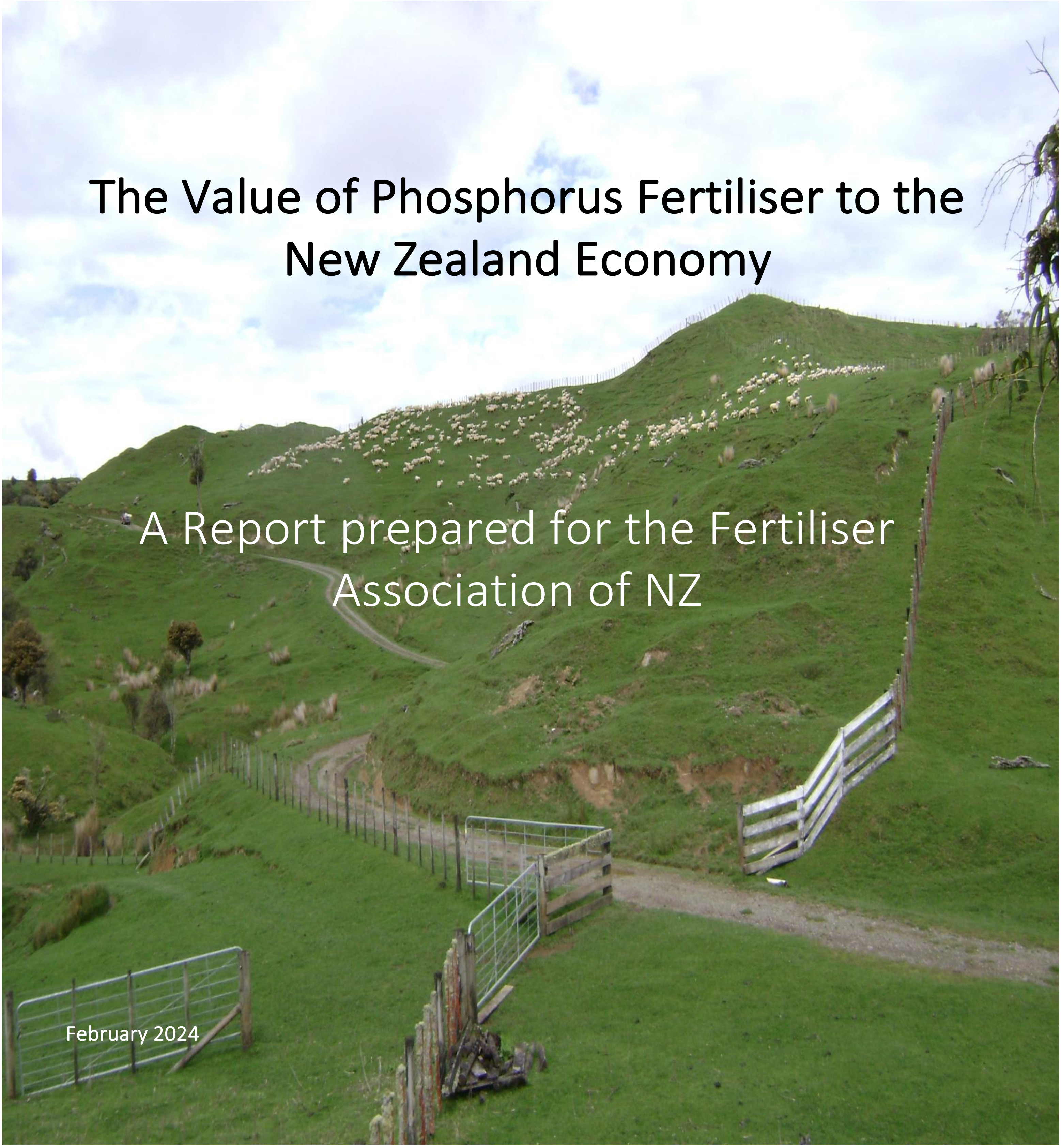
The Value of Phosphorus Fertiliser to the New Zealand Economy

A Report prepared for the Fertiliser Association of NZ

February 2024



Report Contributors:
Lead Author: Phil Journeaux, Journeaux Economics **Contributions from:** (with specialty subject areas) Phil Journeaux, Journeaux Economics, (Pastoral Sector) Gary McDonald, Market Economics (Macro Economics) Sandy Scarrow, Fruition Horticulture (Permanent Horticulture) Stuart Ford, AgriBusiness Group (Vegetables and Arable) Doug Edmeades, Soil Scientist, (Soil Fertility)

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1.0 EXECUTIVE SUMMARY

Phosphorus is an essential element for plant health and growth and which, unfortunately, is naturally deficient in most New Zealand soils.

This has resulted in the development a major industry importing, processing, and applying phosphorus as a fertiliser across the various agricultural production systems within New Zealand, and as such directly underpins a significant proportion of agricultural production, and the profitability of the sector.

The key objective of this analysis was to analyse the impact across the agricultural sector; pastoral, horticultural and arable/vegetable of the absence of phosphorus fertilisers, in terms of production and profitability at the farm gate, and the wider impact on the national economy on GDP, employment, and exports.

Pastoral Sector

For the pastoral sector, this involved the development of 5 dairy and 4 sheep & beef regionally representative models within Farmax and Overseer, which enabled modelling of production, profitability and environmental impacts of farming with and without phosphorus. The key impact of the "without P" (i.e. Olsen P level of 5) scenario was:

- A reduction in pasture dry matter growth of 24-29% depending on soil type, based on the relative pasture DM production curves to Olsen P levels
- A change in the seasonality of the DM growth, and
- A reduction in the quality of the DM, assumed at 10%.
- In the sustained absence of P fertiliser inputs, resulting in P deficiency, other nutrient inputs would have little production effect.

A summary of the results at a national level shows:

Dairy

- Reduction in milksolids production of 1,176 million kgs (a 63% reduction)
- Reduction in farm profitability (EBITDA) of $5 billion (90%)

Sheep & Beef

- Reduction in production of 46%
- Reduction in farm profitability (EBITDA) of $906 million (51%)

In reality, all of the farms as they are currently structured would be uneconomic, requiring a significant restructuring to larger more extensive operations.

The environmental impact, directly as a result of the lower stock numbers and production, at a (weighted average) national level, was:

	Dairy	S&B
Reduction in N leaching	56%	42%
Reduction in P loss	36%	26%
Reduction in GHG Emissions	59%	44%

Permanent Horticulture Sector

This sector was analysed via the 4 main crops: pipfruit, kiwifruit, viticulture, and summerfruit. While phosphorus is an essential macronutrient for perennial horticulture crops and may have less of an impact on yield compared to nitrogen and potassium, it is vital for the overall balanced nutrition of high value fruit production. There is no research within New Zealand available on the impacts of phosphorus deficiency on yields, or the response to phosphorus fertiliser.

Estimates of production reduction were therefore made on the impacts of the "no P" scenario based on the amount of P loss via product and the relative efficiency of P storage within the plants themselves.

The overall impact, at the gross margin[1] level was assessed as:

	Pipfruit	Kiwifruit	Viticulture	Summerfruit	Other Hort
Production reduction	25%	25%	5%	15%	10%
Reduction in GM ($/ha)	$13,927	$24,807	$1,786	$9,753	$8,774
Extrapolated to a national level	$155,800,000	$359,700,000	$74,700,000	$23,500,000	$92,300,000

Overall national reduction in orchard gate profit is $706 million.

Arable/Vegetables

Again, there is very little research literature available on the impacts of P fertiliser application in the arable/vegetable sector. A key point is that nutrient uptake and yield response are not the same thing. When soil test values are low, crops may yield best at fertiliser rates that exceed their actual uptake of the same nutrients, largely because the crops have sparse root systems and a short growing season. The reduction in yield was estimated via the amount of P removed from the system as product, relative to the resultant decline in Olsen P levels.

The analysis investigated four main cropping systems:

- Leafy green vegetables
- Root vegetables
- Cereal grain crops
- Forage brassicas

The impact of the "with/without P" scenarios showed:

Land use	Area of crop grown.	Net loss in EBITDA	Loss in EBITDA
	(ha)	($/ha)	($m)
Leafy Green Vegetables	27,466	14,112	388
Root Vegetables	15,459	6,659	103
Cereal Grain	180,000	2,705	487
Forage Brassica	239,875	1,909	458
Total			1,436

[1] GMs were used for horticulture due to the lack of full orchard financial data

What this shows is that the farmgate impact at a national level, for the "without P" scenario, is $1.4 billion.

Farmgate Summary

The reduction in farmgate operating profit across the three sectors is:

	$ Billion
Pastoral	5.9
Horticulture	0.7
Arable/Vegetable	1.4
Total	8.0

This shows the total economic impact across the three sectors, at the farmgate, totals $8 billion.

Macro Level Impact

Macro-economic impacts were calculated using a 2016 Input-Output Table of the New Zealand Economy, covering 106 industries. Within these industries, the arable industry is included within the sheep & beef industry, and vegetables are included within the horticultural industry.

The modelling incorporated backward linkages which are the services each industry buys in to provide their goods, and forward linkages, which relate to the processing/manufacturing process through to the wharf. These covered: Gross Output, Value Add (GDP), and Employment.

A summary of the results is:

	Units	Horticulture and fruit growing	Sheep, beef cattle and grain farming	Dairy cattle farming	Meat and meat product manufacturing	Dairy product manufacturing	Fertiliser and pesticide manufacturing	Total
Gross Output	$NZ\$_{2016}m$	-4,370	-3,775	-11,640	-4,890	-18,660	-740	-44,070
Value Added	$NZ\$_{2016}m$	-2,260	-1,123	-4,140	-1,358	-5,150	-216	-14,240
Employment	$MECs_{2016}$	-32,620	-20,330	-54,470	-17,450	-34,940	-1,400	-161,210

MEC = Modified Employment Counts (a head count of employees and work proprietors)

This shows that:

- Gross Output reduces by $44 billion (5.5% of NZ total)
- Value Add (GDP) reduces by $14.2 billion (6.3% NZ total)
- Employment reduces by 161,210 MECs (6.7% NZ total)

These reflect annual impacts until the economy starts to adjust.

It is important to note that land use is likely to change in response to the absence of P fertilisers – exactly to what degree or what land use is unknown. This may be to an emergent land use, not currently present. Furthermore, given the quantity of land under consideration any change is likely to lead to transformational change.

Impact on Exports

This was assessed via two methodologies:

(i) The first was a simple extrapolation from the farm-level analysis, where the reduction in production was assessed against the 2023 export figures. This shows an overall reduction in export value from the agricultural sector of $24.8 billion, or a 54% decline.

(ii) The second approach was via the input/output analysis. This involved a 2-step process whereby export losses from the direct farm system changes were estimated at a cost of $21.6 billion (in 2022 values) and the flow on effects across the rest of the New Zealand economy was then also calculated, giving a loss figure of $4.2 billion (in 2022 values), giving an overall loss in export value of $25.8 billion.

Timeline for P Level Decline in Soils

The analysis within this study assumed a direct “with” versus “without” phosphorus fertiliser, with the “without” scenario assuming a relatively low Olsen P level (5).

In reality, with the current levels of Olsen P (circa Olsen 30 - refer Appendix 2) in soils in New Zealand, it would take some time for these levels to drop to the very low level assumed.

Research on the decline of Olsen P in the absence of P fertilisers in New Zealand is relatively limited, and also over a relatively limited time span of 7-11 years. These trials showed declines of 0.6 – 1.25 Olsen P units per year. A modelling exercise based on 41 trials across both dairy and sheep & beef showed that the rate of decline in Olsen P was proportional to the initial Olsen P. For example, at an initial Olsen P of 30 the rate of decline was 3 (1.4 to 5.1) Olsen P units per year. At Olsen P 10 the rate of decline was 1 (0.4 to 1.6).

Olsen P	Modelled Olsen P Decline (Olsen P units /yr) (41 trials (S/B and dairy))	Empirical (Olsen P decline in units/yr)	Soil Group	Farm Type
10	1 (0.4 - 1.6)	0.6 (Ballantrae, 7 years) 0.9 (Te Kuiti, 11 years)	sedimentary	Sheep
20	2 (0.9 - 3.4)	1.25 (Ave Waikato 8 trials, 8 years)		Dairy
30	3 (1.4 - 5.1)	1.25 (Ave Waikato 8 trials, 8 years)	volcanic	Dairy
40	4 (1.8 - 6.8)			

Based on this, and assuming the current Olsen P levels in New Zealand pastoral soils as a starting point, it is estimated that it would take around 20-30 years to reduce down to around an Olsen P of 5. Note there is some variation around this timeline, depending on farm and soil group and whether the modelled or empirical data is used as the basis for the estimate.

No such trials have been done with respect to horticulture or cropping. Given P loss via product take-off is relatively much higher compared with pastoral systems it could be expected that they reach low Olsen P levels comparatively quicker.

An analysis for the arable/vegetable sector estimated that, based on current average Olsen P levels, it would take 7-8 years to reduce down to around an Olsen P of 5.

For permanent horticulture, the time estimate would be slightly longer compared with cropping, mainly because the current average Olsen P level is much higher.

Alternative P Fertilisers

In the absence of any phosphorus fertilisers, either as rock phosphate or manufactured fertilisers e.g. superphosphate, the alternative fertilisers that could be used are manure-based fertilisers such as pig or poultry manure, or commercial compost.

Apart from the practicalities of application, the key issue with using such compost or manures usually comes back to the nutrient content of the manure, its availability, and its relative cost.

Compost application is a common practice in perennial horticulture. There is an existing supply and infrastructure to enable ready access to relatively affordable compost products.

An estimate of the amount of the respective manures available in New Zealand are:

- Pig manure (dry) 17,000 tonnes
- Poultry litter (dry) 346,000 tonnes
- Commercial composts n/a

The amount needed to be applied and the cost of this, relative to superphosphate, is:

kg of P supplied/ha	20	30	40	50
Superphosphate (kg/ha)	222	333	444	556
Pig Slurry (kg/ha)	10,000	15,000	20,000	25,000
Poultry Litter (kg/ha)	1,111	1,667	2,222	2,778
Commercial Compost (Fresh) (kg/ha)	6,667	10,000	13,333	16,667

kg of P supplied/ha	20	30	40	50
Superphosphate	$100	$150	$200	$250
Pig Slurry	$635	$953	$1,270	$1,588
Poultry Litter (South Island)	$88	$132	$176	$219
Poultry Litter (North Island)*	$167	$250	$333	$417
Commercial Compost	$567	$850	$1,133	$1,417

*Applied

This comparison needs to note:

- Transport and spreading costs need to be added to the above costs (other than the North Island poultry litter). It could be expected that given the greater quantities involved, these would disadvantage the alternatives versus super phosphate.
- The "bulk" of the manures and compost would also likely preclude their use on hill country given the practical difficulties involved in spreading.
- Compost does not dissolve like superphosphate and so compost can pose a continued risk of P runoff due to particles of compost sitting on the surface until they are broken down by natural processes and nutrients integrated into the soil. Against this it does increase organic matter in soils.

- The compost, pig manure and poultry litter would also be supplying additional nutrients in the form of nitrogen and potassium.

While there would be opportunity to use such manures in the arable/vegetable sector, again the “bulk” that would need to be applied to provide sufficient P is likely to be uneconomic, plus there is the issue with nitrogen - applying such manures would mean that there would be limited control over the amount of N being applied and the crops are very sensitive to both the timing and volume of their N requirements, which would not be able to be managed.

Overall, in the absence of phosphorus fertilisers, and given the relatively limited supply, it could be expected that such alternative fertilisers would, in the main, be more likely to be used in higher-value production systems, e.g. horticulture, rather than on pastoral or cropping farms.

2.0 BACKGROUND

Phosphorus is an essential nutrient both as a part of several key plant structural compounds and as a catalysis in the conversion of numerous key biochemical reactions in plants. Phosphorus is noted especially for its role in photosynthesis and converting the sun's energy into useful plant compounds[2].

Phosphorus is a vital component of DNA, the genetic "memory unit" of all living things. It is also a component of RNA, the compound that reads the DNA genetic code to build proteins, lipids, and nucleic acid and metabolizing sugars essential for plant structure, seed yield and genetic transfer. The structures of both DNA and RNA are linked together by phosphorus bonds.

Phosphorus is a vital component of adenosine triphosphate (ATP), the "energy unit" of plants. ATP forms during photosynthesis, has phosphorus in its structure, which drives biochemical reactions from the beginning of seedling growth through to the formation of grain and maturity.

Phosphorus is therefore essential for the general health and vigour of all plants and is directly involved in:

- Stimulating root development
- Increased stalk and stem strength
- Improved flower formation and seed production
- More uniform and earlier crop maturity
- Increased nitrogen N-fixing capacity of legumes
- Improvements in crop quality
- Increased resistance to plant diseases
- Increased tillering
- Improved water use efficiency

Within New Zealand soils, phosphorus, along with nitrogen, ranks as the most widespread deficient nutrient (Langer, 1973). At a plant level, grasses are more efficient in taking up phosphorus relative to legumes (clovers) but are often constrained by a limited supply of nitrogen. The most common fertiliser practice which has developed on New Zealand pastoral farms therefore is the application of phosphorus (along with other elements e.g. sulphur, potassium) which encourage clovers to growth which in turn fixes atmospheric nitrogen which then encourages grass growth.

The development of aerial topdressing (of superphosphate) in the late 1940's on hill country saw a significant improvement in pasture growth and composition as a result. Results (Table 1) for the Te Awa hill country research station (Manawatu) show:

[2] Crop Nutrition. https://www.cropnutrition.com/nutrient-management/phosphorus/

Table 1: Effects of subdivision, oversowing, topdressing and stocking rate on pasture characteristics

Pasture Composition		
	1948	1963
Ryegrass	4%	28%
Browntop	23%	16%
Total grasses	**63%**	**70%**
White clover	4%	19%
Total clovers	**6%**	**28%**
Catsear	16%	0%
Total weeds	**20%**	**1%**
Bare ground	**11%**	**0%**

Herbage Production		
	1948/49	Av 1960-63
Dry Matter (kg/ha)	7,870	13,440
Crude protein (% DM)	12%	21%
Crude protein (kg/ha)	920	2,840

Carrying Capacity		
	1948	1963
Ewes/ha	3.75	13.75

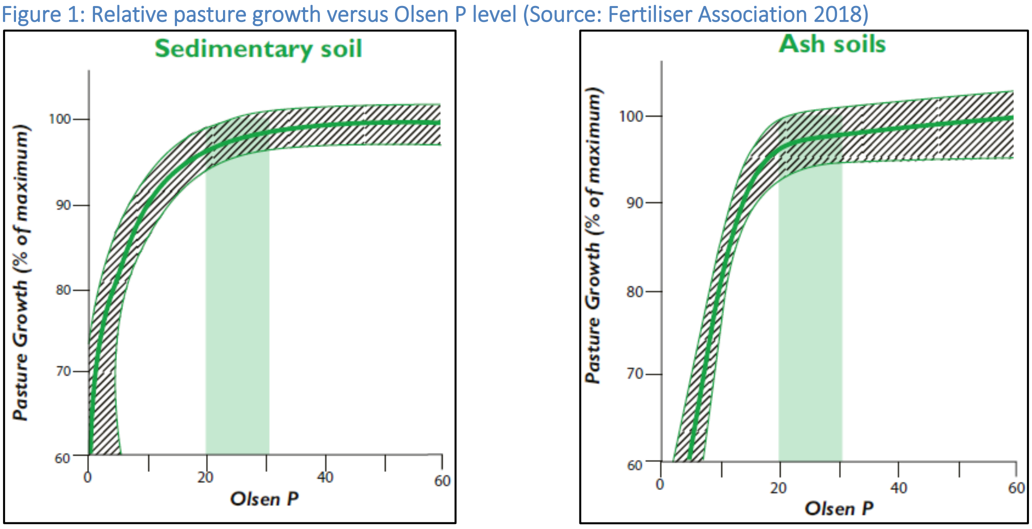
Source: Suckling 1964 – in Langer 1973

2.1 Olsen P Test

While there are a number of tests available to measure plant-available phosphorus levels in soils, the key test used in New Zealand is the Olsen P test. There have been thousands of trials relating phosphorus fertiliser applications to pasture production in order to develop a relationship between an Olsen P level and relative pasture dry matter production (Morton et al 2003, Edmeades et al 2006).

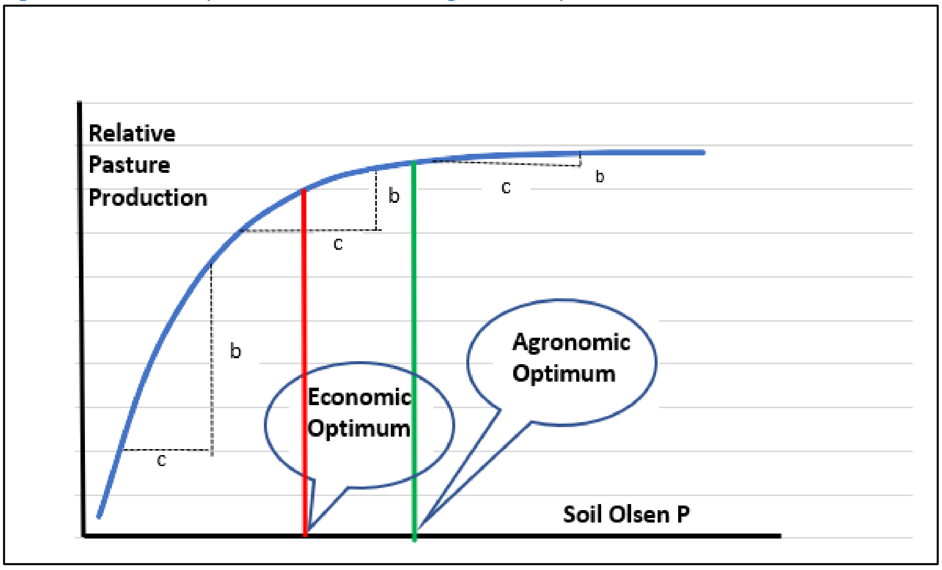
This has given rise to the relative pasture growth versus Olsen P level relationships, which varies depending on soil group.

Figure 1: Relative pasture growth versus Olsen P level (Source: Fertiliser Association 2018)



It is important to note that the relative curves illustrated in Figure 1 relate to the agronomic response/optimum, whereas at a farm level, the amount of fertiliser applied, and the desirable Olsen P level, need to relate to the economics of the farming system – in this case, usually the economic optimum is different to the agronomic optimum (Figure 2).

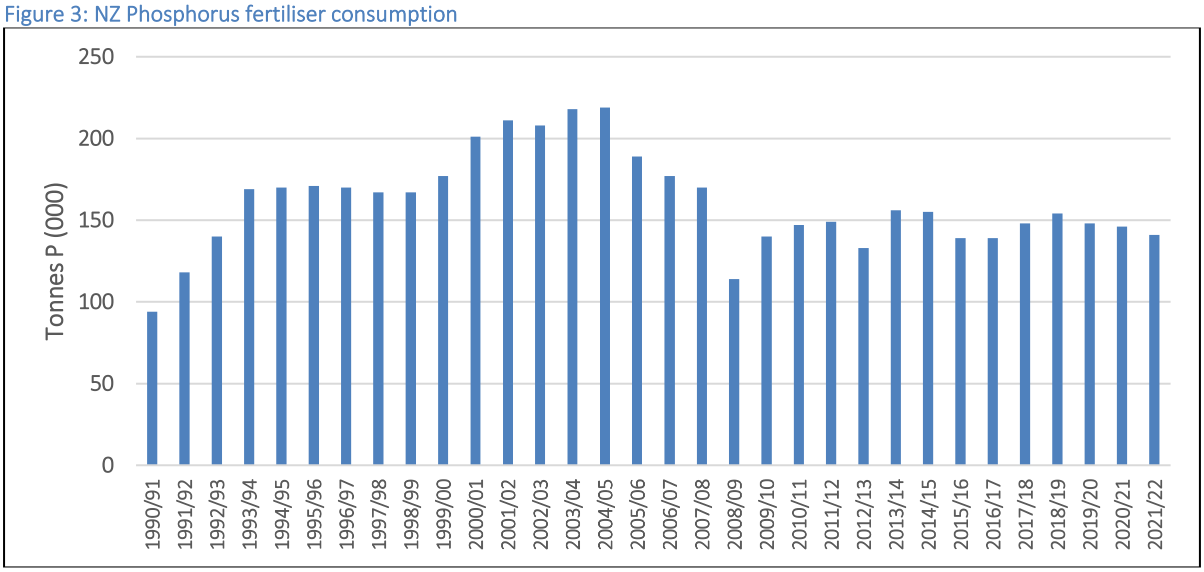
Figure 2: Economic Optimum Olsen P versus Agronomic Optimum



Source: Edmeades et al 2016 [If b is greater than c, it is economic to apply fertiliser]

New Zealand began importing phosphate fertiliser in 1867, with its first shipment of guano from the Pacific Islands, and superphosphate manufacturing commenced near Dunedin in 1881. The use of phosphatic fertiliser peaked in 2005 and has declined by 36% through to 2022 (Figure 3).

Figure 3: NZ Phosphorus fertiliser consumption



Source: Fertiliser Association

The majority of phosphate fertiliser is used across the pastoral sector relative to the others (Table 2):

Table 2: Use of phosphate fertiliser in different agricultural sectors

Sector	Proportion of Phosphate Fertiliser Usage
Sheep and Beef	43%
Dairy	49%
Deer Farming	1%
Arable	4%
Horticulture	4%

Source: Fertiliser Association (2022 Ag Census)

3.0 OBJECTIVE

The key assumption underlying this analysis is that there are no phosphorus-based fertilisers available for use in New Zealand. Given the importance of phosphorus fertiliser to New Zealand farming systems, the key objective of this study was to determine the value of such fertiliser to the New Zealand economy.

4.0 METHODOLOGY

The approach to this study involved several steps:

1. A brief literature review as to the importance of phosphatic fertilisers in New Zealand production systems.

2. An analysis as to the impact of a "with" versus "without" basis, where the "with" scenario is essentially the current situation regarding profitability and production under current P fertiliser usage. The "without" scenario analyses the level of production and profitability where the P level in the soil is assumed to be at a natural level (i.e. a very low Olsen P of 5) for all three sectors analysed.

   This analysis was across 3 key sectors.

   (i) Pastoral Sector. Inasmuch as this sector is the main user of P fertilisers, the analysis was across a range of models developed based on Dairy NZ and Beef+Lamb NZ statistics, in Farmax and Overseer. These models are:

   Table 3: Pastoral Models

Dairy	Sheep & Beef
Northland	North Island Hill Country
Waikato/Bay of Plenty	North Island Intensive
Taranaki	South Island Hill Country
Canterbury	South Island Intensive
Southland	

   An analysis was also carried out on the pastoral models as to the difference between nutrient losses (P, N) from the with/without scenarios, based on the Overseer analysis.

   (ii) Horticultural Sector. This covered 4 main industries:

   - Kiwifruit

- Pipfruit
- Viticulture
- Summerfruit (stonefruit)

Representative models were developed in Excel, in order to analyse the with/without scenarios.

(iii) Arable/Vegetable Sector. This covered 4 key crops:

- Forage Brassica
- Cereal grain
- Green leafy vegetables
- Root vegetables

Again, representative models were developed in Excel, in order to analyse the with/without scenarios.

3. A discussion on the extrapolation of the horticulture/arable cropping analysis across other minor crops.

4. A discussion as to the rate of decline in Olsen P levels in the soil in the absence of P fertilisers, to give an indication of the time period of "decay" of Olsen P levels from current down to base levels.

5. A discussion as to potential other P fertiliser substitutes, e.g. organic fertilisers such as pig and poultry manure.

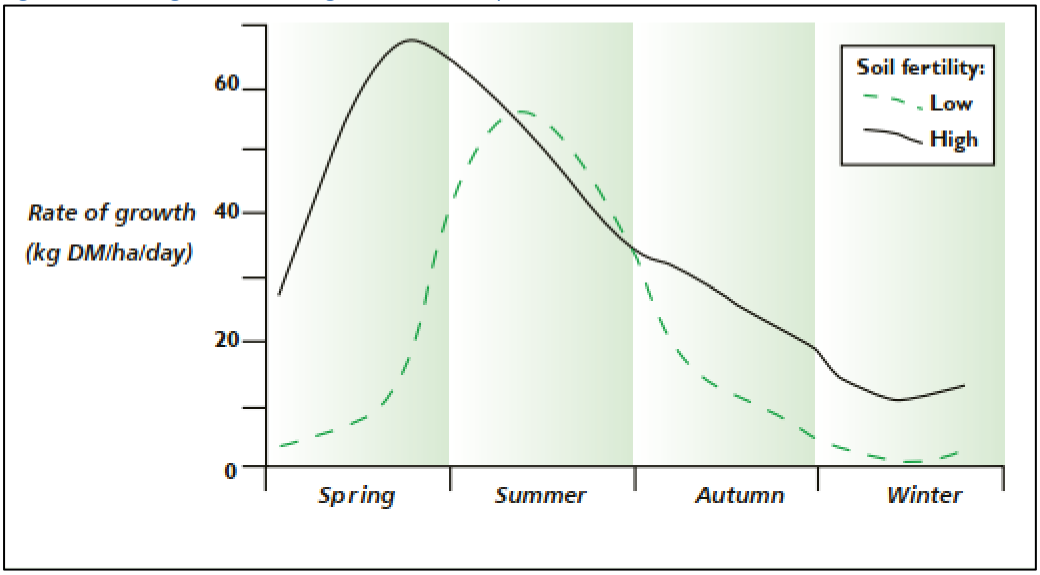
6. The farm-level analysis was then used as the base input material for a macro-economic analysis in order to extrapolate the impact to a national level, which respect to the impact on:
   - Exports
   - GDP
   - Employment

5.0 PASTORAL MODELLING

The main approach used in this analysis was to develop representative dairy and sheep and beef farms (as outlined in Section 4) in Farmax[3] and compare the production and profitability of these farming systems at their current level (i.e. "with" P fertiliser) against the same farm at a natural soil P level (i.e. a low Olsen P level – "without" P fertiliser).

The difference between the with and without scenarios was very largely based on the estimated pasture growth for both, where the "with" pasture growth was reduced down relative to the low Olsen P level to give the "without" situation, with this then also adjusted to represent the change in seasonality of growth expected at a low fertility level.

Figure 4: Pasture growth under high and low fertility levels



Source: Fertiliser Association 2018

The farm system operating in the "with" scenario was then reduced down to the point where it was feasible under the "without" scenario.

The farms were also set up in Overseer[4] to analyse the change in phosphorus loss from the farm system, between the two scenarios.

The farm systems modelled were as outlined in Section 4 (details of the models are shown in Appendix 1), with the dairy models covering 80% of dairy farms and the sheep & beef models covering 73% of all sheep & beef farms.

5.1 Reduction in Pasture Growth in the Absence of Phosphorus Fertiliser

With the difference in pasture growth relative to Olsen P levels differing as to the soil group (Figure 1), the assumption made was that the Waikato/BoP and Taranaki dairy farms were based on a volcanic soil, whereas the remaining dairy farms, and all the sheep & beef farms were based on sedimentary soils.

The national average Olsen P levels (refer Appendix 2) for dairying and sheep & beef are:

[3] Farm systems model. www.farmax.co.nz
[4] Nutrient budget model. www.overser.org.nz

Table 4: Average Olsen P Levels (2020)

	National Average	Volcanic Soils	Sedimentary Soils
Dairy	32	39	30
Sheep & Beef	23	23	23

Source: Fertiliser Association https://www.fertiliser.org.nz/Site/about/soil-health-fertility/nz-soil-olsen-p-levels.aspx (refer Appendix 2)

Referencing these levels to the relative pasture curves shown in Figure 1, the different farm types are operating at:

Table 5: Relative Pasture Growth under Current National Average Olsen P Levels

	Volcanic Soils	Sedimentary Soils
Dairy	98%	99%
Sheep & Beef	96%	99%

Under the "no P" scenario, the assumption is that Olsen P levels would drop back to their natural levels, assumed as Olsen 5. This would take some time, as discussed in Section 9, but for the purposes of this analysis, the modelling was based on the "with scenario" being current pasture growth levels, whereas the "without P" scenario assumed that pasture growth was relative to the Olsen 5 levels. Again utilising the curves shown in Figure 1, an Olsen P level of 5 for volcanic soils is 70% of maximum, and 75% of maximum for sedimentary soils. The reduction in pasture growth for the different farm types were:

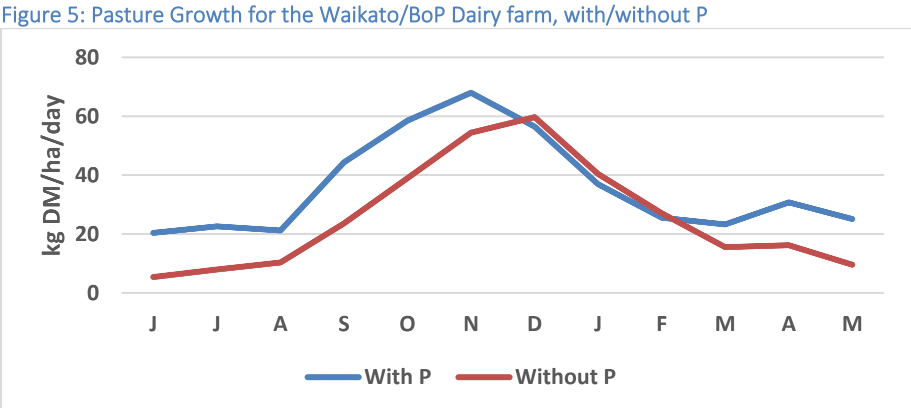
Table 6: Reduction in Pasture Growth due to the Absence of P

	Volcanic Soils	Sedimentary Soils
Dairy	28.6%	24.2%
Sheep & Beef*	27.1%	24.2%

* Some research indicates that unfertilised pastures on hill country would grow ~40% of the DM of a fertilised pasture (Kemp & Lopez, 2016)

These reductions were used within the models to reduce pasture growth, adjusted for the seasonality as per Figure 4, with stock numbers then reduced to accommodate the new feed situation. A representation of the "with" versus "without" scenario for the Waikato/BoP dairy farm is:

Figure 5: Pasture Growth for the Waikato/BoP Dairy farm, with/without P



5.2 Impact on Pasture Quality

As outlined in Table 1, the absence of P fertilisers would also result in a deterioration in pasture quality; the high quality ryegrass/clover pastures which is sustained by P fertiliser (and others) would rapidly deteriorate back to a browntop pasture mix, with plenty of weeds.

This reduction in pasture type and quality would directly compound the impact of the reduction in growth/change in seasonality of the existing pastures and was incorporated into the modelling (as a proxy) by reducing the metabolisable energy (ME) of the pasture by 10%.

5.3 Modelling Parameters

The key assumptions around the modelling were:

- Payouts and schedules were based on a 5-year average
- Farm working expenses were based on the relevant region or farm type from the latest available Dairy NZ or Beef + Lamb NZ economic survey
- The "with" scenario models were the current on-farm situation for the models, using current pasture growth curves. The physical attributes and production levels of each model are as shown in Appendix 1, based on the relevant Dairy NZ or Beef + Lamb NZ Economic Service statistics.

5.3.1 Without Scenario

In the without scenario models, the adjustments were:

- The pasture growth and seasonality were adjusted as discussed in Section 5.1
- Following the reduction in pasture DM production/seasonality/quality, stock numbers were then reduced down to the point where the model was biologically feasible.
- Any crops grown on-farm were eliminated – in the absence of P they would not grow
- Any surplus bought-in supplement was eliminated. Bought-in feeds from crops grown elsewhere (eg Maize silage) still occurred, although this may well not be possible (see Section 7)
- All fertiliser expenditure was eliminated – if P is limiting, then there is little use in applying other fertilisers.
- Other farm working expenses were tied to either cow numbers (dairy farms) or stock units (sheep & beef farms) which then reduced proportionally relative to the reduction in stock numbers.
- Given the reduction in the quality of the pastures, the performance of the farms was also reduced to allow for this. For the dairy farms this was largely via a reduction in per cow milksolids production, which flowed automatically from the modelling. For the sheep & beef farms, the performance reductions were:

Table 7: Reductions in S&B Farm Performance for the No P Farms (Relative to the "With P" Farms)

	NI Hill Country	NI Intensive	SI Hill Country	SI Intensive
Lambing	-5%	-5%	-5%	-5%
Calving	-5%		-5%	
Lamb kg CW	-1.0	-0.5		-1.0
Lamb kg LW			-0.5	
Steer kg CW	-10.0	-18		
Bull kg CW		-12		
Weaner kg LW			-5.0	

5.4 Results

5.4.1 Dairy Farms – Economic Impact

The modelling shows the following impacts on the different farms:

Table 8: Impact of no Phosphorus Fertiliser on Dairy Farms

	Cows	Total kg MS	EBITDA/ha
Northland			
With P	325	104,622	$1,261
Without P	153	28,722	$18
Difference (%)	-53%	-73%	-99%
Waikato/BoP			
With P	386	141,522	$3,171
Without P	191	45,412	$54
Difference (%)	-51%	-68%	-98%
Taranaki			
With P	300	119,470	$3,274
Without P	148	45,791	$361
Difference (%)	-51%	-62%	-89%
Canterbury			
With P	812	341,611	$4,327
Without P	449	139,953	$638
Difference (%)	-45%	-59%	-85%
Southland			
With P	604	261,030	$3,535
Without P	362	126,455	$770
Difference (%)	-40%	-52%	-78%

If this is extrapolated to the national level, the impact is:

Table 9: Extrapolation of Farm gate Impact to the National Level

	kg MS	Number of Farms	Total MS
National average farm	173,010	10,796	1,867,815,960
No P farm	64,111		692,146,059
Difference (kg MS)			-1,175,669,901
Difference (%)			-63%
Reduction in EBITDA for the national average farm			-$462,851
Total reduction at a national level			-$4,996,941,228

As can be seen from Table 9, at a national level there is a 63% reduction in milksolids production, and a farm gate cost of $5 billion.

5.4.2 *Sheep & Beef Farms – Economic Impact*

The modelling showed the following impact on the different farms:

Table 10: Impact of no Phosphorus Fertiliser on Sheep & Beef Farms

		Total Sheep	Total cattle	SU/ha	EBITDA/ha	Production (kg product/ha)
NI Hill Country	With P	2,217	444	9.6	$168	179.6
	No P	1,173	240	5.6	$121	89.7
	Difference (%)	-47%	-46%	-42%	-28%	-50%
NI Intensive	With P	1,179	386	12.0	$603	284.9
	No P	728	253	8.4	$346	173.1
	Difference (%)	-38%	-34%	-30%	-43%	-39%
SI Hill Country	With P	4,596	421	5.0	$72	72.8
	No P	2,986	274	3.5	$56	44.3
	Difference (%)	-35%	-35%	-30%	-22%	-39%
SI Intensive	With P	2,427	83	13.4	$507	318.1
	No P	1,578	54	10.1	$372	195.5
	Difference (%)	-35%	-35%	-25%	-27%	-39%

The key difference in the impact on the sheep & beef farms is that, proportionally, the EBITDA did not reduce as much as for the dairy farms. The main reason for this is that while gross revenues approximately halved, fertiliser costs, which are the largest single operating cost for sheep & beef farms, were eliminated, thereby also significantly reducing farm working expenditure.

If the figures are extrapolated to the national level, on a weighted basis, then:

- Production would fall by 46%
- The EBITDA for the average farm would reduce by $141.69/hectare. The 5-year average EBITDA for the Beef+Lamb NZ Economic Service all class average farm (Class 9) = $362.17/hectare. The reduction therefore in the "no P" scenario is 39% of this.
- Extrapolated to the national level, the reduction in farm-gate EBITDA equates to $906.4 million.

Comment

None of the pastoral farms modelled would be commercially viable under the “no P” scenario – the remanent EBITDA would not be sufficient to cover all the remaining costs of operating the farm, e.g.: personal drawings, debt servicing, farm development, capital expenditure/replacement, and debt reduction.

In reality therefore, there would be a major amalgamation of farms into much larger, more extensive operations – with economies of scale, along with the attendant social and economic costs of doing this.

5.4.3 Environmental Impacts

The pastoral farms were modelled via Overseer, to determine the impact of the “no P” scenario.

The results for the dairy models were:

Table 11: Environmental Impacts on Dairy Farms with no Phosphorus Fertiliser

Northland	With P	No P	% Diff		Waikato/BoP	With P	No P	% Diff
N leaching (kg N/ha)	36	11	-69%		N leaching (kg N/ha)	32	15	-53%
P loss (kg P/ha)	2.1	1.5	-29%		P loss (kg P/ha)	0.8	0.5	-38%
Gross GHG (T CO_2e/ha)	9.5	3.4	-65%		Gross GHG (T CO_2e/ha)	12.8	5.1	-60%
Biological GHG (T CO_2e/ha)	7.7	2.9	-62%		Biological GHG (T CO_2e/ha)	10.5	4.2	-60%
Taranaki					**Canterbury**			
N leaching (kg N/ha)	41	17	-59%		N leaching (kg N/ha)	63	25	-60%
P loss (kg P/ha)	0.7	0.4	-43%		P loss (kg P/ha)	0.9	0.6	-33%
Gross GHG (T CO_2e/ha)	12	4.9	-59%		Gross GHG (T CO_2e/ha)	16.4	7.3	-55%
Biological GHG (T CO_2e/ha)	9.9	4.2	-58%		Biological GHG (T CO_2e/ha)	14.0	6.5	-54%
Southland					**National (Weighted Average)**			
N leaching (kg N/ha)	22	11	-50%		N leaching (kg N/ha)	37	16	-56%
P loss (kg P/ha)	1.2	0.9	-25%		P loss (kg P/ha)	1.0	0.6	-36%
Gross GHG (T CO_2e/ha)	12.6	6.2	-51%		Gross GHG (T CO_2e/ha)	12.8	5.3	-59%
Biological GHG (T CO_2e/ha)	10.7	5.4	-49%		Biological GHG (T CO_2e/ha)	10.6	4.5	-58%

As Table 11 shows, at the national level the absence of P fertilisers, and consequent reduction in Olsen P levels on dairy farms has resulted in a;

- 56% reduction in nitrate leaching
- 36% reduction in phosphorus loss
- 59% reduction in greenhouse gas emissions

For the sheep & beef farms the results were:

Table 12: Environmental Impacts on Sheep & Beef Farms with no Phosphorus Fertiliser

NI Hill Country	With P	No P	% Diff
N leaching (kg N/ha)	16	8	-50%
P loss (kg P/ha)	0.6	0.4	-33%
Gross GHG (T CO_2e/ha)	3.5	1.8	-49%
Biological GHG (T CO_2e/ha)	3.2	1.7	-47%

NI Intensive	With P	No P	% Diff
N leaching (kg N/ha)	10	9	-10%
P loss (kg P/ha)	0.6	0.5	-17%
Gross GHG (T CO_2e/ha)	4.6	2.9	-37%
Biological GHG (T CO_2e/ha)	4.2	2.7	-36%

SI Hill Country	With P	No P	% Diff
N leaching (kg N/ha)	9	7	-22%
P loss (kg P/ha)	0.3	0.3	0%
Gross GHG (T CO_2e/ha)	1.8	1.1	-39%
Biological GHG (T CO_2e/ha)	1.6	1.1	-35%

SI Intensive	With P	No P	% Diff
N leaching (kg N/ha)	16	7	-56%
P loss (kg P/ha)	1.4	1.1	-21%
Gross GHG (T CO_2e/ha)	5.0	3.2	-36%
Biological GHG (T CO_2e/ha)	4.6	3.1	-33%

National (Weighted Average)			
N leaching (kg N/ha)	14	8	-42%
P loss (kg P/ha)	0.7	0.5	-26%
Gross GHG (T CO_2e/ha)	3.7	2.1	-44%
Biological GHG (T CO_2e/ha)	3.4	2.0	-42%

For the Sheep & Beef farms at the national level, the absence of P fertilisers will result in a;

- 42% reduction in nitrate leaching
- 26% reduction in phosphorus loss
- 44% reduction in greenhouse gas emissions

As could be expected, the key reason for the reduction in environmental impact was largely due to the reduction in stock numbers, coupled with no fertiliser application.

6.0 HORTICULTURAL MODELLING

6.1 Background

Phosphorus is an essential macronutrient for perennial horticulture crops. The nutrient plays a crucial role in overall plant growth and functionality. Particularly, phosphorus is required for root development, photosynthesis and energy transfer, flower and fruit development and aiding resistance to stress and disease. Phosphorus is also essential in the utilisation and uptake of other essential nutrients such as nitrogen and zinc. Whilst phosphorus may have less of an impact on yield compared to nitrogen and potassium in permanent horticulture, it is vital for the overall balanced nutrition of high value fruit production.

Phosphorus is less mobile in the plant, and a relatively small amount of phosphorus is taken off in harvested fruit removed, compared with other macronutrients. Much of the phosphorus will accumulate in fruiting wood (Smith et al., 1987) and therefore be recycled into soils and further production from mulched pruning wood. It is important that phosphorus plant content reserves are sustained so that the nutrient is available during the initial phases of early spring growth.

Unlike in the pastoral sector, there are not the calibrated yield curves that clearly demonstrate the impact of phosphorus applications and resultant yields in horticultural crops. Research around the topic is limited. Much of the research reports describes deficiency symptoms but little work has been done to measure the impact of phosphorus deficiency on commercial production.

Growers typically apply phosphorus based on Olsen P levels in the soil. In the crops focused on in this report, kiwifruit, pipfruit, summerfruit and wine grapes, Olsen P levels of >30 are considered ideal. (Clarke et al, 1986). Many of the areas in which these crops are grown had median Olsen P levels at or above this level when reported in 2020 with land classified as use for 'orchards' reported as having the highest Olsen P levels at an average of 47, when compared to other land uses, such as dairy at 32, arable at 24 and sheep and beef at an Olsen P of 23 (refer Appendix 2).

Table 13: Average Horticultural Olsen P levels 2020

	Ash	Sedimentary	Pumice	Peat	Average
Orchards (Permanent Horticulture)	48	37	46	n/a	47

Source: Fertiliser Association of NZ. Association https://www.fertiliser.org.nz/Site/about/soil-health-fertility/nz-soil-olsen-p-levels.aspx

Typically, land used for orchards or permanent horticultural crops has been under the same land use for decades or has been converted from high quality pastoral land. As a result of this, the majority of the permanent horticulture industry already inhabit fertilised soils which had already high Olsen P levels and well supplied soil reserves.

Considering this, only maintenance applications of phosphorus are generally recommended to supply the plant with the required phosphorus for that season's growth, and capital applications is not considered necessary unless the soil reserves are considerably low (i.e. <10 Olsen P (Clarke et al. 1986)). There is little information available as to what the impact of reducing or removing the maintenance dressing of phosphorus would be on the long term productivity or viability of the horticulture industry. More recent developments have commonly been on more marginal land and is unlikely to have such high reserves of phosphorus, and thus may be impacted at a faster rate than orchards which have been established in higher quality soils.

There has also not been sufficient research to understand how long it will take for the soil reserves to be depleted without the recommended maintenance applications of phosphorus and whether the substitutes available will be suitable to supply enough nutrients at the correct time to target plant uptake and performance and mitigate environmental impacts most effectively.

Given the lack of research data, the assumption was the same as for the pastoral analysis, namely that the "no P" scenario results in a reduction in Olsen P down to 5. The time taken to achieve this is discussed in Section 9.1.3.

6.2 Methodology

In order to estimate the economic impact of the lack of availability of phosphorus, information has been collected at a macro level in terms of total volume and value of exports from various horticultural crops and then at a grower level on a per hectare basis.

A standard methodology was developed for this analysis. At the macro level, the five-year average export value and volume was calculated from export statistics. Gross margins were developed for four high value crops: kiwifruit, pipfruit, wine grapes and summerfruit. Cherries were used as a proxy for summerfruit (being the single largest summerfruit crop), where as a hybrid gross margin weighted by the varietal split was used (e.g. the kiwifruit gross margin was constructed as a hybrid of both gold and green) for the other crops.

Data in the various horticultural industries is available to varying degrees. Some is reported on an industry wide level in quite some detail. For example, Zespri, the marketer of kiwifruit from New Zealand internationally, reports in a detailed manner on a variety by variety basis. Other horticultural crops do not have data reported to this level and some have more of a domestic market focus.

To ensure consistency in the manner in which the data has been put together it was decided to:

- Use export statistics reported by Statistics New Zealand rather than industry data for export income and volume.
- Use viticultural monitoring data for crop volumes and income for wine grape growers.
- Use Freshfacts publications to provide detail on the value and volume of domestic produce where this is significant and available.
- Use available data and adjust for increases in price to generate gross margins.

The reduction in yield that might occur as a result of no access to phosphorus as an annual input was then estimated.

A reduction in volume exported from New Zealand may possibly increase international prices. This was not accounted for in the analysis.

6.3 Kiwifruit

Kiwifruit is grown predominantly in the upper North Island. Much of the Bay of Plenty and Waikato kiwifruit production is grown on volcanic ash; allophanic and pumice soils. Most of Auckland and Northland production takes place on volcanic brown soils, Gisborne and Hawkes Bay production on recent sedimentary soils and South Island production sees a mixture of sedimentary and brown volcanic soils. This range in soil types and their subsequent phosphate retention and nutrient profiles can result in a varied approach to kiwifruit nutrition and fertiliser regime depending on soil type and current soil nutrient reserves. However volcanic soils, which the majority of kiwifruit production takes place on, have a moderate to high ASC.

Table 14: Area Planted in Kiwifruit by Region

Region	Ha
Northland	630
Auckland	632
Bay of Plenty	11,429
Waikato	619
Gisborne	485
Hawkes Bay	212
Lower North Island	78
Tasman	427
Total	14,512

Source: Zespri Annual Report 2022/23

Of the 14,500 ha of kiwifruit in production, more than half (57%) is now in the highly productive, high value Gold3 variety.

The five-year average export earnings from kiwifruit are around $2.5 billion from a five year average volume of 565 million kilograms of fruit (Statistics NZ).

As most of the soils in which kiwifruit production takes place have high phosphorus retention, owing to high iron and aluminium content, and greenfield developments are usually conversions from pastoral grazing, noticeable phosphorus deficiencies are rarely expressed in kiwifruit vines. Kiwifruit vines must be placed under extreme phosphorus restrictions to show symptoms of deficiency. Kiwifruit vines have a tolerance to high levels of phosphorus present in the soil and can maintain comparatively low levels of phosphorus present in the plant growing in such soils (Smith et al., 1985).

Phosphorus deficiency, under laboratory research (Buwalda et al. 1987), shows severely restricted growth, reduced trunk size, chlorosis (yellowing) in older leaves and the underside midrib of leaves can become reddened. As noted above, for general phosphorus requirements in horticulture, phosphorus deficiencies will be impacting kiwifruit vines in less obvious ways, such as reduced root development, photosynthesis, energy transfer, flower and fruit development. Such reductions in production are not likely to be recognised as phosphorus deficiency or recognised at all. However, all the deficiency impacts will affect production yields.

A reduction in phosphate fertiliser would result in less replacement cane growth, the cane on which fruit is produced in the following growing season. Growers could change management practices to account for this, but it is likely that a lack of phosphorus fertiliser would reduce yield significantly.

It is estimated that crop removal of phosphorus is around 6 kg/ha with every 25,000 kg of fruit harvested (Clarke, et al. 1986). Yields of 40,000 kg/ha (10,000 export trays) are typical for the conventionally grown green kiwifruit and 55,000 kg/ha (13,750 trays) for the higher yielding gold kiwifruit.

Growers typically apply phosphate fertilisers in their late winter, early spring nutrition programme based on their soil test results. It is not uncommon for growers to apply no phosphate, with the intention of "mining" the soil reserves of phosphate. Where phosphate is applied, amounts of 30-40 kg/ha are typical (J. Benge, Zespri International Ltd, pers comms, October 2023).

Kiwifruit is also grown organically without the use of synthetic phosphate fertilisers. For the 2022 harvest, there were around 750 hectares of organic production in New Zealand, which relies mainly on compost and organic certified foliar feeds, such as seaweeds, for nutritional inputs. Though the average yields achieved by organic growers are lower than conventional growers, it demonstrates that kiwifruit can be grown successfully without inputs of synthetic phosphorus fertilisers.

6.3.1 Kiwifruit Financial Model

The kiwifruit financial model is a hybrid of green and gold kiwifruit. The "without P" model assumed a 25% reduction in fruit volumes which resulted in both reduced income and reduced variable costs. Fixed costs, other than the cost of the phosphorus and total fertiliser inputs, did not change. Total fertiliser inputs would be reduced by 25% also as the inputs, mainly nitrogen and potassium are applied on the basis of target yield.

Table 15: Financial Impact of no Phosphorus Fertiliser on Kiwifruit

Kiwifruit Model	With Phosphorus (per ha)	Without Phosphorus (per ha)
Yield (kgs)	42,741	31,551
Income ($/kg weighted)	$3.69	$3.69
Income ($/ha)	**$157,904**	**$116,561**
Post Harvest Costs ($)	$50,536	$37,305
Orchard Gate Return ($)	**$107,368**	**$79,257**
Total Labour Expenses ($)	$38,887	$36,481
Fertiliser and Lime ($)	$2,578	$1,680
Other Direct Expenses ($)	$10,867	$10,867
Total Direct Expenses ($)	**$52,333**	**$49,028**
Gross Margin ($)	**$55,035**	**$30,229**

Extrapolated to the national level, this represents a reduction of $359.7 million.

6.4 Pipfruit

Most of the commercial apples and pears grown throughout New Zealand are grown in the Hawkes Bay region's recent sedimentary soils, developed from historic riverbeds. Nelson pipfruit production occurs on a mixture of sedimentary and volcanic ash soils, Gisborne on sedimentary soils and Central Otago production takes place on varied semiarid, pallic and volcanic brown soils. Semiarid soils and pallic soils typically have a very low to low phosphorus retention and would require a different fertiliser regime to those trees grown on ash soils.

There was a total of 11,190 ha in pipfruit production in 2022. Cyclone Gabrielle impacted severely on the major growing regions and remaining areas are yet to be quantified. The five-year average export income from pipfruit is $830.1 million from the five year average 367 tonnes exported (Statistics NZ).

Phosphorus plays a vital role in high value pipfruit production. It is important for overall plant health, and important for trees being resistant to damaging fungal diseases. It is essential that there is adequate phosphorus stored in the plant, so during new spring growth, the nutrient is available to optimize root development and activity, as well as provide nutrient necessary for effective bud burst, flower cluster development and fruit set. Phosphorus levels within fruit also have an impact on pipfruit appearance and long-term storage. Optimal available phosphorus can increase fruit size, helps with colour development, increases calcium levels in fruit, fruit firmness and plays a part in reducing storage diseases and disorders such as low temperature breakdown.

Phosphorus deficiencies has been shown to reduce apple yields. An Australian 10-year study (Cripps, 1987) found that a 'with and without' control of phosphorus for mature apple trees saw a 30% reduction in total weight of harvested fruit where there was no phosphorus fertiliser application. Since this study was published, growing systems have changed significantly with higher density plantings requiring less structural wood to be produced. The assumption is that there would be a yield reduction, but not as large as reported in this study.

Growers typically apply phosphate fertilisers in their spring nutrition programme based on their soil test results. It is not uncommon for growers to apply no phosphate. When phosphate is applied, amounts of 20-30 kg/ha are typical (Dryden. G, 2023, pers comm).

Crop removal of phosphorus amounts to around 0.7 - 1.4 kg/ha in a 10 tonne crop (Clarke et al. 1986). With average yields estimated to be 60,000 kg/ha, this amounts to annual crop removal of 4.2 – 8.4 kg/ha.

6.4.1 Pipfruit Financial Model

The pipfruit financial model is a hybrid of the range of varieties grown and a mix of export and domestic consumption. The without model assumed a 25% reduction in fruit volumes. The yield reduction resulted in both reduced income and also reduced variable costs. Fixed costs, other than the cost of the phosphorus and total fertiliser inputs did not change. Again, total fertiliser was reduced on the anticipated yield reduction. It is important to note that income price for pipfruit is presented as after postharvest costs have been deducted, and so the gross margin is calculated from income minus direct expenses, unlike the other crops where it is calculated as orchard gate return minus direct expenses.

Table 16: Financial Impact of no Phosphorus Fertiliser on Pipfruit

Pipfruit Model	With Phosphorus (per ha)	Without Phosphorus (per ha)
Yield (kgs)	60,000	45,000
Income ($/kg weighted)	$1.14	$1.14
Income ($/ha)	**$68,500**	**$51,375**
Post Harvest Costs ($)	$33,712	$25,284
Orchard Gate Return ($)	**$34,788**	**$26,091**
Total Labour Expenses ($)	$34,232	$31,261
Fertiliser and Lime ($)	$625	$398
Other Direct Expenses ($)	$11,848	$11,223
Total Direct Expenses ($)	**$46,079**	**$42,881**
Gross Margin ($)	**$22,421**	**$8,494**

Extrapolated to the national level, this represents a reduction of $155.8 million.

6.5 Viticulture

Gisborne, Hawkes Bay, Marlborough and Canterbury viticulture grape production takes place on recent sedimentary soils built up from historic alluvial deposits. These soils have a medium phosphorus retention of around 30%.

Table 17: Area Planted in Winegrapes by Region

Region	Ha
Northland	73
Auckland	276
Waikato/ Bay of Plenty	13
Gisborne	1,300
Hawke's Bay	4,805
Wairarapa	1,089
Marlborough	29,654
Nelson	1,080
North Canterbury	1,464
Central Otago	2,054
Waitaki Valley	52
Total	41,860

Source: NZ Winegrowers Annual Report, 2022

Wine growing is the largest, by area, horticultural crop grown in New Zealand with close to 42,000 ha planted. The majority (70%) of this production occurs in the Marlborough region. The five-year average volume of 271,000 litres generated an average of $1.84 billion in exports (Statistics NZ).

Soils deficient in phosphorus, Olsen P < 10, produce lower yields (Lazcano et al. 2020). Once capital phosphorus reserves are established, maintenance phosphorus application may not occur every year, only as indicated by soil and/or leaf testing. Because grape vines require comparatively lower levels of phosphorus compared to other high value New Zealand crops, vines can utilise the small reserves levels (i.e. weathering of apatite) as it becomes slowly available in the soil soluble solution.

It is important to have optimal available phosphorus during flower bud development, fruit set and fruit expansion. Optimal phosphorus soil reserves help to increase the number of grape berries within a bunch and the overall bunch weight (Australian Wine Research Institute, 2023). Where available phosphorus is low, grape vines will show reduced vegetative and reproductive growth, often initially presenting as stunted shoots. Leaves may become bronzed or red in colour in older leaves, as nutrition will be sent to developing leaves.

Grape vines produce a considerable amount of vegetative growth over summer, much of which is pruned off in winter leaving a small amount of fruiting wood to produce a crop. There are some who have argued that phosphorus deficiency could benefit wine grape production, owing to lower more concentrated yields. This has not been proven.

Wine growers typically apply small amounts of phosphorus to their vineyards with annual quantities ranging from 0 -20kg/ha (Dryden, G, 2023, pers comm). Crop removal of phosphorus amounts to 8 kg in a 20,000 kg/ha harvested (Clarke et al. 1986). With annual yields slightly lower that this at 15,100 kg/ha (MPI Viticulture Monitoring Report) this results in just over 6 kg/ha being removed in the harvest.

6.5.1 Viticulture Financial Model

The viticulture financial model is a hybrid of the range of varieties grown and a mix of export and domestic consumption. The without model assumed a 5% reduction in harvested volumes. The yield reduction resulted in both reduced income but not reduced variable costs as most of the crop is machine harvested and the cost of this harvesting would be little impacted by a small reduction in yield. Wine grapes are most often sold to the winemaker at contract rates and the post-harvest and wine making, costs are not taken into account in the viticulture analysis. Fixed costs, other than the cost of the phosphorus input did not change. Though because phosphorus is such a minor input, this has no impact on total spending on fertiliser.

Table 18: Financial Impact of no Phosphorus Fertiliser on Viticulture

Viticulture Model	**With Phosphorus (per ha)**	**Without Phosphorus (per ha)**
Yield (kgs)	15,100	14,350
Income ($/kg weighted)	$2.37	$2.37
Income ($/ha)	**$35,712**	**$33,926**
Post Harvest Costs ($)	$0	$0
Orchard Gate Return ($)	$35,712	$33,926
Total Labour Expenses ($)	$9,300	$9,300
Fertiliser and Lime ($)	$500	$500
Other Direct Expenses ($)	$3,570	$3,570
Total Direct Expenses ($)	$13,370	$13,370
Gross Margin ($)	**$22,342**	**$20,556**

Extrapolated to the national level, this represents a reduction of $74.4 million.

6.6 Summerfruit

Summerfruit includes cherries, apricots, peaches, plums and nectarines. Two thirds of summerfruit is produced in Central Otago with the balance in Hawkes Bay on sedimentary soils. The orchards in Central Otago on semiarid and pallic soils have a low phosphorus retention.

Table 19: Area Planted in Summerfruit by Region

Region	Ha
Central Otago	1,442
Hawkes Bay	467
Other Regions	332
Total	2,241

Source: FreshFacts 2023

Exports are mostly of cherries and apricots with minor volumes of other summerfruit also being exported. Export volumes amounted to 2,993 tonnes in the three years to June 2022. Exports volumes have not been separated from domestic volumes in data accessed. The total export value for the past five years has been an average of $63 million.

The role of phosphorus in summerfruit production is significant for root development, especially in juvenile trees, for leaf growth, flower development and fruit set. Whilst not required in large amounts for summerfruit, phosphorus can have a causal effect on the number of flower buds, and fruitsets (Ystaas & Froynes, 1990). This leads to implications with the amount of fruit produced per tree. Like pipfruit, phosphorus does play a role in the colouration of summerfruit, important for high value export crops.

Summerfruit trees can display varying phosphorus deficiency symptoms. Typically, deficient trees will present with chlorosis (discolouring in leaves), eventuating in leaf necrosis and defoliation in extreme cases. Maturity in fruit can be delayed and produce smaller lower quality fruit with less sugar content due to the decrease in energy transfer. As with pipfruit production, the impact of reduced tree growth is not as significant with the higher density plantings typical of new developments.

Yields range considerably for the various summerfruit crops grown in New Zealand. A typical cherry yield is around 10,500 kg/ha whereas peaches grown for canning can yield as much as 40,000 kg/ha (Clarke et al. 1986). Crop removal is estimated to be 2 kg/ha phosphorus in a 10,000 kg crop resulting in amounts of 2 kg/ha being removed in cherry production and 8 kg/ha from a peach crop.

Annual phosphorus applications in summerfruit production ranges from 0 - 100 kg/ha depending on Olsen P levels. At a moderate Olsen P (10 – 30 units) applications of 20 – 30 kg/ha are typical.

6.6.1 Summerfruit Financial Model

The summerfruit financial model uses cherries as a base as this is the highest volume of summerfruit exported and the largest area (58%) of summerfruit type grown, with 1,250 ha in production. The without model assumed a 15% reduction in harvested volumes. The yield reduction resulted in both reduced income and reduced variable costs as harvesting and postharvest costs are reduced. Because phosphorus is such a minor input, this has no impact on total spending on fertiliser.

Table 20: Financial Impact of no Phosphorus Fertiliser on Summerfruit

Summerfruit Model	**With Phosphorus (per ha)**	**Without Phosphorus (per ha)**
Yield (kgs)	10,500	8,925
Income ($/kg weighted)	$16.00	$16.00
Income ($/ha)	**$168,000**	**$142,800**
Post Harvest Costs ($)	$59,125	$50,256
Orchard Gate Return ($)	**$108,875**	**$92,544**
Total Labour Expenses ($)	$67,375	$60,878
Fertiliser and Lime ($)	$545	$463
Other Direct Expenses ($)	$13,189	$12,976
Total Direct Expenses ($)	**$80,896**	**$74,317**
Gross Margin ($)	**$27,980**	**$18,227**

Extrapolated to the national level, this represents a reduction of $21.9 million.

6.7 Rest of Horticulture

This analysis has focused on four significant horticultural crops. The impact of no phosphorus fertilisers will also impact the entire horticultural industry. Most of these other crops are grown in areas of relatively good Olsen P levels (NZ Fertiliser Association) due to their previous growing history and therefore fertiliser regime. Those industries based on more marginal land, with lower soil phosphorus reserves would be impacted more than those longstanding industries on soil with higher phosphorus reserves.

If kiwifruit, pipfruit, summerfruit and vineyard areas are removed from the national production statistics, there are a further 10,525 ha left in horticultural production. From this area there were a five-year average of 89.2 million kgs of produce exported at a five-year average of $503 million. It was estimated that the overall reduction in yield from this area would be 10% if phosphorus were no longer available.

6.8 Summary

The reduction in export volumes and value is assumed to be significant but not catastrophic as a result of the lack of access to mineral phosphorus. It must be noted however, that this estimate is based on very limited empirical evidence, rather a judgement on the relative importance of phosphorus in the particular crops considered and the changes in management that could mitigate this impact.

The overall impact on the sector, at the farm gate, is estimated as follows:

Table 21: Total Horticultural Farm Gate Impact

Pipfruit	$155,850,000
Kiwifruit	$359,740,000
Viticulture	$74,740,000
Summerfruit	$23,500,000
Other horticulture*	$92,340,000
Total	$706,170,000

*Based on a weighted average per hectare cost across the 4 main crops

A key mitigation for horticulture, in the absence of mineral phosphorus fertilisers, would be access to organic material, as discussed in Section 10.

7.0 ARABLE/VEGETABLE MODELLING

7.1 Background

There is very little national or international research into the impacts of P fertiliser application in this sector that has been carried out on similar soils and climatic conditions to those experienced in New Zealand. The vast majority of information that has been used in this section of the report have been gained from:

- Nutrient management for vegetable crops in New Zealand. JB Reid & JD Morton. (2020)
- Managing Soil Fertility on Cropping Farms. Nichols A et al. (Revised June 2017)
- Fertiliser Use on New Zealand Forage Crops. Morton J et al. (Revised 2020).

All the major nutrients are taken up from the soil solution in the ionic form. When supply of any one nutrient is very low it will limit crop growth and yield, but the limitation becomes less and less as more of the nutrient is supplied. It may even reach the point where adding more will decrease growth and yield. If any single nutrient is limiting growth, it will reduce the responsiveness of the crop to additions of the other nutrients.

Crops take up most of their mineral nutrients from the soil. Only a fraction of the total amount of nutrients held in soil is rapidly available to plants. Vegetable crops typically have a short growing season and need to take up large quantities of nutrients quickly. Their root systems are quite sparse and have little time to explore the soil and access nutrients in it.

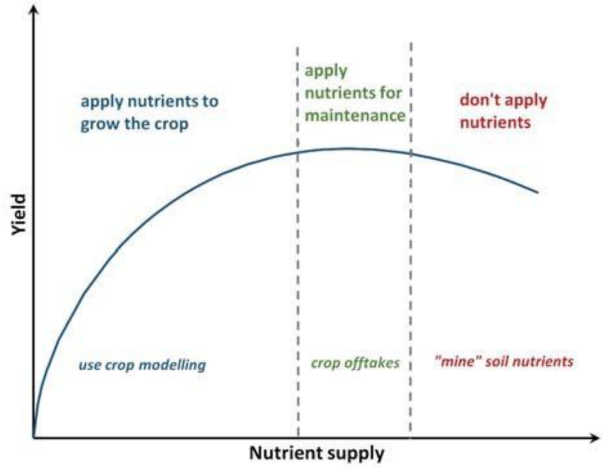
Compared with pasture species therefore, arable crops and most vegetable crops require the soil to have quite high concentrations of mineral nutrients to maintain a high rate of nutrient uptake.

It is easy to overestimate the amount of nutrients that need to be added to a soil for optimum vegetable growth. Some vegetables can take up nutrients well beyond the amounts they actually need (luxury uptake). Leafy vegetables and root crops are predisposed to luxury uptake (especially of N and K), and this may be associated with negative effects on crop quality. Furthermore, yield of some crops can be decreased by an over-supply of some nutrients.

The main factors that influence the likely outcomes from nutrient additions are:

- Potential yield — this dictates the maximum amount of nutrients the crop needs, and is influenced mainly by weather, the plant population and quality considerations for marketing (e.g. plant size).
- Non-nutritional factors that lower potential yield to field yield. Examples are water stress, poor soil structure, pests and diseases.
- Chemical fertility of the soil (quantified by soil testing).
- Nature of the additions and how they are applied — are the nutrients quickly or slowly available, are they broadcast or banded, when are they applied relative to crop needs?

Figure 6: Typical response of crop yield to the total supply of a single nutrient (from the soil and from addition). The upper limit of yield is set by crop characteristics and the weather



Source: Reid and Morton 2020

A key point is that nutrient uptake and yield response are not the same thing. When soil test values are low, crops may yield best at fertiliser rates that exceed their actual uptake of the same nutrients. This is because the crops have sparse root systems and a short growing season. However, the disparity between uptake and the fertiliser rate for the best yield should be reduced by careful placement and timing of fertiliser applications.

7.1.1 Vegetables

The following tables show the range of P required to grow the various crops at a range of Olsen P levels and the typical amounts of P removed by the crop.

7.1.1.1 Buttercup Squash

Table 22: Range of P (kg/ha) required to grow Buttercup Squash at a range of Olsen

Olsen P	P required for a yield of 40 t/ha	P required for a yield of 28 t/ha
10	50	30
20	40	20
30	30	10
40	20	11
50	16	nil
60	nil	

What this table shows is that (for example) to produce a yield of 40T/ha, at an Olsen P of 10 within the soil, 50kg P/ha fertiliser needs to be applied. At an Olsen P of 20, 40kg P/ha is required, etc.

The volume of P which is removed by the growing of a 40 t/ha crop is 16 kg P/ha and for a 28 t/ha crop is 11 kg P/ha.

7.1.1.2 Cabbage, Broccoli and Cauliflower

Table 23: Marketable yield and offtake of P for Cabbage, Broccoli and Cauliflower

Crop	Marketable Yield (t/ha)	Offtake Kg P/ha
Cabbage, winter planted	68	19
Cabbage, summer planted	45	13
Broccoli, winter planted	16	10
Broccoli, summer planted	11	7
Cauliflower, winter planted	33	20
Cauliflower, summer planted	22	13

It is suggested that the optimum rate of Olsen P to grow Cabbage, Broccoli and Cauliflower is 50.

7.1.1.3 Carrots

Table 24: Range of P (kg/ha) required to grow Carrots at a range of Olsen P's

Olsen P	P required for a yield of 100 t/ha	P required for a yield of 170 t/ha
10	30	70
15	30	60
20	25	50
30	nil	40
40	nil	nil

Again, to grow 100t/ha in a soil with Olsen P of 10, 30 kg P/ha must be applied, and to grow 170t/ha, 70 kg P/ha must be applied.

The volume of P which is removed by the growing of a 100 t/ha crop is 31 kg P/ha.

7.1.1.4 Onions

Table 25: Range of P (kg/ha) required to grow Onions at a range of Olsen P's

Olsen P	P required for a yield of 10 t/ha
10	up to 270
20	200
25	170
30	140
35	100

The volume of P which is removed by the growing of an 8 t/ha crop is 18 kg P/ha.

7.1.1.4.1 Process Peas

Process peas have an offtake of approximately 5 kg P/ha therefore yield responses to the application of P is unlikely unless the Olsen P is <10.

7.1.1.5 Potatoes

Potatoes often respond strongly to P fertiliser when soil Olsen P is low, but the response curve flattens out quickly, and yield may be suppressed if P supply is beyond the optimum. The soil optimum figure depends on the volume of crop expected with a range of optimum Olsen P levels as illustrated below.

Table 26: Optimum Olsen P values for a range of Potato crops and the calculated offtake of P for the crop.

Volume of crop expected.	Optimum Olsen P (Level at which maintenance requirement = 0)	Offtake of P Kg /ha
100 t/ha (main crop, table variety)	50	37
87 t/ha (main crop processing variety)	45	32
76 t/ha (early harvest, table variety)	35	29
50 t/ha (winter planted crop, table variety)	30	18

7.1.1.6 Spinach, Silver Beet, and Beetroot

The optimum Olsen P for Spinach, Silver Beet, and Beetroot is 35

Table 27: The calculated offtake of P for a range of crops at a range of yields.

Crop	Field yield fresh (t/ha)	Offtake of P (kg /ha)
Spinach	15	7
	20	9
	25	11
Silverbeet	10	5
	20	9
	30	14
Beetroot, roots	40	14
	60	22

7.1.1.7 Sweetcorn

Table 28: Range of P (kg/ha) required to grow Sweetcorn at a range of Olsen P's

Olsen P	P required for a yield of 20 t/ha	P required for a yield of 30t/ha
10	80	up to 140
20	20	80
25	nil	60
30	nil	40
35	nil	nil

The volume of P which is removed by the growing of a 20 t/ha crop is 9 kg P/ha and for a 30 t/ha crop is 14 kg P/ha.

7.1.2 Arable

The available literature reports the following information on the response to P fertiliser.
In the small number of trials carried out, yield responses to P in wheat have not been measured above Olsen P 15. Since wheat, however, is usually grown in a crop rotation, Olsen P levels should be maintained in the 20-30 range required for near maximum production for pasture and other crops (Fertiliser Association 2009).

For optimum yield in Barley with adequate moisture and N supply, an Olsen P of 20-25 is required. To maintain Olsen P within or above this range, apply 10-30 kg P/ha at planting, depending on yield potential.

Grain maize trials within NZ shows small economic yield responses only on rare occasions, e.g. when Olsen P is <10. Where soil Olsen P levels are >10, it is still beneficial to apply 20 kg P/ha as a starter to help plant establishment.

For Grass Seed, soil Olsen P levels should be 15-25. Annual maintenance requirements will be 20-30 kg P/ha but will vary according to the dry matter produced and whether the extra P demands caused by grazing or silage making need to be addressed.

For White Clover seed an Olsen P of 10 is sufficient for establishment, assisting with root growth and N fixation. Increased available P increases vegetative growth. Olsen P above 15 can decrease seed yield due increased canopy size and stolon shading.

Table 29: Offtake of P across a range of arable crops by yield

Crop	Yield (T/ha)	Offtake of P (kg/ha)
Wheat – low yield	5	21
Wheat – high yield	12	48
Barley – low yield	5	22
Barley – high yield	8	34
Oats	7	26
Maize	12	36
Peas	5	19
Ryegrass	2	17
White Clover	1	6
Oilseed Rape	2	15

7.1.3 Brassicas

The major brassica crops grown in New Zealand include Kale, Rape, Swedes, Turnips and Leafy Turnips (Pasja/Hunter). Kale and swedes are mainly grown as winter fodder crops, turnips as summer forage crops and rape as either winter or summer crops.

As for all crops, the major factors that determine the nutrient requirements for brassicas include:

- The amount of plant-available nutrients supplied by the soil
- The yield potential of the crop as determined by soil type and climate

High yielding brassica crops have large mineral nutrient requirements. The maintenance P requirement for a 12 T/ ha crop of brassicas is between 34 and 36 kg P/ha.

7.2 Methodology

An initial literature review was carried out to determine the optimum P value for each crop, the offtake of P and the amount of P that is required to lift Olsen P by one unit for the majority of crops, relative to soil type. In the absence of any research literature on the reduction of Olsen P with no P fertiliser use under a cropping regime, reductions in yield are based on the annual offtake of P divided by the amount that the Olsen P would reduce by one unit if not replaced.

The next step was to create financial models (in Excel) for the four key crops investigated:

- Leafy Green Vegetables,
- Root Vegetables,
- Cereal grains and
- Forage Brassica.

7.2.1 Leafy Green Vegetables

The model which was created to represent leafy green vegetables was based on a model which has been used to represent this sector in the past which has both the yields and prices used as representative of this sector nationally.

Table 30: Crops, yields and prices used in the Leafy Green Vegetable Model

Crop	Yield (t/ha)	Price ($/T)
Cauliflower	30	1,150
Spinach	22	2,200
Onions	65	550
Broccoli	18	1,667
Squash	20	750
Spinach	22	2,200
Cabbage	40	950
Sweetcorn	21	700

The expenditure parameters that were used are based on individual crop gross margins which have been recently updated for some work carried out for the Auckland Council (PerrinAg 2023).

7.2.2 Root Vegetables

The root vegetable model is based on a root vegetable model which was created by ECan for their MGM project (Hume et al 2105). Both the prices received, and expenditure of this model have been updated to represent the current prices and expenditure. Because it is necessary to rotate the crops this rotation has some arable crops in it as well.

Table 31: Crops, yields and prices used in the Root Vegetable Model

Crop	Yield	Price
	(t/ha)	($/T)
Potato (long)	84.6	325
Wheat (autumn)	11	450
Forage oats (autumn)	4	
Carrots	80	275
Maize silage	20	415
Peas (green)	9.3	355
Barley (spring)	8	450
Ryegrass seed	1.8	2,400

7.2.3 Cereal Grain

The cereal grain model is again based on a model which was created by ECan for their MGM project. The prices received, and expenditure of this model have been updated to represent the current prices and expenditure.

Table 32: Crops, yields and prices used in the Root Vegetable Model

Crop	Yield	Price
	(t/ha)	($/T)
Peas (green)	9.3	355
Forage oats (autumn)	4	
Barley (spring)	9.4	450
Maize silage	20.7	390
Wheat (autumn)	13	550
Clover seed	0.7	6,200

7.2.4 Forage Brassicas

Forage brassica crops are grown:

- On sheep and beef properties in order to provide sufficient feed for the livestock over the winter months or as a source of fattening feed throughout the year but mainly in the summer months,
- on sheep and beef, arable, dairy support and dairy farms to provide feed for non-lactating dairy animals.

In order to represent the financial impact of these crops a financial budget was constructed which represents the use of brassica crops to feed non lactating dairy stock on land which is not owned by the dairy farmer as it was felt that is the most relevant way to be able to represent the true financial return for the brassica crop.

7.2.5 Calculation of the Impact of No P

The calculation of the impact of the “without P” scenario relied on the limited information in the literature as to the impact of a lack of P on crop yields. The assumptions used in the modelling are shown in Table 33.

Table 33: Yield of each land use compared with the status quo (%)

Land use	Yield Year 1	Yield Year 2	Yield Year 3	Yield Year 4
Leafy Green Vegetables	87	75	62.5	50
Root Vegetables	87	73	60	40
Cereal Grain	85	70	55	40
Forage Brassica	95	80	60	40

The yields that are displayed in Table 33 are the percentage of the yield achieved relative to the status quo after the soil Olsen P levels are diminished below the optimum level for each crop type. Note that in most instances the current Olsen P levels are well above the optimum level required to achieve the yields used. This means that in all instances there is a period of time when no P is applied in which the yield of the crop remains the same as that achieved in the status quo year.

The prices received in the models were not altered as there is no information as to what the price elasticity is for any of the crops modelled and therefore assumed that demand would be met by importing the crops or by substitution for other similar products to meet the unsatisfied demand.
All expenditure items that were yield dependant (eg: harvest labour, freight) were reduced by the same percentage as the yields.

7.3 Results

The results of the "with/without P" are shown below.

Table 34: Transition from the status quo to an equilibrium of no P ($/ha)

	Leavy Green Vegetables		Root Vegetables		Cereal Grain		Forage Brassicas	
	With P	Without P	With P	Without P	With P	Without P	With P	Without P
Gross Farm Revenue	$32,990	$16,495	$13,391	$5,991	$6,137	$2,877	$3,600	$1,440
Operating expenses	$16,755	$14,372	$7,477	$6,736	$3,910	$3,355	$1,393	$1,142
EBITDA	$16,235	$2,123	$5,914	-$745	$2,227	-$478	$2,207	$298

The differences in EBITDA for the different crops are:

- Leafy green vegetables: $14,112/ha (an 87% reduction)
- Root Vegetables: $6,659/ha (a >100% reduction)
- Cereal Grains: $2,705 (a >100% reduction)
- Forage Brassicas: $1,909 (an 87% reduction)

Extrapolating this to the national level shows:

Table 35: National impact of the loss of EBITDA

Land use	Area of crop grown.	Net loss in EBITDA	Loss in EBITDA
	(ha)	($/ha)	($m)
Leafy Green Vegetables	27,466	14,112	388
Root Vegetables	15,459	6,659	103
Cereal Grain	180,000	2,705	487
Forage Brassica	239,875	1,909	458
Total			1,436

As shown above, the national impact on the arable/vegetable in the “without P” scenario is $1.4 billion.

8.0 MACRO ECONOMIC ANALYSIS

8.1 Background - The Multiplier Effect

The multiplier effect is where a change in spending in one area of the economy stimulates a change in spending in other areas. For example, farmers spend money on buying in inputs such as fertiliser, which in turns means the fertiliser company spends money on inputs and wages, with the workers in turn spending money on further services they need, and so on.

In economic jargon, this is explained as: if there is an increase in final demand for a particular product (or service), it can be assumed that there will be an increase in the output of that product, as producers react to meet the increased demand: this is the “direct effect”. As these producers increase their output, there will also be an increase in demand on their suppliers and so on down the supply chain: this is the “indirect effect” (i.e., Type I multipliers). As a result of the direct and indirect effects the level of household income throughout the economy will increase because of increased employment. A proportion of this increased income will be re-spent on final goods and services: this is the “induced effect” (i.e., Type II multipliers) (Butcher, 1985).

Value-add multipliers provide estimates of value added to products resulting from the sale of a good or service to another sector. This Value Add includes the cost of employee compensation, indirect business taxes, and proprietary and other property income.

In this analysis value-add multipliers were applied across the changes in income for the relevant sector. This gives an indication of the impact on GDP of change in economic activity because of not using phosphorus fertilisers, or the use of substitutes.

The multipliers used were the Type II multipliers for each of the sectors, derived at the national level. These were applied across the economic differences calculated for each sector.
In addition, both forward and backward linkages were used: backward relate to the services each industry buys in to provide their goods, while forward linkages relate to the processing/manufacturing process through to the wharf.

8.2 Macro-Economic Modelling

The macro-economic impacts were calculated using a 2016 Input-Output Table of the New Zealand Economy. This model covers 106 industries, plus 7 primary inputs:

- Taxes of products
- Compensation of employees
- Operating surplus
- Consumption of fixed capital
- Other taxes on products, subsidies, and
- International impacts

Plus 7 final demands:

- Household final consumption
- Non-profit institutions serving households (NPISH)
- Consumption
- Central government consumption
- Local government consumption

- Gross fixed capital formation
- Changes in inventories and international exports.

Using these, a vector of employment, and matrix algebra, a set of input-output multipliers were generated for gross output, value add, and employment. Using these multipliers and the direct impacts outlined in Section 8.2 the direct, indirect (i.e., supply chain), and induced (i.e., occurring from household expenditure by workers) backward linkage impacts were calculated. Forward linkage impacts through processors were also evaluated.

8.3 Direct Impacts

Within the input/output industry tables, the arable industry is included within the sheep & beef industry, and vegetables are included within the horticultural industry. Farm gate impacts were aligned to input-output sectors as per the following concordance (Table 36). The direct impacts (derived by summing up the farm gate impacts as per the Table 36 concordance) are shown in Table 37.

Table 36: Concordance matching Primary Activities to Input-Output Sectors

Green Leavy Vegetables	Horticulture and fruit growing
Root Vegetable	
Forage Brassicas	
Pipfruit	
Kiwifruit	
Viticulture	
Summerfruit	
Other Horticulture	
NI Hill Country Farming	Sheep, beef cattle and grain farming
NI Intensive Farming	
SI Hill Country Farming	
SI Intensive Farming	
Cereal Grain Cropping	
Northland Dairy Farming	Dairy cattle farming
Waikato/BoP Dairy Farming	
Taranaki Dairy Farming	
Canterbury Dairy Farming	
Southland Dairy Farming	

Table 37: Summary of Direct Impacts of "without P" aligning with the Input-Output tables ($$_{2016}$ million)

	Units	Horticulture and fruit growing	Sheep, beef cattle and grain farming	Dairy cattle farming	Meat and meat product manufacturing	Dairy product manufacturing	Fertiliser and pesticide manufacturing	Total
Gross Output	NZ$$_{2016}$m	-2,240	-1,973	-5,990	-3,220	-11,670	-373	-25,460
Value Added	NZ$$_{2016}$m	-1,090	-562	-1,770	-576	-2,380	-78	-6,450
Employment	MECs$_{2016}$	-20,680	-11,660	-27,210	-9,030	-8,170	-284	-77,020

8.3.1 Results

The "without P" scenario involves simply modelling what would be the net economic impacts if P fertiliser was no longer used and no adaptation took place. In the real world, farmers would likely not only change their farm systems, but also possibly change their land use, potentially to farming activities not seen before. So, assuming impacts can be measured, with and without P fertiliser, the figures below likely overstate the impact.

Effectively, general equilibrium effects would kick in, not only structural change, but also pricing, substitution and transformation impacts. Reduced earnings at the farm gate would, for example, see investors move capital out of farming, freeing up capital for uses in other types of business within New Zealand. Thus, the impacts are likely to be less than those portrayed by a simple multiplier analysis. Significantly more work would be required to capture these changes, particularly if adaptation through time was considered, as well as the myriad of other general equilibrium impacts that might occur as the New Zealand rebalances to the removal of P fertiliser.

A summary of the macro-economic impacts is shown below (Table 38) with a breakdown by direct, indirect, and induced flow-on impacts; forward linkages through meat and meat product manufacturing and fertilizer and dairy product manufacturing; and direct, indirect, and induced flow-on impacts from the fertilizer and pesticide manufacturing industry are shown in Appendix 4.

Note:

- All results are presented as net losses for a single year.
- Gross output and value-added impacts are expressed in NZ$$_{2016}$millions and are for a single year.
- Employment impacts are expressed in Modified Employee Counts (MECs) per year. MECs are equivalent to a head count of employees and working proprietors. Importantly, these are end-of-February 2016 equivalents. Thus, they may not pick up impacts on seasonal workers, including troughs and peaks, that exist at other times throughout the year.
- The modelling considers direct, indirect, and induced impacts associated with P fertiliser use, principally through farming, but also direct, indirect, and induced losses to the fertiliser industry itself. Also included, as noted above, are the losses of forward linkages to meat and dairy processing.
- Small interdependencies exist between the farming industries (horticulture and fruit growing' sheep, beef cattle and grain farming; and dairy cattle farming), processing industries (meat and meat produce manufacturing and dairy product manufacturing) and fertiliser and pesticide manufacturing industry which are not fully accounted for.

Table 38: Summary of macro-economic impacts

	Units	Horticulture and fruit growing	Sheep, beef cattle and grain farming	Dairy cattle farming	Meat and meat product manufacturing	Dairy product manufacturing	Fertiliser and pesticide manufacturing	Total
Gross Output	NZ$$_{2016}$m	-4,370	-3,775	-11,640	-4,890	-18,660	-740	-44,070
Value Added	NZ$$_{2016}$m	-2,260	-1,123	-4,140	-1,358	-5,150	-216	-14,240
Employment	MECs$_{2016}$	-32,620	-20,330	-54,470	-17,450	-34,940	-1,400	-161,210

MEC = Modified Employment Counts (a head count of employees and work proprietors)

To avoid double counting, indirect and induced impacts calculated for meat product manufacturing and dairy product manufacturing exclude downstream impacts on dairy cattle farming and sheep, beef cattle and grain farming (and subsequent modelling rounds therefrom)

Overall, therefore the impact is:

- Gross Output reduces by $44 billion (5.5% of NZ total)
- Value Add (GDP) reduces by $14.2 billion (6.3% NZ total)
- Employment reduces by 161,210 MECs (6.7% NZ total)

8.3.2 Caveats

A note on P as a limiting factor

It is worth noting that for many New Zealand soils P is the limiting factor in biomass production. Thus, P cannot readily be substituted for. This means that removal of P would also mean that the use of N, K and other fertilisers would also be impacted. The full impacts of P being a "limiting factor" in the use of other nutrients is difficult to ascertain, mainly due to the likely structural change that would occur within the economy. This requires additional information on the nature of this change, and more importantly, the alternatives which may likely emerge (including understanding changes in labour, capital, and land-use as factors-of-production) within the New Zealand economy. This would require significant future work including the use of a General Equilibrium model to understanding the dynamic implications associated with pricing, substitution, and transformation effects, under a range of plausible alternative development futures for New Zealand.

A note on General Equilibrium effects

It is also beyond the scope of this study to consider the general equilibrium effects of removal of P fertilisers. General equilibrium effects include change in price, substitution and transformation effects, and other dynamics economic effects. There are several reasons why these effects have not been considered. Firstly, a partial equilibrium analysis would need to be undertaken for the farm system level impacts (i.e., for fruit and horticulture crops; sheep, beef, and crop farming, and for dairy farming). The reduction in P would likely see the price of other key ingredients into the farm system change in a non-linear way. Such changes are not easy to predict and are only crudely covered in the direct impacts. Secondly, land use is likely to change in response to P reduction – exactly to what degree or what land use is unknown. This may be to an emergent land use, not currently present. Furthermore, given the quantity of land under consideration any change is likely to lead to transformational change.

The figures shown in Table 38 represent an annual impact. As discussed earlier in the report, the absence of P fertiliser would mean many farms, particularly in the pastoral and cropping sectors, would be uneconomic under their current structure. This would obviously precipitate a restructuring into large more extensive units, or into other land uses (e.g. forestry). This is a "general equilibrium" effect as outlined above. So the initial impact, as calculated, would then alter as the economy adjusted to the new reality – how long this may take is difficult to assess.

8.4 Impact on Exports

Obviously, the reduction in production as outlined in this report would directly result in a reduction in the amount of produce New Zealand would be able to export, or potentially have to increase imports of in order to substitute for any reduction in domestic supply (e.g. grains, vegetables).

If these reductions in production levels are directly extrapolated as a reduction in in the value of exports, the monetary cost of this is:

Table 39: Value of Exports with/without P fertiliser ($ millions)

	2023 Export Values*	Without P
Meat & Wool	11,940	6,448
Dairy	25,120	9,294
Horticulture	6,210	5,232
Arable/Vegetable	955	495
Total	46,248	21,469

*Source: Situation and Outlook for Primary Industries (SOPI) MPI 2023

This table shows a reduction in primary exports of $24.8 billion, or a 54% reduction.

It is difficult to be overly accurate on this impact, as the reduction in volume would allow New Zealand to concentrate on the better paying markets, thereby somewhat ameliorating the overall cost. Similarly, the net effect of exports minus imports is also difficult to estimate given that the reduction in primary production would reduce imports for the sector – obviously there would be no imports of phosphate rock, for example.

In addition to the exports losses felt in primary and associated processing sectors, losses will also be felt in other sectors of the New Zealand economy. These were estimated in two steps:

Firstly, the macro-economic model developed for Section 8.2 was modified to calculate export losses based on the direct farm system changes calculated in Sections 5 to 7. This provided a cross-check of the value of export losses provided in Table 39 above. Based on this modelling, the estimate of the reduction in exports, in primary and associated processing sectors, to be in the order of $\$_{2022Q3}$21.6 billion. This is approximately 87% of the value recorded in Table 39.

Several reasons exist for the difference in estimates, including:

(i) The macro-economic modelling is undertaken in basic prices, while the values presented in Table 39 are in purchases prices, which accounts for most of the difference;
(ii) The $24.8 billion is for the 2023 year, while the macroeconomic estimate is for the year ending September 30, 2022[5] - this accounts for some of the variation; and
(iii) Small structural differences in industry operation between 2016 and 2023 which is likely to be a smaller share of the discrepancy. Overall, in the context of the I/O analysis, the estimates are very close.

Secondly, based on the macro-economic modelling results the flow-on impacts felt in the remaining sectors of the New Zealand economy i.e., including other manufacturing, wholesale

[5] It is worth noting that the macroeconomic analysis is undertaken for the year ending March 31, 2016. Inflators, based on the Producers' Price Index and Gross Domestic Project are then applied to inflator results to September 30, 2022.

and retail trade, construction, transport, all services and so on were also estimated. This generated an additional flow-on export losses of approximately $\$_{2022Q3}$4.2 billion, giving a total overall reduction of $\$_{2022Q3}$25.8 billion.

9.0 SOIL PHOSPHATE "DECAY" - PHOSPHORUS BUFFERING CAPACITY OF SOILS

The analysis within this study assumes a direct "with" versus "without" phosphorus fertiliser, with the "without" scenario assuming a relatively low Olsen P level (5).

In reality, with the current levels of Olsen P (circa Olsen 30 - refer Appendix 2) in soils in New Zealand, it would take some time for these levels to drop to the very low level assumed (Olsen P 5).

The rate of decline in P levels in theory is related to the soil anion storage capacity (ASC), which is a measure of the soil's ability to bind negatively charged ions, like phosphate. Soils with a high ASC have a greater ability to bind phosphate, as they have more sites for it to attach to than those with a low ASC. This means more phosphorus is required to raise the Olsen P of these soils, but once they have bound the phosphorus, they will have greater reserves and their Olsen P levels will be slower to fall.

In this respect, soils with a high ASC, such as a volcanic soil with an ASC of 70, Olsen P will take a while to fall. On the other hand, a soil with a low ASC, like a sedimentary soil with an ASC below 30, will lose P faster.

To determine the buffering capacity of soils with respect to phosphorus, there are two variables which need to be defined:

(i) The amount of P fertiliser required to raise the Olsen P test by one unit – Delta P
(ii) The rate of decline of the Olsen P test when P fertiliser is withheld – Alpha P

9.1.1 Raising Olsen P Levels

Roberts and Morton (2004) summarised data from field trials and estimated Delta P to be 11kg P/ha (range 7-18) for volcanic soils and 5 kg P/ha (range 4-7) for sedimentary soils. Wake and Ali (2018) modelled data from 41 trials, on both volcanic and sedimentary soils, and estimated Delta to be on average 12 (range 7 to 35).

9.1.2 Reducing Olsen P Levels - Pasture

The rate of decline in the soil Olsen P levels, when fertiliser P has been withheld, has been measured in two trials on sedimentary soils under sheep grazing. At Te Kuiti (Dodd and Ledgard 1999), the soil Olsen P level declined by 10 units, over 11 years (i.e. 0.9 Olsen P units per year). Similar results were measured at Ballantrae (0.6 Olsen units per year) over a 7-year period (Lambert et al 1990). Note that in both trials the initial Olsen P level was 14.

In eight trials on volcanic soils under dairying (Feyter et al 1988) the average rate of decline in Olsen P was 1.25 units per year. In these trials the initial Olsen P was about 32 units. The researchers noted that the effect on pasture production of applying no fertiliser for two years was negligible in half the cases but resulted in a reduction in pasture production of more than 10% in the other half. The latter effects were partly predictable from low soil test levels or a high stocking rate.

Based on models, using data from 41 field trial across both dairying and dry stock farms, it was found (Wake and Ali, 2018) that the rate of decline in Olsen P was proportional to the initial

Olsen P. For example, at an initial Olsen P of 30 the rate of decline was 3 (1.4 to 5.1) Olsen P units per year. At Olsen P 10 the rate of decline was 1 (0.4 to 1.6).

Table 40: Change in Olsen P/year when fertiliser P withheld. From Modelled and Empirical data

Olsen P	Modelled Olsen P Decline (Olsen P units /yr) (41 trials (S/B and dairy))	Empirical (Olsen P decline in units/yr)	Soil Group	Farm Type
10	1 (0.4 - 1.6)	0.6 (Ballantrae, 7 yrs), 0.9 (Te Kuiti, 11 yrs)	sedimentary	Sheep
20	2 (0.9 - 3.4)	1.25 (Ave Waikato 8 trials, 8 years)		Dairy
30	3 (1.4 - 5.1)	1.25 (Ave Waikato 8 trials, 8 years)	volcanic	Dairy
40	4 (1.8 - 6.8)			

From this data it would appear that any decline in Olsen P levels due to a lack of fertiliser P would be relatively linear in nature.

Based on this, and assuming the current Olsen P levels in New Zealand pastoral soils as a starting point, it is estimated that it would take around 20-30 years to reduce down to around an Olsen P of 5. Note there is some variation around this timeline, depending on farm and soil type and whether the modelled or empirical data is used as the basis for the estimate.

In this context it is to be noted that in the initial 1-2 years of withholding fertiliser P, a decline in Olsen P may not be detected using normal farm scale soil testing protocols, even though decreases in pasture and animal production are evident (O'Conner et al (1985)). In the longer term decreases in Olsen P levels become apparent commensurate with the decline pasture and animal production. As a rule of thumb these three parameters will decline at about 5% per annum (Lambert et al 1990, Dodd and Ledgard 1999).

9.1.3 Reducing Olsen P Levels - Horticulture

There is little research literature available on the reduction of Olsen P levels with no P fertiliser use under a permanent horticultural system. Given P loss via product take-off is relatively much higher compared with pastoral systems it could be expected that they reach low Olsen P levels comparatively quicker.

As outlined below in section 9.1.4, the estimate for the decline in cropping systems is 7-8 years. It could be expected that under permanent horticulture the decline would take slightly longer, given a higher average starting Olsen P level. It is not possible to differentiate this rate of decline between the different crops.

9.1.4 Reducing Olsen P Levels - Arable/Vegetable Sector

In the absence of any research literature on the reduction of Olsen P with no P fertiliser use under a cropping regime, the annual offtake of P was divided by the amount that the Olsen P would reduce by one unit if not replaced. This gave the number of years that it would take to reduce the store of P in the soil to a level where actual Olsen P level was below the optimum P level. The result for each rotation was averaged and then that figure was used for each rotation. The results of this calculation and the range are shown below (refer Appendix 3 for detail).

Table 41: Years to negative impact on yield and range within the rotation

Land use	Years to negative impact on Yield.	Range within the rotation.
	Average of Crops	
Leafy Green Vegetables	3	2 - 4
Root Vegetables	7	3 - 13
Cereal Grain	6	1 - 13
Forage Brassica	8	

This showed that the decline in Olsen P to the "No P" status, took on average around 7-8 years.

10.0 ALTERNATIVE P FERTILISERS

In the absence of any phosphorus fertilisers, either as rock phosphate or manufactured fertilisers e.g. superphosphate, the alternative fertilisers that could be used are manure-based fertilisers such as pig or poultry manure, or commercial compost.

Apart from the practicalities of application, the key issue with using such manures usually comes back to the nutrient content of the manure/green waste and its availability. Compost application is a common practice in perennial horticulture as there is an existing supply and infrastructure to enable ready access to relatively affordable compost products.

The nutrient content of the manures can vary depending on whether its fresh or dry, from differing ages/classes of poultry or pigs, and the type of feed provided.

Table 42: Typical NPK Content of Manures

Poultry Litter	Average	Range
Nitrogen	2.6%	1.4-8.4%
Phosphorus	1.8%	1.2-2.8%
Potassium	1.0%	0.9-2.0%
Sulphur	0.6%	0.45-0.75%
Pig Slurry	**Average**	
Nitrogen	4.2%	
Phosphorus	0.8%	
Potassium	2.2%	

Source: Poultry Litter: Best practice guidelines for using poultry litter on pastures.
https://www.thepoultrysite.com/articles/best-practice-guidelines-for-using-poultry-litter-on-pastures-1
Pig manure: Pig Manure: A valuable Fertiliser. Teagasc Pig Development Centre
https://www.teagasc.ie/media/website/publications/2020/pig-manure-a-valuable-fertiliser.pdf

Data from New Zealand Piggeries (Braugh, 2018) showed the following nutrient content:

Table 43: New Zealand Pig Manure – Average Nutrient Content

	N	P	K
Screened Slurry	1.5%	0.2%	0.5%
Screen + Pond	0.5%	0.1%	0.4%
Ponds	0.2%	0.1%	0.2%

Commercial composts also vary considerably in nutrient content depending on the type and proportion of the ingredients which go into the compost mix. Typical ingredients can include a range of green waste products such as bark and wood chips, and to a lesser extent reject fruit and seaweed extracts, mixed with animal by-products such as chicken manure, and blood and bone. A common mix used in horticulture is a 50:50 chicken manure and green waste compost. When manure is mixed with green waste, this 'dilutes' the nutrient content, thus, requiring large amounts of the products to use needed to supply the same amount of N, P and K. Table 44 below summarises the high variability in nutrient content in commercial compost.

In horticulture, compost is primarily used to increase organic matter in the soil and the nutrient content is a secondary benefit to its application. However, as many commercial composts are certified organic, it allows this to be used as the main source of nutrients for organic horticultural producers.

Table 44: Typical NPKS Content on a dry weight basis for Compost

Commercial Compost	Average	Range
Nitrogen	2.0%	0.75-2.3%
Phosphorus	0.6%	0.2-1%
Potassium	1.0%	0.3-1.85%
Sulphur	0.3%	0.15-0.55%

Source: Websites of Revital Fertilisers, Living Earth, Bennett Fertiliser, and lab results taken by Fruition Horticulture BOP.

From the above data, the amount of manure which would need to be applied, relative to phosphorus supplied by an application of superphosphate would be:

Table 45: Amount of fertiliser needed to be applied to provide the amount of P/ha

kg of P supplied/ha	20	30	40	50
Superphosphate (kg/ha)	222	333	444	556
Pig Slurry (kg/ha)	10,000	15,000	20,000	25,000
Poultry Litter (kg/ha)	1,111	1,667	2,222	2,778
Commercial Compost (kg/ha fresh)	6,667	10,000	13,333	16,667

As can be seen from Table 45 the amount of animal manure/compost required would be substantial. Information on the amount of pig and poultry manure available in New Zealand is difficult to obtain but estimates are:

(i) Pig Manure. There were 262,400 pigs farmed in New Zealand in 2022[6], with each pig estimated to produce 720kg fresh waste per year[7]. This equates to 189,000 tonnes of fresh manure, or 17,000 tonnes of dry manure.

(ii) Poultry manure. An estimate was made in 2019 (Quin, 2019) of the amount of poultry manure produced in New Zealand. This was 900,000 tonnes of fresh manure which would equate to approximately 346,000 tonnes of dry manure.

(iii) There is no information readily available on the quantities of commercial compost available.

The total area in perennial horticulture in New Zealand is 38,268 hectares (Fresh Facts 2023), and the area in grapes is 41,860 hectares (Section 6.5). Assuming a maintenance application of P, the amounts of pig slurry/poultry litter required are:

[6] Statistica. https://www.statista.com/statistics/974513/new-zealand-pig-livestock-numbers/#:~:text=As%20of%20June%202022%2C%20there,has%20decreased%20significantly%20since%202011.

[7] Wikifarmer. https://wikifarmer.com/pig-manure-production-and-waste-management/#:~:text=It%20is%20estimated%20that%20a,pig%20can%20exceed%202200%20lbs

Table 46: Amount of alternative fertilisers required for the horticultural industry (tonnes)

Pig slurry	**20kg P/ha**	**30 kgP/ha**
Perennial horticulture	382,680	574,020
	5kg P/ha	**10kg P/ha**
Wine grapes	11,628	23,256
Total Tonnes	**394,308**	**597,276**
Poultry Litter	**20kg P/ha**	**30 kg P/ha**
Perennial horticulture	42,516	63,793
	5kg P/ha	**10kg P/ha**
Wine grapes	11,628	23,256
Total Tonnes	**54,144**	**87,048**
Compost (fresh weight)*	**20kg P/ha**	**30 kg P/ha**
Perennial horticulture	255,094	382,680
	5kg P/ha	**10kg P/ha**
Wine grapes	69,767	127,560
Total Tonnes	**324,861**	**510,240**

*Assumes 50% moisture content

As can be seen from Table 46, there would be insufficient pig slurry or compost available in the country, but there would be of poultry litter to satisfy the horticultural industry.

Providing a costing on these alternative fertilisers is also difficult, given that prices vary around the country, and often the supply is targeted at home gardens at relatively high prices. An estimate of the cost of pig manure is $63.50/m^3 [8] while for poultry litter is $79/tonne[9] (South Island) and $150/T[10] (applied – North Island). For commercial compost bought in bulk, an estimate of cost is $85/tonne or $140/tonne including cartage and spreading (North Island)[10].

For superphosphate the price is $449/tonne[11]. The price comparison based on Table 45 above shows:

Table 47: Price Comparison of Different Fertilisers ($/ha)

kg of P supplied/ha	**20**	**30**	**40**	**50**
Superphosphate	$100	$150	$199	$250
Pig Slurry	$635	$953	$1,270	$1,588
Poultry Litter (South Island)	$88	$132	$176	$219
Poultry Litter (North Island)	$167	$250	$333	$417
Commercial Compost	$567	$850	$1,133	$1,417

[8] https://gardeningsupplies.co.nz/soils-composts-soil-conditioners/composts/pig-mix/
[9] https://www.poulfert.co.nz/canterbury-fertiliser.php
[10] Fruition Horticulture pers com
[11] Ballance Fertiliser Price List August 2023. https://ballance.co.nz/medias/Price-List-effective-3-August-2023.pdf?context=bWFzdGVyfHJvb3R8Mzc0MzIzMnxhcHBsaWNhdGlvbi9wZGZ8aGE2L2g1Zi85NTg2MDA5MDc5ODM4L1ByaWNlIExpc3QgZWZmZWN0aXZlIDMgQXVndXN0IDIwMjMucGRmfGQwNzg5Y2ZjMDE3ODNmOTU5NDUzNWM3MGMwYWE5NWY0NDRlOGNjZjE3MTk0OTUyYWZkNzlmZDdmZDEyN2MwMDY

As can be seen from this comparison, poultry litter at the lower price is very competitive compared with super-phosphate.

This comparison also needs to note:

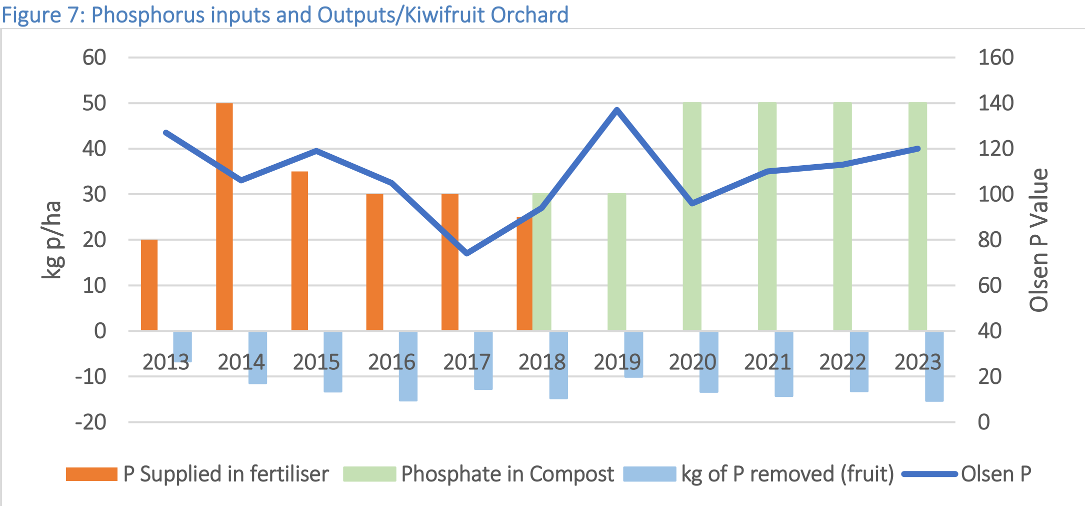
- Transport and spreading costs need to be added to the above costs (other than the North Island poultry litter). It could be expected that given the greater quantities involved, these would disadvantage pig manure, poultry litter and compost versus super-phosphate.
- The "bulk" of the manures and compost would also likely preclude their use on hill country given the practical difficulties involved in spreading.
- Compost does not dissolve like super-phosphate[12] and can pose a continued risk of P runoff due to particles of compost sitting on the surface until they are broken down by natural processes and nutrients integrated into the soil.
- The compost, pig manure and poultry litter would also be supplying additional nutrients in the form of nitrogen and potassium. Compost also adds organic matter to soils.

Overall, in the absence of phosphorus fertilisers, and given the relatively limited supply, it could be expected that such alternative fertilisers would, in the main, be more likely to be used in higher-value production systems, e.g. horticulture, rather than on pastoral farms.

To a certain extent this is already happening, as evidenced in the following figure based on a kiwifruit orchard in the Bay of Plenty. Regular soil testing on this orchard, as a part of routine monitoring to construct the annual nutrition programme, shows how the phosphorus levels have been influenced by fertiliser and compost applications and removal of phosphorus in the crop. From 2013 through to 2018 phosphorus fertiliser was applied in the annual maintenance programme. Although reducing the amount of phosphorus applied helped utilise soil phosphorus reserves, which were high, Olsen P test value units remained well above an optimal range of 20-50 units. This is largely due to the soil's medium to high retention of phosphorus. Fruit yield, and a reduction in phosphorus fertiliser inputs, saw Olsen P values trending down.

In 2018 the orchard started applying compost at 3.0 Tonnes/ha in response to low soil carbon levels, lifting this to 5 .0 Tonnes/ha in 2020. As the figure shows, Olsen P levels were very high (>120 in 2013), returning to around this level in 2023.

Figure 7: Phosphorus inputs and Outputs/Kiwifruit Orchard



[12] https://hortnews.extension.iastate.edu/faq/how-long-does-it-take-compost-pile-break-down

For the arable/vegetable sector, the increased cost of applying sufficient P via commercial composts, pig manure or poultry litter would be uneconomic. The other key issue is that, proportionally, such manures contain much more nitrogen than phosphorus. Applying such manures would mean be that there would be limited control over the amount of N being applied and the crops modelled are very sensitive to both the timing and volume of their N requirements, which would not be able to be managed.

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12.0 APPENDIX 1: PASTORAL FARM MODELS

Dairy Models

	Effective area (ha)	Cows milked	Cows/ha	Total kg Milk Solids
Northland	144	325	2.3	104,405
Waikato/BoP	135	386	2.9	116,557
Taranaki	109	304	2.8	119,561
Canterbury	235	812	3.5	341,515
Southland	225	604	2.7	255,010

Note:

- Northland is a weighted average of Northland region + Rodney district
- Waikato/BoP is a weighted average of the Waikato + Bay of Plenty regions
- Canterbury is a weighted average of Canterbury North + Canterbury South

Sheep & Beef Models

	Effective area (ha)	Total SU	SU/ha	Lambing %	Calving %	Total Sheep	Total Cattle
North Island Hill Country	548	4,972	8.9	131%	81%	2,779	482
NI Intensive Finishing	280	2,827	10.1	135%		1,179	387
South Island Hill Country	1,500	6,702	4.5	128%	83%	4,915	428
SI Intensive Finishing	256	2,796	10.9	134%		2,568	83

Note: North Island Hill Country is a weighted average of the B+L NZ Class 3 (Hard Hill Country) + Class 4 (Easy Hill Country)

13.0 APPENDIX 2: NATIONAL OLSEN P LEVELS

National Olsen P Levels (2020)

	National Average	Volcanic Soils	Sedimentary Soils	Pumice Soils	Peat Soils
Dairy	32	39	30	43	36
Sheep & Beef	23	23	23	22	16
Horticulture	34	40	30	23	30
Arable	24	28	23	26	35
Orchard	47	48	37	46	na

Source: https://www.fertiliser.org.nz/Site/about/soil-health-fertility/nz-soil-olsen-p-levels.aspx

14.0 APPENDIX 3. IMPACT OF DECLINING P: ARABLE/VEGETABLE

The following illustrate the impact in the decline in P across the 4 modelled crops, where the last year is assumed to be the "no P" status quo.

Leavy green vegetables ($/ha)

Year	1	2	3	4	5	6	7	8
Gross Farm Revenue	32,990	32,990	32,990	32,990	28,867	24,743	20,619	16,495
Total Farm Operating Expenses	16,755	16,100	16,100	16,100	15,263	14,425	13,588	14,372
EBITDA	16,235	16,890	16,890	16,890	13,604	10,317	7,031	2,123

The EBITDA reduces from $16,235/ha to $2,123/ha which is just 13% of the status quo figure.

Root Vegetables

Year	1	2	3	4	5	6	7
Gross Farm Revenue	13,391	13,391	13,391	11,849	9,999	8,458	5,991
Total Farm Operating Expenses	7,477	7,477	7,477	6,736	6,736	6,736	6,736
EBITDA	5,914	5,914	5,914	5,114	3,264	1,722	-745

The EBITDA reduces from $5,914/ha to -$745/ha which is unsustainable and so land use change would result.

Cereal Grains

Year	1	2	3	4	5	6	7
Gross Farm Revenue	6,137	6,137	6,137	5,322	4,507	3,692	2,877
Total Farm Operating Expenses	3,910	3,355	3,355	3,355	3,355	3,355	3,355
EBITDA	2,227	2,782	2,783	1,967	1,152	337	-478

The EBITDA reduces from $2,227/ha to -$478/ha which is unsustainable and so land use change would result.

Forage Brassicas

Year	1	2	3	4	5	6	7
Gross Farm Revenue	3,600	3,600	3,600	3,420	2,880	2,160	1,440
Total Farm Operating Expenses	1,393	1,142	1,142	1,142	1,142	1,142	1,142
EBITDA	2,207	2,458	2,458	2,278	1,738	1,018	298

The EBITDA reduces from $2,207/ha to $298/ha which is just 13% of the status quo figure.

15.0 APPENDIX 4. I/O SUMMARIES

2016 National Input-Output & Multiplier Summary

		Units	Horticulture and fruit growing	Sheep, beef cattle and grain farming	Dairy cattle farming	Meat and meat product manufacturing	Dairy product manufacturing	Fertiliser and pesticide manufacturing	Total New Zealand
Gross Output (NZ$2016m)		NZ$2016m	3,624	6,767	9,024	10,883	18,326	1,759	802,307
Value Added (NZ$2016m)		NZ$2016m	1,500	2,764	2,943	1,945	3,738	366	226,564
Employment (MECs)		MECs2016	33,523	40,016	40,979	30,441	12,820	1,341	2,413,686
Value Added: Gross Output Ratio			0.4139	0.4085	0.3261	0.1787	0.2040	0.2081	
Employment: Gross Output Ratio (MECs/$m)		MECs/NZ$2016m	9.25	5.91	4.54	2.80	0.70	0.76	
Backward linkage multipliers									
Gross Output	Type I		1.94	1.90	1.92	2.45	2.49	1.97	
	Type II		1.95	1.91	1.94	2.47	2.51	1.98	
Value Added	Type I		2.05	1.97	2.31	4.54	3.87	2.74	
	Type II		2.07	2.00	2.34	4.60	3.92	2.78	
Employment	Type I		1.57	1.73	1.98	3.69	10.24	4.84	
	Type II		1.58	1.74	2.00	3.72	10.38	4.93	

2023 Direct, indirect and induced backward and forward linkage impacts per year

		Units	Horticulture and fruit growing	Sheep, beef cattle and grain farming	Dairy cattle farming	Meat and meat product manufacturing	Dairy product manufacturing	Fertiliser and pesticide manufacturing	Total
Direct impacts	Gross Output	$NZ\$_{2016}m$	-2,240	-1,973	-5,990	-3,220	-11,670	-373	-25,460
	Value Added	$NZ\$_{2016}m$	-1,090	-562	-1,770	-576	-2,380	-78	-6,450
	Employment	$MECs_{2016}$	-20,680	-11,660	-27,210	-9,030	-8,170	-284	-77,020
Indirect impacts	Gross Output	$NZ\$_{2016}m$	-2,098	-1,767	-5,540	-1,629	-6,850	-360	-18,250
	Value Added	$NZ\$_{2016}m$	-1,150	-548	-2,320	-761	-2,700	-135	-7,610
	Employment	$MECs_{2016}$	-11,770	-8,500	-26,770	-8,230	-26,090	-1,090	-82,450
Induced impacts	Gross Output	$NZ\$_{2016}m$	-36	-35	-102	-41	-141	-6	-361
	Value Added	$NZ\$_{2016}m$	-22	-13	-49	-21	-74	-3	-182
	Employment	$MECs_{2016}$	-173	-168	-495	-196	-683	-28	-1,740
Total Linkage impacts	Gross Output	$NZ\$_{2016}m$	-4,370	-3,775	-11,640	-4,890	-18,660	-740	-44,070
	Value Added	$NZ\$_{2016}m$	-2,260	-1,123	-4,140	-1,358	-5,150	-216	-14,240
	Employment	$MECs_{2016}$	-32,620	-20,330	-54,470	-17,450	-34,940	-1,400	-161,210

Contact

Phil Journeaux

Agricultural Economist
027 511 8161
phil.journeaux@agecon.co.nz