results; black lines) and pay back periods (cumulative net cash differences which include interest on debt; blue lines) for a Merino wether enterprise at Bookham, NSW (further details: see the worked example on page 18, and financial budgeting example on pages 28-30).

How long does it take your cash position to be better than your current situation?

The benefit of viewing a cumulative cash flow analysis is it helps you to get a sense of how long takes for an investment plan to break even (i.e., when cumulative cash flow difference equals $0). A cumulative cash flow takes into account the total sum of cash spent on extra fertiliser, livestock and interest paid in debt. Figure 23 shows that higher fertiliser prices also increase the time to break even in a fertiliser management program. However, in this example, even at a fertilizer price of $1,000/t, the break-even timeframe for a productive enterprise has only been increased by one year.

Often producers will react quickly to increases in fertiliser price; sometimes by reducing fertiliser inputs. This analysis demonstrates fertilizer price may only have a relatively small impact on the overall, longer-term benefit of a soil fertility management plan.

What is the impact of livestock gross margin?

Roughly similar farms within districts often achieve substantially different gross margins per DSE. The major factor in these differences is the choice of livestock genotype and their productivity. For example, the difference between the top 10% and bottom 10% of high accuracy teams from an Australia-wide Merino bloodline comparison was 19% or $6.34/DSE (Atkins et al. in 2007). The range across the industry is greater than this (in today's money, up to $20/DSE) because only major bloodlines were evaluated in the Merino bloodline trials.

Figure 24 demonstrates the substantial impact that differences in gross margins per DSE can have on cash flow in a fertiliser investment. Profitability is higher and payback periods are shorter for enterprises which run productive livestock. Enterprises which achieve high gross margins per DSE have a much greater chance of affording fertiliser that can further lift overall profitability.

The analysis also shows that livestock with a gross margin of ~$30/DSE generate a relatively low internal rate of return (i.e., 18% at $30/DSE compared with 37% at $50/DSE) and push the break-even position from 4.5 out to 7.5 years.

At this level of performance, the fertiliser program becomes a questionable investment. It may be better to initially focus on fixing the low return from your livestock.

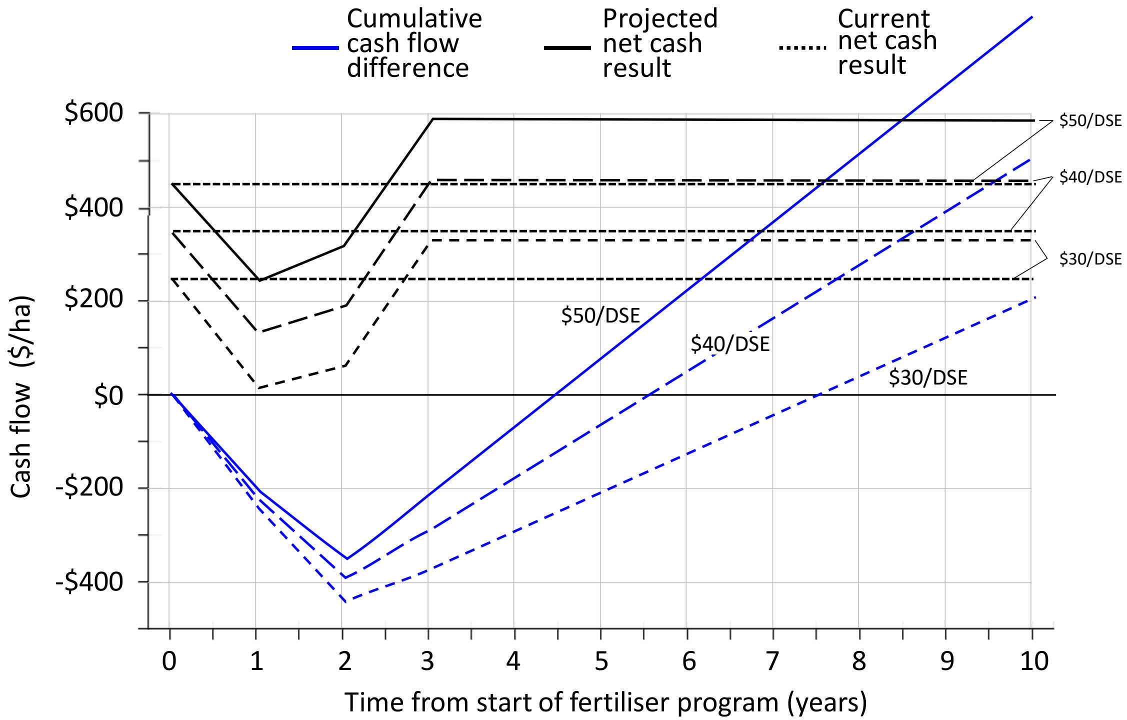


Figure 24: Impact of livestock gross margin on profitability (net cash results; black lines) and pay back periods (cumulative cash flow differences; blue lines) which may be expected by enterprises which achieve different gross margins per DSE.

Other benefits of improved soil fertility: Improving soil fertility and, therefore, pasture vigour results in pastures which are more competitive against weeds. This can reduce weed management costs. If the fertiliser decision pays for itself then this benefit is achieved at no cost to the business. In addition, while fertiliser is a direct cost to the business it also has the potential to increase the future capital value of the land.

Interaction of prices and livestock performance

The price of fertiliser is set by world markets and cannot be controlled on farm. Producers are often very sensitive to movements in fertiliser price and will often reduce or redirect fertiliser applications when the price increases.

Figure 25 highlights the impacts of livestock gross margin return compared to fertiliser price. It examines the effect of a very large jump in fertilizer price (from $450 to $1,000/tonne) for two similar enterprises which differ in the productivity of their livestock. The enterprises which runs more productive livestock is always more profitable. Applying fertiliser to paddocks that are below their critical P requirement to increase stocking rate further increases the return per hectare. Even at the very high fertiliser price. However, increases in fertiliser price (in the absence of an increase in livestock returns) do reduce profitability, and also increase business risk by pushing out the break-even time for a fertiliser investment.

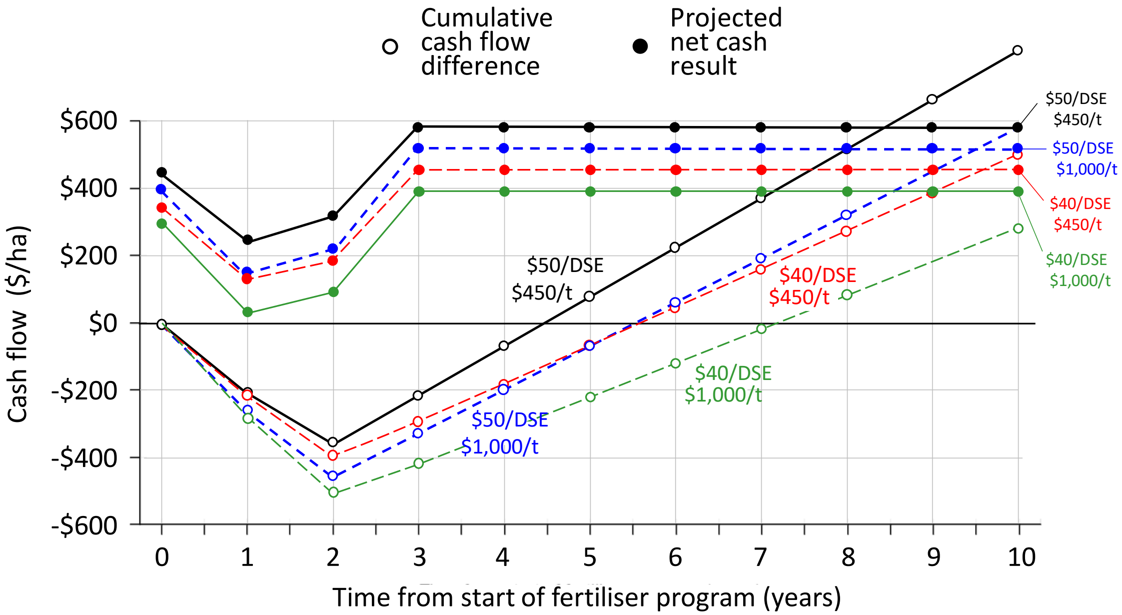


Figure 25: Impact of livestock gross margin on profitability (net cash results; black lines) and pay back periods (cumulative cash flow differences; blue lines) which may be expected by enterprises which achieve different gross margins per DSE.

Interestingly, in this example the enterprise which generates $50/DSE while paying $1,000/t for fertiliser (blue dashed line) generates a greater cash return than an enterprise generating $40/DSE and paying only $450/t (red dashed line); both break even at around the 5.5-year mark. In other words, the $50/DSE enterprise is able to generate sufficient income to more than offset a $550/t increase in fertiliser price.

REMEMBER: Fertiliser price is set by world markets and cannot be controlled on farm. If prices are not looking rosy and you don't want to lie down and be run over by the world market take control of the things you can influence:
(i) Fertiliser cost can be minimised by ensuring soil fertility management is on target for your soil and stock numbers.
(ii) Focus on the variables you can control directly (e.g., your livestock gross margin or stocking rate). These variables strongly influence the profitability of fertiliser decisions.

STEP 5

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Appendix 1: DSE ratings for various classes of livestock

Annual DSE ratings for livestock are required for estimating stocking rates and carrying capacity in the 5 Easy Steps worksheet and on-line tool

Breeding stock

The easiest way to work out your DSE rating is to use the number of females which calve or lamb down.

Table 1 data includes the breeding female for 12 months, progeny for the period listed in the heading and the replacement females.

Note that the mature female bodyweight is gut empty (in the yards for 12 hrs) and fleece free for sheep. Gut fill in cattle can be 30 to 40 kg. A 50 kg ewe (fleece free and no gut fill) straight out of the paddock (gut fill now 3.5 kg), with half a fleece (2.5 kg) and in mid pregnancy (2 kg) could weigh 57 kg.

Examples:
I have 1,000, 50 kg ewes lambing at 95% and all progeny are kept on the property for 12 months. → 1000 x 2.2 = 2,200 DSE for the enterprise.
This includes the ewes, progeny and replacement ewes.

I have 1,000, 70 kg first cross ewes lambing down at 125% with all lambs sold by eight months. → 1000 x 2.73 = 2,730 DSE for the enterprise.
This includes the ewes for 12 months and the progeny for eight months.

I have 100, 600 kg cows producing selling weaners. → 100 x 13.9 = 1,390 DSE.
If all progeny are kept on the property to 12 months then the DSE increases to:
100 x 17.9 = 1,790 DSE.

Dry stock over 12 months of age

If you have additional stock such as wethers or steers older than 12 months or are trading cattle/sheep, use the values in Table 2 to add to your breeding DSE total.

Example:
You have 50 trade steers bought in at 250 kg and sold in 6 months at 430 kg. Use the 1 kg/day column and pick a DSE value liveweight that is halfway between 250 and 430 kg:
e.g., 10 x 50 x 0.5 = 250 DSE. A value of 0.5 is used because the cattle were only on the property for 6 months.
You also have 1,000, 60 kg wethers sold at two years, 1000 x 1.2 = 1200 DSE

Your breeding unit totalled 2,200 DSE.
Therefore, breeders 2,200 + wethers 1,200 + steers 250 = 4,650 DSE.

Table 1. Annual DSE ratings for breeding enterprises

Self-replacing Merino enterprise

50 kg Merino ewe (mature weight; fleece free and no gut fill)

Marking percentage	All progeny kept for 12 months	Wethers sold at 5 months, all ewes kept
105	2.3	2.1
95	2.2	2
85	2.1	1.93
75	2.0	1.86

60 kg Merino ewe (mature weight; fleece free and no gut fill)

Marking percentage	All progeny kept for 12 mths	Wethers sold at 5 months, all ewes kept
105	2.8	2.5
95	2.7	2.4
85	2.6	2.3
75	2.5	2.26

Prime lamb enterprise (buy in replacement ewes)

70 kg first cross ewe (mature weight; fleece free and no gut fill)

Marking percentage	All lambs sold at 8 months	All lambs sold at 12 months
135	2.9	3.1
125	2.7	3.0
115	2.6	2.9
105	2.5	2.8

80 kg first cross ewe (mature weight; fleece free and no gut fill)

Marking percentage	All lambs sold at 8 months	All lambs sold at 12 months
135	3.16	3.9
125	3.1	3.7
115	2.99	3.6
105	2.9	3.4

Self-replacing beef cattle enterprise

Cow liveweight (kg)*	Steers and surplus heifers all sold at 8 months	Steers and surplus heifers all sold at 12 months
500	12.1	15.0
600	13.9	17.2
700	16.2	20.0

* Mature cow liveweight (adult cow, Fat Score 3, no gut fill)

Table 2. DSE ratings for livestock during the year

These ratings are for the animal while it is in the listed category: e.g., for a 500 kg cow, while she is lactating the rating is 15.2 (cow and calf). However, the cow may only lactate for six months. The category that applies for the preceding six months is 'pregnant' with a rating of 8.4.

Mature ewes					
Liveweight (kg)	Dry	Pregnant*		Lactating^	
		Single	*Twin*	*Single*	*Twin*
40	0.9	1.1	1.3	2.1	2.9
50	1	1.3	1.5	2.5	3.4
60	1.2	1.4	1.6	2.9	4.1
70	1.3	1.6	1.9	3.9	4.3
80	1.4	1.9	2.2	5.9	6.5

* 120 days pregnant

^ Peak lactation (4 weeks after birth)

Breeding cattle			
Liveweight (kg)	Dry	Pregnant*	Lactating^
350	6	7	12.3
400	6.5	7.7	13.7
450	6.9	8.2	14.8
500	7.1	8.4	15.2
550	7.7	9	16.5
600	8.4	9.7	17.3
650	9.1	10.5	18.1
700	9.5	13.1	19.2

*8 months pregnant

^ Peak lactation (4 months after birth)

Growing lambs					
Liveweight (kg)	Growth (g/day)				
	100	*150*	*200*	*250*	*300*
20	1	1.3	1.6	1.8	1.9
30	1.3	1.7	2	2.2	2.4
40	1.6	1.9	2.2	2.5	2.7
50	1.8	2.1	2.5	2.8	3.1
60	2	2.3	2.7	3.1	3.4

Growing cattle				
Liveweight (kg)	Growth (kg/day)			
	0.5	*1.0*	*1.5*	*2.0*
200	5.3	6.8	8.3	10.9
250	*6.4*	*8.1*	*9.7*	*12.3*
300	7.3	9.2	11.1	13.5
350	*8.4*	*10.6*	*12.9*	*15.2*
400	9.1	11.4	13.7	16.8
450	*9.7*	*12.6*	*15.3*	*18.0*
500	10.3	13.4	16.1	19.0

Notes:

Pregnancy values reflect the average energy value for the whole of pregnancy. For the majority of a pregnancy the figure overestimates the energy required but it underestimates the energy during the rapid growth of the foetus towards the end of pregnancy.

In the early stages of lactation, the majority of the energy is used by the cow; near the end energy is more evenly used by the cow and her progeny.

Appendix 2: Livestock gross margin template examples

WOOL & LAMB GROSS MARGIN BUDGET

Enterprise:	**Wool or lamb enterprise**				
Enterprise Unit:	1,000	*18 um ewe*	1.9	DSE/animal	
Pasture:	*native*				
		Total DSE	1900	DSE	
INCOME:					**Total**
	Number sold		$ per head		
Livestock sales	177	*CFA ewes*	39		$6,956
	2	*CFA rams*	61		$122
	435	*weth weaners*	38		$16,530
	201	*ewe hoggets*	50		$10,050
	-		-		$0
Total	815	head			
	Kilograms sold (clean or greasy)		$ per kg (clean or greasy)		
Wool sales	6,000	*1177 ewes* at 5.1 kg	7.10		$42,600
	70	*10 rams* at 7 kg	6.79		$475
	1,450	*426 ewe lmb* at 3.4 kg	6.40		$9,280
	360	*crutchings*	2.97		$1,069
	-		-		$0
Total	7,880	kg			
		A. Total Income:			$87,082
VARIABLE COSTS:	**Number**		$		
Replacements	2	rams @	900	per head	$1,800
	-	wethers @	-	per head	$0
	-	ewes @	-	per head	$0
Husbandry					
Drenching & vaccination	2,300	@	1.30	per head	$2,990
Dipping and jetting	1,800	@	2.00	per head	$3,600
Scanning	1,000	@	0.90	per head	$900
Mules & mark	900	@	3.75	per head	$3,375
Shearing	1,600	@	5.74	per head	$9,184
Crutching	1,800	@	0.85	per head	$1,530
Wool selling cost			4,000.00	in total	$4,000
Fodder and supplementary feeds					
Fodder crops			-	in total	$0
Feed: Hay, Grain etc			4,000	in total	$4,000
Pasture maintenance			5,500	in total	$5,500
Livestock selling costs	815	@	3.50	per head	$2,853
Commission on livestock sales			5.00	%	$1,683
Other cost			-	in total	$0
		B. Total Variable Costs:			$41,414
			GM including pasture cost		GM excluding pasture cost
		GROSS MARGIN (A-B)	$45,668		$51,168
		GROSS MARGIN/animal	$46		$51
		GROSS MARGIN/DSE	$ 24.04		$ 26.93

BEEF CATTLE GROSS MARGIN BUDGET

Enterprise:	**Beef breeding enterprise**			
Enterprise Unit:	100 cows @	15.0 DSE per cow		
Pasture:	*enter pasture type*	Total DSE		1,500 DSE

INCOME:

	Number sold		$ per head	Total
	6	*Cows*	610	$3,660
	-	*Calves*	-	$0
	42	*Weaner Steers*	507	$21,294
	21	*Weaner Heifers*	414	$8,694
	-	*Steers*	-	$0
	-	*Heifers*	-	$0
	1	*Bulls*	1,033	$1,033
	-	*Cull Repl Heifers*	-	$0
	-	*Cull (for age) Cows*	-	$0
	13	*OTHER*	610	$7,930
Total	83			

A. Total Income: $42,611

VARIABLE COSTS:

Replacements	1	bulls @	4,500	$/head	$4,500
	-	cows @	-	$/head	$0
	-	heifers @	-	$/head	$0
Livestock and vet costs.			1,036		$1,036
Ear tags	83	@	2.90		$241
Fodder crops			-		$0
Feed: Hay, Grain, Silage, Molasses etc			2,400		$2,400
Pasture maintenance			-		$0
Livestock selling cost			2,800		$2,800
Other cost (eg labour)			-		$0

B. Total Variable Costs: $10,977

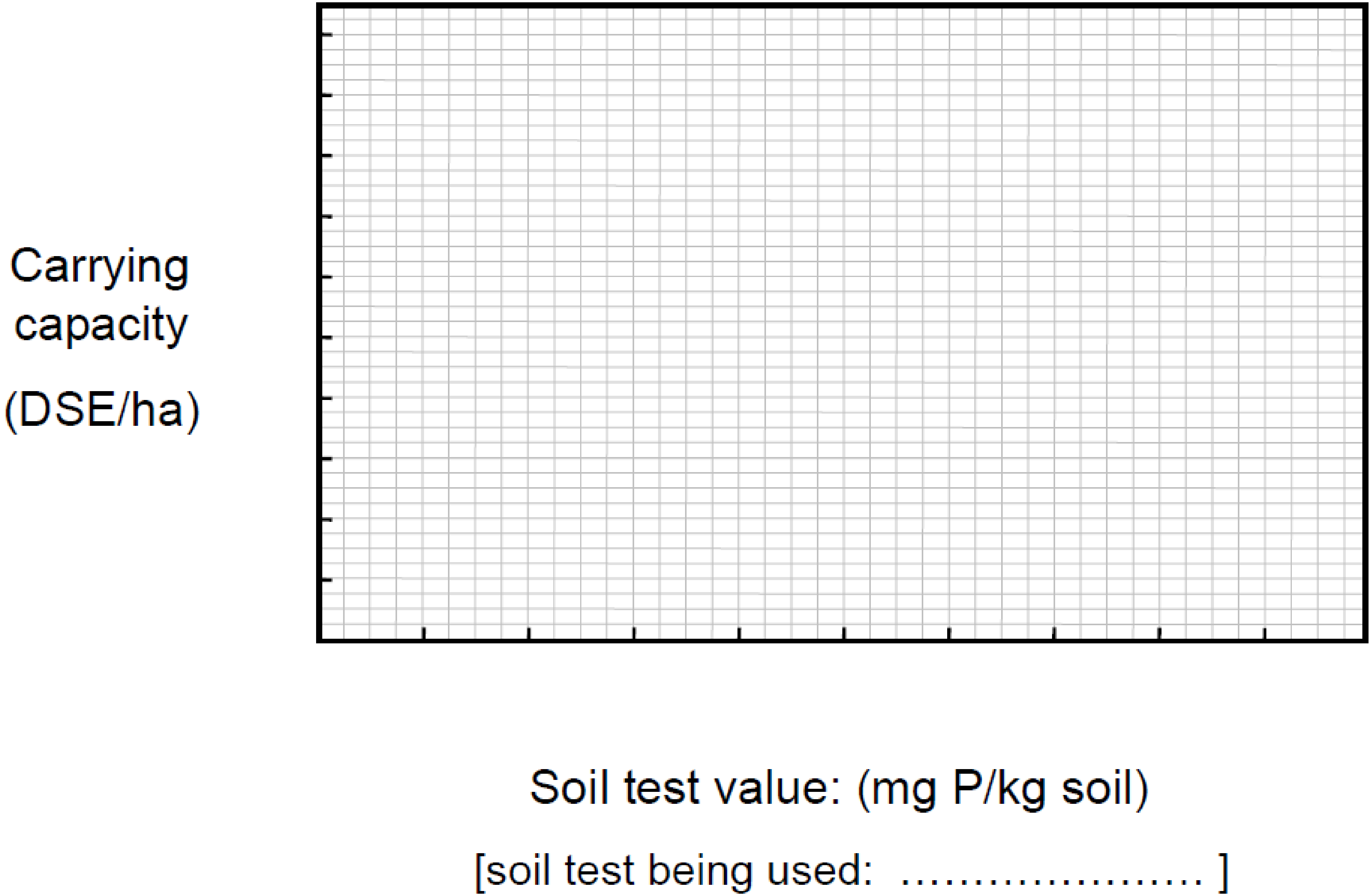
	GM including pasture cost	GM excluding pasture cost
GROSS MARGIN (A-B)	$31,634	$31,634
GROSS MARGIN/COW	$316	$316
GROSS MARGIN/DSE	$ 21.09	$ 21.09

Note: These tables do not include up to date costs and prices, they are provided as examples only. You will need to fill the templates with your own data.

Appendix 3

Example work sheet for recording planned fertiliser applications

Land Management Unit (LMU)	Unit size	PBI	Critical P (Colwell or Olsen)	Current soil P level	Soil P target for next year	Amount of P to meet soil fertility target		Current livestock			Planned stocking rate at target P for next year			Additional livestock required
	ha		mg P/kg soil	mg P/kg	mg P/kg	kg/ha	kg/LMU	No. & Type /LMU	DSE /LMU	DSE /ha	DSE /ha	DSE /LMU	No. /LMU	
Totals for property														


Carrying capacity
(DSE/ha)
Soil test value: (mg P/kg soil)
[soil test being used: ....]

NOTES:

The 'Five Easy Steps' software tool and booklet were developed originally in 2009 by CSIRO and NSW Department of Planning, Industry & Environment (Department of Primary Industries) with financial assistance from Pastures Australia, which was a joint venture for investment in the generic improvement, management and adoption of pasture plants across Australia. Pastures Australia partners were: Meat and Livestock Australia, the Grains Research and Development Corporation, Australian Wool Innovation Ltd., Dairy Australia and AgriFutures Australia.

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