Environmental Protection Authority

Economic assessment of paraquat use in New Zealand

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Abbreviations

a.i.	Active ingredient (paraquat ion)
EPA	NZ Environmental Protection Authority
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
LOC	Level of concern
MPI	NZ Ministry for Primary Industries
NZIER	New Zealand Institute for Economic Research
PPE	Personal protective equipment
RPE	Respiratory protective equipment
US EPA	US Environmental Protection Agency

Executive summary

Paraquat use contributes $30 million-$60 million to annual gross domestic product, which could be lost if a ban was in place

Using available information, stakeholder views and relevant assumptions we have been able to estimate the current contribution of paraquat to national income (GDP). In 2017 dollars, paraquat is estimated to contribute $29.8 million-$60.2 million to annual GDP. We are able to use this baseline figure to calculate the possible loss in GDP from alternative (restrictive) scenarios.

Assuming an effective ban on paraquat and no effective herbicidal replacement, the upper bound loss in GDP would be the inverse of the baseline figures above. That is, New Zealand's GDP could be up to $60.2 million lower were paraquat not available. While this is less than one half of one per cent of annual GDP, that figure would be far more significant from the growers' perspective.

Restricting the maximum application rate to 300 grams of active ingredient per hectare (g a.i./ha) would put around $58 million in GDP at risk

Two further restricted scenarios involved the maximum application rate for paraquat ion (the active ingredient) being set at:

- 300 g a.i./ha (300 grams of active ingredient per hectare); or
- 400 g a.i./ha (400 grams of active ingredient per hectare)

The more restrictive case of a maximum application rate of 300 g a.i./ha could result in around 96 per cent of the existing annual GDP contribution (around $58 million) being put at risk, driven largely by impacts on clover. This figure uses the high use assumption in respect of paraquat as a share of herbicide use.

The less restrictive case of a maximum application rate of 400 g a.i./ha would result in around 29 per cent of the existing annual GDP contribution (around $17 million) being put at risk. This figure uses the high use assumption in respect of paraquat as a share of herbicide use.

A range of limitations apply to our estimates, the most material relating to assumptions on yield and proportional paraquat use

While we are confident in the robustness of these results (i.e. they are broadly in line with existing studies elsewhere), we note there are some limitations which impacted the scope of our enquiry. These are:

- *data availability* – the lack of hard data on:
  - relationships between paraquat and total herbicide use and crop yield meant a reliance on parameters assumed from other studies
  - quantifiable and monetisable impacts on the environment and human health from paraquat use meant that only qualitative treatment of the costs was possible

  - the availability and costs of alternatives to paraquat meant a reliance on assumptions was needed.
- *interactive effects with and efficacy of other herbicides*- in the time available we were unable to undertake a thorough analysis of other herbicides which would have provided more insight into indirect impacts of paraquat use restrictions. Further any restriction on paraquat may impact on other chemicals used in tandem with paraquat such as diquat, meaning our estimate of potential economic loss may be understated
- *point-in-time estimation* – the contemporaneous nature of the analysis (related to data availability) limited the ability to model potentially important future states, particularly for:
  - weed resistance management
  - any option value that might pertain to paraquat availability in future (e.g. to mitigate the impacts of biosecurity incursion)
  - alternative land uses and the contribution to economic impacts (e.g. land that is no longer used for growing might be used for housing, with concomitant economic and other outcomes).

To the extent that any of the limitations can be addressed in future, the estimates produced in this work would be more robust and/or precise.

1. Introduction

The Environmental Protection Authority (EPA) has commenced a reassessment process pertaining to the use of paraquat, a herbicide with a range of crop protection purposes.

As part of the reassessment, the EPA has commissioned a report estimating the costs and benefits of paraquat use in New Zealand, the subject of this report. The findings of this report will be used to inform final decisions on the nature and extent of continued use of paraquat in New Zealand.

The focus of this report is on the economic aspects associated with paraquat use. That is, to what extent does paraquat use contribute to New Zealand's economy? Human health impacts and environmental effects of paraquat use are also covered, though in much less detail as these elements will be assessed in more depth elsewhere.

The starting point for the analysis is the status quo, or 'business as usual' situation. We then consider the effects of two alternative scenarios: one where paraquat is effectively banned and another scenario involving a restriction on the use of paraquat (i.e. a maximum application rate).

The results of this analysis are contained in section 3 below, which follows a section containing relevant context and describes the nature of costs and benefits under study. A range of appendices contain more detailed explanations of key inputs and parameters used in the modelling work.

2. Understanding costs and benefits of paraquat

This section describes the main elements used in the analysis. We outline the ways in which paraquat is used and by implication the benefits from such use for a range of crops. We begin by presenting some context on the volume of paraquat used and application rates in New Zealand.

2.1 Paraquat sales and application rates

2.1.1 Estimated sales were around 46 tonnes in 2017, up from around nine tonnes in 2004

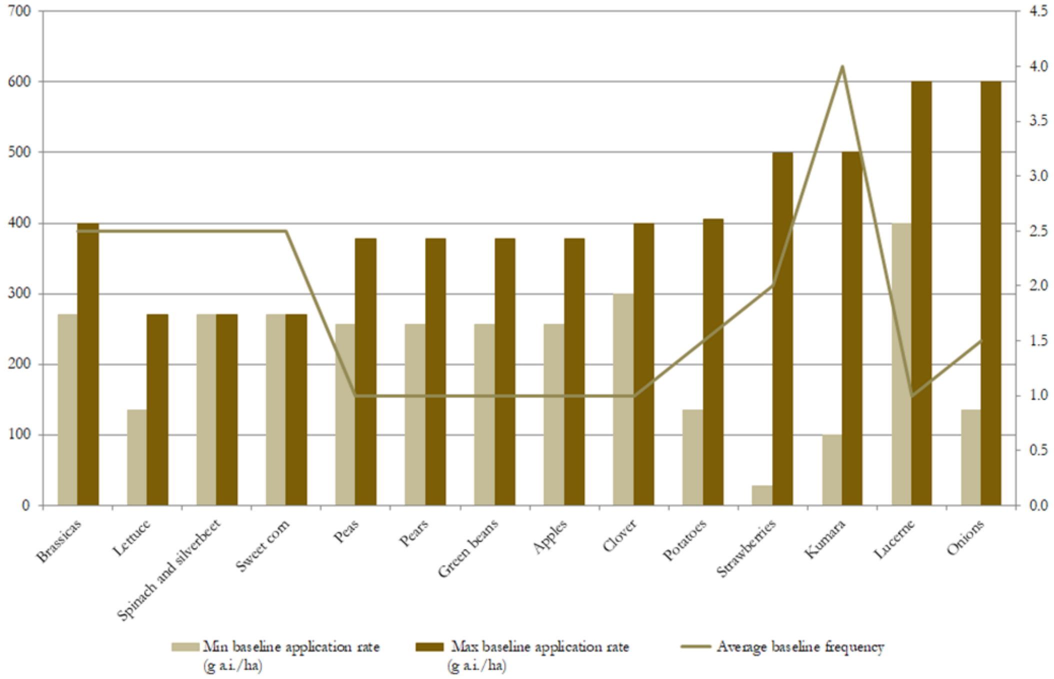
Based on data supplied by paraquat manufacturers and importers, we estimate that about 37 tonnes of active ingredient were sold in 2017. Assuming that this number represents 80% of the entire market, total sales of active ingredient (a.i.), in this case paraquat ion, are estimated to be around 46 tonnes. This figure accords with our own estimate based on crop surface area and application rates for each crop (around 45 tonnes or 280,000 litres). It is difficult to determine the total costs of paraquat, but we estimate that to be around $4.3 million. Note that these numbers reflect a significant increase from the 8.92 tonnes of a.i. of bipyridyls sold in 2004 (Manktelow et al, 2005).

2.1.2 Application rates for our sample vary from a low of 27 grams of a.i. per hectare to a high of 600 grams of a.i. per hectare

The number of applications varies with the use situation. There is typically one application per crop per cycle, but repeat applications may be required to control further germination or regrowth of weeds in certain situations where non-selective control is acceptable (e.g. non-crop areas).

The figure below shows application rates and frequency for each crop investigated in this study. The crops are ordered in an increasing order of maximum application rate (g a.i./ha). We note that application rates can be as high as 2,200 g a.i./ha but none of the stakeholders we spoke to mentioned rates so high.

Figure 1 Paraquat application rates and frequency of application



Source: Sapere based on information from paraquat users

2.2 Beneficial properties of paraquat

The EPA issued a Call for Information (CFI) on the use of paraquat, from which insights around existing beneficial uses of paraquat were gleaned. In particular, paraquat is beneficial due to its:

- *Broad use ability* – paraquat is used at different times and growth stages of crops and paraquat labels carry more generic rather than specific crop claims.
- *Rapid action*– paraquat works rapidly in the presence of light, rapidly desiccating foliage and reducing weed competition for water and nutrients.
- *Non-systemic activity* – paraquat will destroy the plant tissue that it comes into contact with, but does not kill the entire plant. Because only those plant parts that come directly into contact with paraquat are affected, if a few drops land on an emerging crop, the damage caused is restricted and is significantly less than it would be with other broad-spectrum herbicides.
- *Contribution to weed resistance management* – paraquat is in a different chemical group to other herbicide options and offers an additional mode of action to manage (or avoid) weed resistance, which is a major concern to the sustainability of arable and horticultural cropping. This has both present and future value, potentially for ryegrass, plantain, lucerne and clover.
- *Rapid adsorption into soil* – paraquat is rapidly adsorbed into soil, which deactivates its herbicidal activity. Rapid adsorption in soil reduces the risk of paraquat leaching into waterways.

- *Efficacy in a range of temperatures* – paraquat is effective in low temperatures (i.e. it works quickly and crisps up old green crops before they are hoed in for planting) as well as for pre-emergence application for non-selective weed control in seeded (horticultural and arable) crops sown in spring.

In addition, paraquat is rain-fast within 15-30 minutes of application, which can reduce the need for reapplication, resulting in cost savings and reducing the amount of a.i. going into the environment.

Finally, paraquat can provide value as an option to respond to any biosecurity risks from an incursion of new invasive weed species. Paraquat's properties mean there is a relatively high probability that it will be efficacious on a new invasive weed (that could disrupt New Zealand's ecosystems) and will be less risky in terms of collateral damage to existing species if the new invasive weed grows in close proximity to such existing species.

2.3 Users and uses of paraquat

A range of industry sectors use paraquat at present mainly for the purpose of controlling weeds in crops or feedstock (see Table 1). Thus, paraquat provides protection against yield loss directly (i.e. in crops consumed by humans such as onions, beans and the like) as well as indirectly (i.e. in crops used for the production of consumable products such as meat and milk).

Table 1 Paraquat use by sectors in New Zealand

Industry	Purpose of paraquat use in industry
Dairy	Used to kill the pasture sword prior to pasture renewable or crop establishment
Deer	Control of weeds that tend to colonise lucerne, plantain and clover crops
Beef & sheep	Lucerne provides quality feed for young cattle and sheep
Arable industry	Control of weeds in seed crops
Horticulture	Control of weeds in vegetables and fruit. Desiccation of crops. Winemakers New Zealand do not allow the use of paraquat on vineyards
Forestry	Weed control in forest nursery beds

Industry	Purpose of paraquat use in industry
Urban areas	Regional councils have reported no use, but can be used for fence lines and stockyards; banks, drains and waterways, streets and industrial sites

In respect of crops specifically, paraquat use varies across the life-cycle of the specific crop, further indicating the range of beneficial use of paraquat. Table 2 shows the crops covered in this study and the stages where paraquat is used. Again, we compiled this data based on responses to the EPA's CFI and separate follow-up discussions with submitters and other stakeholders.

Some crops, such as boysenberries, celery and squash are not included due to lack of data. We do not expect that this exclusion would materially change our results.

Table 2 Paraquat use by stage in crop life-cycle

Crop	Pre-planting/ Pre-emergence weed control	Weed control during the year	Pre-harvest weed control	Pre-harvest dessication	Post-harvest weed control
Apples		✓			
Brassicas	✓				✓
Clover seed crop		✓	✓		✓
Green beans	✓	✓			
Kumara	✓	✓			
Lettuce	✓	✓			
Lucerne		✓			
Onions	✓				
Pea seed crop				✓	
Pears		✓			
Potatoes	✓	✓	✓	✓	
Spinach and silverbeet	✓				

Crop	Pre-planting/ Pre-emergence weed control	Weed control during the year	Pre-harvest weed control	Pre-harvest dessication	Post-harvest weed control
Stone fruit	✓	✓			
Strawberries		✓	✓		
Sweet corn	✓				

Source: Sapere based on information from paraquat users

2.4 Relative importance of paraquat

2.4.1 Alternatives to paraquat

A key driver of the impact of the alternative scenarios (i.e. banning or restricting use of paraquat) is the availability of substitutes. All else equal, the greater the availability of substitutes, the lesser the impact of the restrictive scenarios (and vice versa). Therefore, relative importance is expressed in terms of the efficacy of alternatives. Both herbicidal and non-herbicidal alternatives are considered

Herbicidal alternatives

Alternatives to paraquat include glyphosate, glufosinate, amitrole, terbuthylazine, saflufenacil. Whilst alternative products are used in conjunction with paraquat for weed control, if used on their own, these alternatives need to be used at higher rates to be efficacious. Use at those concentrations causes significant damage to the kumara crop in particular, meaning that if growers used less paraquat and more alternatives, yields would decrease.[1]

Glyphosate and glufosinate are most commonly referred to, hence we concentrate on them. We note that assessing herbicidal alternatives is not straightforward as:

- glyphosate and other options are not direct substitutes for paraquat; they are often used as complements; and
- relative efficacy depends on myriad factors such as weather, category of crop, area, soil type, weather, size of operation and the season.

Thus, our examination of alternatives is something of a simplification, based on available (but patchy) data. This is an area where further work would be beneficial, but we understand it would involve considerable effort and time and it is not clear who would fund such an undertaking. Notwithstanding this, we present our summation of the possible alternatives below.

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[1] Market Access Soutionz submission on Reassessment of paraquat and paraquat-containing substance, p.16.

Glyphosate

Glyphosate is the most widely used herbicide in the world, including in New Zealand. It kills a range of weeds that can affect production on farms, orchards and gardens if left unchecked. The herbicide is used in about 90 products, with Roundup being the most recognised brand.[2]

Glyphosate has a lower hazard classification than paraquat, and in some instances may be efficacious. However, there are claims (and some evidence)[3] of increasing weed resistance to glyphosate, the corollary being that if the mode of action associated with Preeglone was removed then weed resistance to glyphosate would accelerate. This would leave growers with fewer options for weed control and consequently increase the prospect of crop loss.

> **'When the resistant ryegrass spreads to pastoral farming then, to the best of my knowledge, paraquat and diquat are the only remaining non-residual herbicides available to kill the pasture sward prior to pasture renewal or crop establishment.' (Dairy NZ)**

Glufosinate

Glufosinate is a non-selective contact herbicide, active against a range of broadleaf weeds and grasses. Many orchardists readily swap to glufosinate and/or rotated the use of glyphosate with glufosinate.

Glufosinate has been used relatively regularly by some growers in preference to glyphosate before any glyphosate resistance issues arose. However, it has come to light that there is potential for cross-resistance between glyphosate and glufosinate, meaning that it is not a stand-alone resistance management option.

We understand that glufosinate is typically ineffective at low temperatures and not suitable for use in spring. In addition, glusofinate is thought to kill clovers and is therefore not able to be used in closer seed production.[4]

Summary

Notwithstanding the inherent difficulty establishing a complete understanding of the suitability of alternative to paraquat, given the crucial role such understandings play in the analysis of all three scenarios, we have attempted to summarise the importance of paraquat relative to glyphosate and glufosinate.

Table 3 summarises the relative importance of paraquat versus alternative herbicides. The categories of importance reflect the different stages of crop life-cycle that paraquat is used for in different crops.

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[2] https://www.mpi.govt.nz/food-safety/whats-in-our-food/chemicals-and-food/agricultural-compounds-and-residues/glyphosate/

[3] For instance, the Foundation for Arable Research has confirmed that glyphosate resistance has been found in two two species of annual and perennial ryegrass in the northern South Island

[4] Federated Farmers' and Foundation for Arable Research submissions on Reassessment of paraquat and paraquat-containing substances, p.6 and p.2 respectively.

Table 3 Importance of paraquat vs alternatives

Scale of relative importance	Description	Crops
High	Paraquat does not have suitable alternatives, because there is crop damage risk from using glyphosate or glufosinate	Clover seed crop, kumara, Lucerne, potatoes, strawberries, stone fruit
Medium	Glyphosate or glufosinate could be used as alternatives but there is increasing weed resistance, or paraquat is used for that crop as a pre-harvest desiccant only	Brassicas, green beans, lettuce, onions, pea seed crop, spinach and silverbeet, sweet corn
Low	Paraquat is not an essential herbicide as confirmed by users	Apples, pears

Meanwhile Table 4 provides an overview of the importance of paraquat use as compared to glyphosate and glufosinate for different stages of the crop life-cycle.

Both tables are used in the subsequent impact analysis that follows. For our analysis, the most important conclusion we can draw from the available evidence/expert opinion is that there are limited alternatives for kumara, clover and lucerne, which we will highlight further in the next section of the report.

Table 4 Herbicide use at different stages of crop life-cycle

Crop stage	Crop	Paraquat	Glyphosate	Glufosinate
Fallow burn-off when weeds are small	Brassicas, lettuce, spinach and silverbeet, sweet corn	Works well under cool temperatures and helps manage weed resistance	Can be used but there's increasing weed resistance	Does not work well under cool temperatures
Preparation of stale seed beds	Green beans, plantain	Works well under cool temperatures and helps manage weed resistance	Can be used but there's increasing weed resistance	Does not work well under cool temperatures
Crop pre-emergence	Kumara, onions, potatoes	Works well under cool temperatures and helps manage weed resistance	Can be used but there's increasing weed resistance	Does not work well under cool temperatures
Dormancy period	Lucerne	Works well under cool temperatures and does not damage crop	Risk of crop damage	Does not work well under cool temperatures; also risk of crop damage
Crop spraying	Clover seed crop, kumara, lucerne, stone fruit (sprayed underneath trees)	Does not damage crop	Risk of crop damage	Risk of crop damage
Inter-row weeding	Green beans, kumara, strawberries	Does not damage crop	Risk of crop damage	Risk of crop damage

Crop stage	Crop	Paraquat	Glyphosate	Glufosinate
Pre-harvest dessicant	Pea seed crop, potatoes	Does not damage crop and helps manage weed resistance	Can be used but there's increasing weed resistance; also risk of crop damage	Risk of crop damage; also cross-resistance if glyphosate-resistance has developed
Pre-harvest weed control	Clover seed crop, strawberries, potatoes	Does not damage crop and helps manage weed resistance	Can be used but there's increasing weed resistance; also risk of crop damage	Risk of crop damage; also cross-resistance if glyphosate-resistance has developed

Source: Sapere based on discussion with paraquat users

Non-herbicidal alternative risks damage and is cost-prohibitive

The non-herbicidal alternative considered was physical removal of weed, which could potentially be done using labour and/or machinery. The dairy and horticulture sectors both raised concerns at the possibility of having to use physical methods to remove weeds if faced with the prospect of unavailable or ineffective herbicidal options. Other sectors did not raise the issue, but we do not necessarily take that as indicating they don't see any problems with such an alternative (i.e. it may be that they have not thought about the prospect because it seems too far-fetched).

The costs and risks associated with mechanical removal of weed were identified include:[5]

- The cost of mechanical removal is many times greater than using herbicide.
- Such on-going practices can degrade the quality and structure of soils.
- Soil loss following increase ploughing activities can occur through rainfall or wind events – potentially causing negative impacts on nearby waterways.
- Increased use of machinery for such practices increases the risk of invasive weed species being spread to other properties potentially over long distances.

We were provided with data from the representative of selected horticulture industries on the estimated costs of labour being employed to remove weeds in the absence of herbicidal options. The calculations were based on assumed hourly rates, time required to clear a hectare of land and the frequency of weeding per season.

Data from growers indicated that the costs associated with hand weeding would be in the order of 70 times those associated with paraquat use (due largely to the increased frequency and time needed to cover the land area), assuming the quality and quantity of required labour is available.

This estimation, while 'rough and ready' suggests that physical treatment of weeds would at best add significant cost to the production process and at worst could result in some crop production becoming economically unviable to produce.

2.5 Costs associated with paraquat use

The use of paraquat, and indeed almost any chemical is not costless. From a societal perspective there may be detrimental effects that need to be considered alongside the beneficial effects outlined immediately above. The two areas of cost relevant to this study are environmental and human health impacts.

Given the time constraints (and purpose) of this study, our treatment of these cost impacts is less detailed than would otherwise be the case (i.e. the material is largely qualitative and risk-based in nature).

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[5] DairyNZ submission on Reassessment of paraquat and paraquat-containing substances, p.1.

2.5.1 Environmental effects

Perhaps not surprisingly, our examination of existing material on the environmental effects of paraquat use indicates that risks to the environment tend to relate to the rate at which paraquat is applied. That is, at higher application rates, environmental risk rises.

At higher application rates (e.g. > 1kg a.i./ha) environmental risks likely arise for algae and aquatic plant species, and some birds and bees. Risks of groundwater contamination are expected to be low given the high adsorption of paraquat and the fact that it is almost immobile in soil. Risks to sediment-dwelling organisms are also expected to be low. Sediments integrate the effects of surface water contamination over time and space, and in this way may present a hazard to aquatic communities in future.

It is possible that some of these effects could be mitigated, through measures such as buffer-zone control or other controls that could manage spray drift or unintentional application on waterways. Restrictions an application rates and application methods could also mitigate identified risks.

Overall, the assessment of possible environmental effects is largely an exercise in relative risk rather than absolute certainty. The difficulty in quantifying and monetising environmental effects restricts our ability to fully consider the possible costs of paraquat use against the estimated benefits. We understand that the EPA will be assessing environmental factors in more depth as part of their work and that this will add to the broader understanding of relevant costs and benefits.

2.5.2 Human health effects

A literature search on the human health impacts of paraquat use suggested that a wide array of relevant articles and reports existed. The overwhelming majority of such publications related to overseas jurisdictions, with a heavy focus on developing countries and the United States.

The dimensions of possible harm identified in the literature were:

- Occupational and accidental exposure
  - Acute poisoning and fatalities
  - Skin irritation, eye injury/impaired sight
- Chronic effects
  - Parkinson's
  - Impaired lung function
  - Depression
- Self-harm/suicide

From the perspective of this study, examining chronic health effects (perhaps from a quality of life perspective) would be of most interest due to the potential for significant costs to accrue over time. That is not to say that deaths are not important or material cost-wise, but self-harm and suicide events would, in our view, only tangentially be impacted by the alternative (restricted) scenarios under study.[6]

Undertaking a full assessment of possible human health impacts was not possible within the time and resource constraints of this project. Furthermore, it was difficult to reconcile in a definitive sense the range of (often confounding) evidence of impacts. Applying overseas results to a New Zealand context is also fraught when labour practise and regulatory regimes differ. In addition, there was very little direct New Zealand evidence to draw from.[7]

The EPA risk assessment for paraquat finds that paraquat presents greater risk than other herbicides and requires greater risk mitigation measures. However, overall the risks to human health from paraquat use are assessed as acceptable up to an application rate of 350g a.i./ha, provided the correct protective equipment is used. Risks from bystander exposure and worker re-entry were acceptable.

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[6] It is likely that even in the situation of an effective ban on paraquat, residual supplies could still be used self-harm purposes. Moreover, the number of suicides may not be affected at all, as people would find and use an alternative.

[7] We do note that data from the National Poisons Centre revealed that the occurrence of incidents involving paraquat was low and the proportion of incidents that would be captured by the alternative scenarios under study would be even lower.

3. Estimation of economic impact of paraquat

As indicated above, the economic aspect of this study assumes some prominence in this study given that the major beneficial impacts are production related. We express the economic effects in terms of Gross Domestic Product (GDP), as it is a commonly used and relatively well understood measure of a nation's income. In addition, relevant GDP data is readily available on which our estimates are based.

Data availability is a key determinant of the way the analysis is conducted. The study could have looked directly at paraquat users' costs and revenues to determine economic and financial impacts. Another possible approach could be based on findings on the economic costs of weeds on productive land. Both of these approaches have far greater data demands, rendering them prohibitive in the time and resources available for this project. They may be useful areas to explore in further research work.

3.1 Baseline scenario

The baseline or status quo scenario is determined by calculating the contribution to annual GDP that paraquat currently makes. It is a point-in-time estimate, which does not account for possible changes in respective prices or volumes in future.

By construction, the baseline scenario determines the 'effective ban' scenario as the latter is the inverse of the former. That is, if paraquat were to be banned, annual GDP would reduce by the estimated GDP contribution attributable to paraquat.

3.1.1 Overview of approach

We multiply three factors to calculate the product: crop contribution to GDP attributable to paraquat (see Figure 2).

Figure 2 Estimating paraquat contribution to GDP

Crop contribution to GDP X Herbicide contribution to crop yield (%) X Share of paraquat in NZ herbicide use (%) = Crop contribution to GDP attributable to paraquat

Crop contribution to GDP

We utilise available data on crop contribution to GDP, adjusted for inflation to 2017. This data was sourced from a report prepared the Ministry of Primary Industries, estimating the value of plant species in New Zealand.[8] The study uses standard techniques to derive its estimates and we are therefore comfortable with the numbers produced. We understand that

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[8] NZIER (2015)

work has been commissioned on the economic value of the crop protection industry to New Zealand, which would likely produce estimates that could be useful to the analysis we have undertaken. However, the report is not scheduled to be completed until March 2019, meaning we are unable to use it at this point.

Herbicide contribution to crop yield

For most crops, we calculated the herbicide contribution to crop yield by using the estimates in a 2007 paper for U.S. crops,[9] adjusted for use in the New Zealand context. That is, we convert existing data from elsewhere to its New Zealand equivalent to make the estimates as New Zealand-specific and relevant as possible.

The conversion process used to derive a New Zealand equivalent factor comes from a paper estimating the economic impact of paraquat in Australia.[10] The adjustment is essentially a scale factor relating the use of crop protection products (CPP), which include herbicides, to total hectares in use. Appendix 3 contains further detail on the calculation process.

We estimate a scale factor of 0.46, which in broad terms means that the intensity of herbicide use in New Zealand is less than half that of the U.S. By contrast, the scale factor for Australia was estimated to be 1.45.[11] This is consistent with our understanding (based on a discussion with a herbicide manufacturer) that weed resistance is a much greater issue in Australia than in New Zealand. Differences in the composition of crops grown may also be a contributor.

Appendix 4 provides the estimates for crop yield attributable to the use of total herbicide and of paraquat specifically.

Share of paraquat in New Zealand herbicide use

In the absence of specific data, we rely on assumptions derived from other available sources for this parameter. We assume a range determined by ‘a high’ and a ‘low’ percentage share of New Zealand herbicide use relating to paraquat. The figure used for the low case in 1 per cent, while the high case uses 3.2 per cent.

The higher figure is based on Manktelow (2005, representing the share of paraquat use on Australia as a share of total herbicides.[12] The lower figure represents the smallest share of paraquat out of total herbicide sales reported by New Zealand importers and manufacturers that we surveyed. We note that the actual share of total herbicide use explained by paraquat would vary by crop, but we only had crop-specific data for kumara.

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[9] Gianessi (2007)

[10] DeloitteAccessEconomics (2018)

[11] *Ibid.*

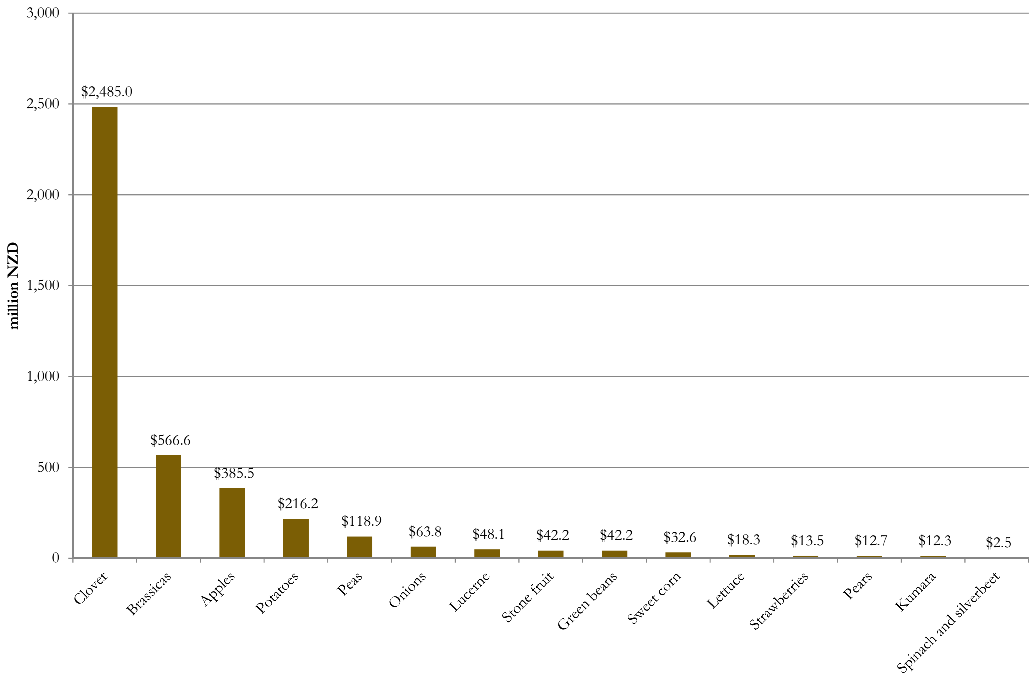
[12] DeloitteAccessEconomics (2013), table 4.3.

3.1.2 Crop contribution to GDP is around $4 billion

Crop contribution to GDP reflects the value added along the entire value chain. Where paraquat is used for seed crops only, the entire value chain of the crop is considered, given that seeds are eventually used to produce the crop used by dependent industries.

Total annual value added (GDP) for the crops investigated is approximately $4 billion. The major contributor to this total is clover, which accounts for over half of the total, primarily due to its value as a feedstock.

Figure 3 Total crop contribution to GDP



Source: NZIER (2015)

3.1.3 Paraquat contribution to GDP is $30 million-$60 million per annum

Table 5 shows that the current share of total relevant GDP attributable to paraquat is between $30 million and $60 million per annum (2017 dollars).[13] That is, in the absence of paraquat New Zealand's annual GDP would reduce by a minimum of $30 million and a maximum of $60 million.

These figures represent a 'worst-case' scenario (or upper bound) associated with a general lack of replacement herbicide options being available. It may be that other products and/or innovative solutions arise, which would lower the estimates.

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[13] Further explanation for why the high and low scenario figures in the table for clover and lucerne are the same is contained in Appendix 4.

Table 5 Paraquat contribution to GDP by crop

Crop	Paraquat contribution to GDP (high)	Paraquat contribution to GDP (low)
Apples	$844,821	$256,977
Brassicas	$1,158,959	$364,877
Clover	$39,465,391	$12,424,961
Green beans	$123,366	$38,840
Kumara	$6,160,333	$6,160,333
Lettuce	$34,815	$10,961
Lucerne	$9,610,374	$9,610,374
Onions	$400,631	$126,131
Pea seed crop	$157,986	$49,739
Pears	$950,288	$299,181
Potatoes	$1,010,967	$318,285
Spinach and silverbeet	$18,105	$5,700
Stone fruit	$67,887	$21,373
Strawberries	$59,194	$18,636
Sweet corn	$119,256	$37,546
Total	**$60,182,374**	**$29,752,914**

3.2 Restricted use scenario

The figures above give the baseline contribution of paraquat to New Zealand's GDP (equivalently its economic value to New Zealand), the inverse of which represents the estimated economic loss to New Zealand if paraquat was not available, all else equal.

In addition, we estimate an illustrative restricted scenario, where paraquat is still available but the maximum application rate is constrained (i.e. 300 g a.i./ha; and 400 g a.i./ha).[14]

3.2.1 Scenario description

Table 6 Description of restricted use scenario

Nature of restriction	Detail	Comment
Limit on application rate	Maximum application rate: Option A: 300g a.i./ha Option B: 400g a.i./ha	Restriction proposed in terms of g active ingredient because different products contain different concentrations of active ingredient. Option A allow for some use in lucerne production; while Option B would not allow use in lucerne production.
Limit on application frequency	One application per year	
Restrict application to certain specified application methods	Application by ground-based boom spray only, applied using coarse sprays. Aerial and hand-held applications are prohibited.	This would have the effect of also prohibiting spot treatment use of paraquat using hand-held equipment
Buffer zone	60m downward buffer zone to protect sensitive areas (including water bodies)	
Use of PPE and RPE	Personal protective equipment required for mixing, loading and application: full PPE and respiratory protective equipment	

Source: EPA

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[14] Ultimately, the restricted scenario, if any, will be determined by the EPA and thus may differ from our illustrative example.

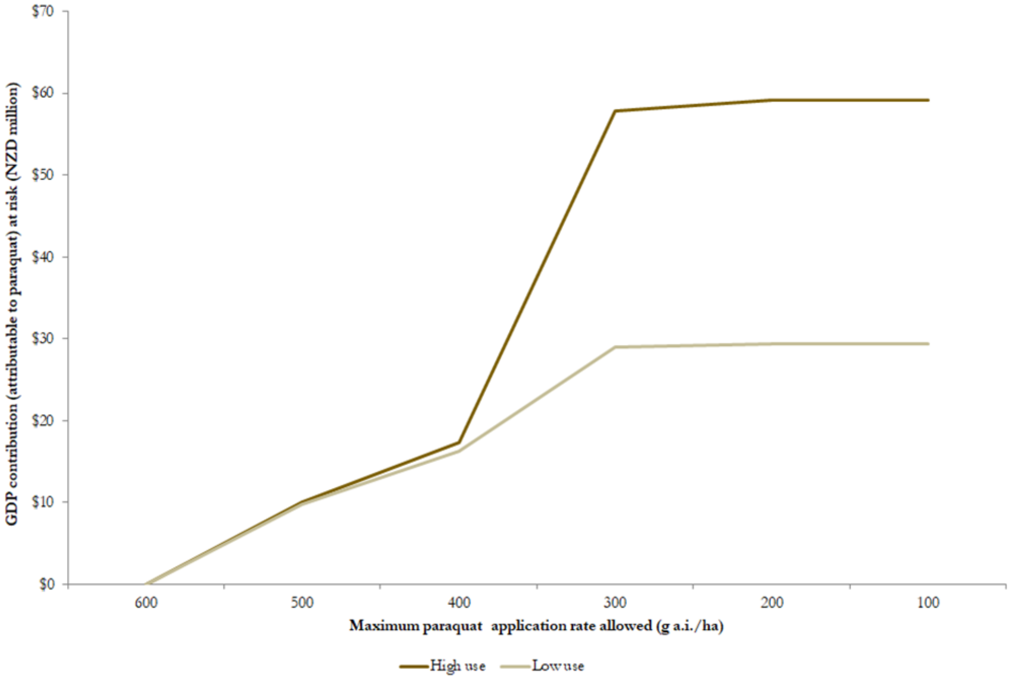
3.2.2 Reductions in GDP most material at 300 g a.i/ha, due mainly to clover

The specific results presented here relate to restrictions to paraquat application rates (i.e. g a.i./ha). We focus on the impact of restrictions on the maximum application rate used for each crop, and assume that if the maximum required application rate at present cannot be used for a stage of the crop life-cycle in the restricted (future) scenario, the entire value of the crop is at risk. This gives us an upper bound of the value at risk (as measured by paraquat contribution to GDP) from application restrictions. We model restriction levels from 100g a.i/ha to 600g a.i/ha.

The upper-bound paraquat value at risk assumes that paraquat use in crops for which paraquat use is of medium or high importance (as defined in Table 3) cannot be substituted with other herbicides. Paraqaut use in crops where paraquat is of low importance is assumed to be easily substitutable with other herbicides.

At a maximum application rate of 400 g a.i./ha the upper-bound potential loss in annual GDP is around $17 million, while at a maximum application rate of 400 g a.i./ha the potential loss in annual GDP is around $58 million. The materiality of the 300 g a.i./ha restriction is illustrated graphically in Figure 4 and Figure 5.

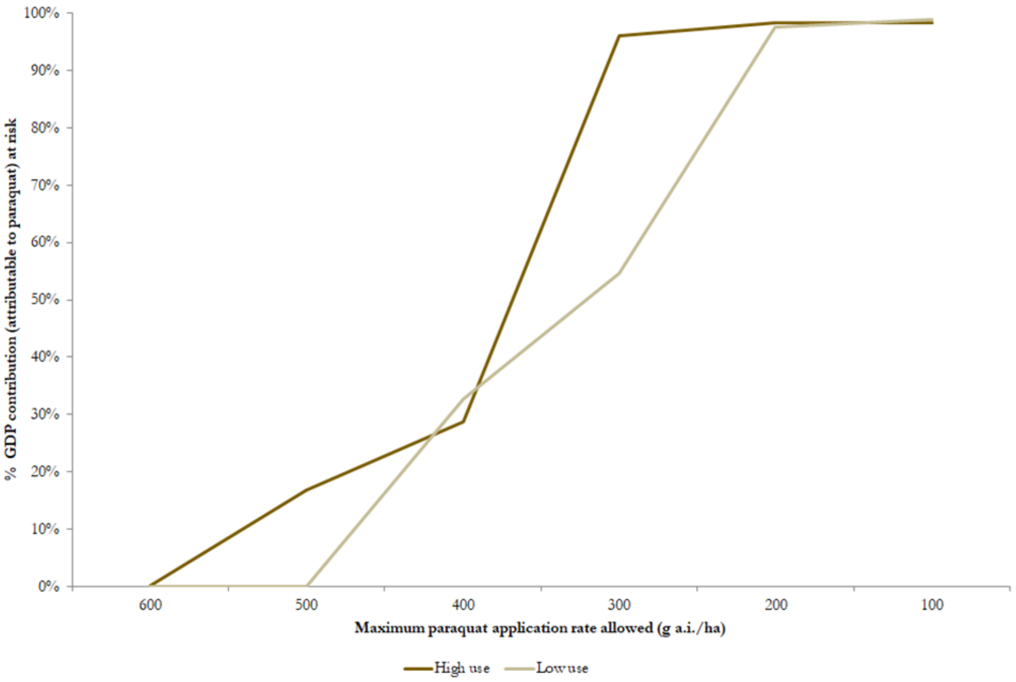
Figure 4 GDP value at risk due to restricted maximum application rate of paraquat



Source: Sapere analysis

The graph below shows the percentage of paraquat baseline value that is at risk from different levels of restricted use.

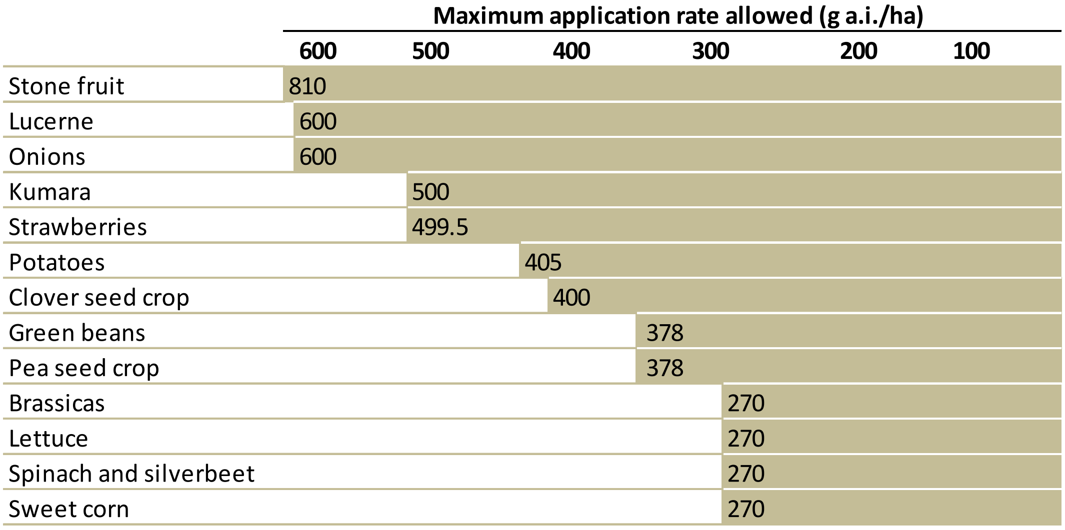
Figure 5 Percent paraquat value at risk due to restricted maximum application rate of paraquat



Source: Sapere analysis

Figure 6 shows the maximum application rate that would place the entire crop's value (associated with paraquat) at risk. Given clover's importance in terms of contribution to GDP (see Table 5) the maximum application rate for clover of 400 g a.i./ha is a key driver of the dramatic increase in the GDP value at risk from paraquat restrictions at maximum application rates below 400 g a.i./ha.

Figure 6 Crop value at risk by maximum allowed paraquat application rate



Stone fruit	810
Lucerne	600
Onions	600
Kumara	500
Strawberries	499.5
Potatoes	405
Clover seed crop	400
Green beans	378
Pea seed crop	378
Brassicas	270
Lettuce	270
Spinach and silverbeet	270
Sweet corn	270

▨ means that the crop value (attributed to paraquat use) is at risk at the respective application rate restriction level

Source: Sapere analysis

3.3 Sensitivity analysis

In terms of sensitivity analysis the major element we alter is the scale factor for New Zealand. Recall that this was derived specifically for New Zealand from estimates for Australia. In the sensitivity testing we use the Australian scale factor directly, which increases the scale factor by a factor of three (from 0.46 to 1.45).

3.3.1 Results largely insensitive to scale factor changes

Table 7 compares the estimated annual GDP contribution attributable to paraquat using a scale factor of 1.45 to the baseline situation in the high use scenario (i.e. paraquat accounts for 3.2% of total herbicide use). In addition, we include comparisons across a range of application rate restrictions.

As can be seen, the greatest sensitivity to the scale factor is at the lowest level of restriction (i.e. highest allowed application rate). At this level, the change in value only reflects an increase in paraquat-related GDP contribution from stone fruit. At the 400g a.i./ha restriction, the change in value mainly reflects an increase in paraquat-related GDP contribution from potatoes and onions.

Overall, given the three-fold increase in the New Zealand scale factor, we conclude that the results are not particularly sensitive to the scale factor, except for the least restrictive (highest maximum allowable application rate) situation. However, at this level, paraquat-related GDP contribution at risk is low.

Table 7 Sensitivity analysis in the high-scenario

Metric	NZ scale factor = 0.46	NZ scale factor = 1.45	Proportional change
Paraquat GDP value	$60,182,374	$68,782,434	14%
Paraquat GDP value at risk at 100g a.i./ha restriction	$59,179,566	$65,621,409	11%
Paraquat GDP value at risk at 200g a.i./ha restriction	$59,179,566	$65,621,409	11%
Paraquat GDP value at risk at 300g a.i./ha restriction	$57,848,431	$61,425,442	6%
Paraquat GDP value at risk at 400g a.i./ha restriction	$17,309,386	$20,620,891	19%
Paraquat GDP value at risk at 500g a.i./ha restriction	$10,078,891	$11,087,222	10%
Paraquat GDP value at risk at 600g a.i./ha restriction	$67,887	$213,991	215%

3.3.2 Other parameter changes

In addition to altering the scale factor, we could have undertaken sensitivity analysis of the results to changes in the assumed paraquat contribution to yields and/or the share of herbicide use accounted for by paraquat. The latter is particularly important for clover, where expert opinion supported a herbicide contribution to yield of 50 per cent. To the extent that that share of total herbicide use on clover explained by paraquat is above the assumed maximum we have used (3.2%), our results could change markedly.

Unfortunately, we do not have any further reliable evidence on which to base a change to the proportion of herbicide use accounted for paraquat for clover, or other crops. Further, there is insufficient supporting evidence around the assumed contribution of paraquat to crop yields for us to have confidence that the changes are plausible.

Thus, we do not conduct sensitivity analysis on those parameters. It is possible that the figures we have used prompt a reaction from relevant experts (or further work) such that alternative values can be used in such sensitivity analysis in future.

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- Dairy NZ
- Deer Industry New Zealand
- Federated Farmers
- Federation for Arable Research
- FarmShop

- Lincoln University
- Massey University
- New Zealand Apples and Pears
- Potatoes New Zealand
- Ravensdown
- Solutionz
- Syngenta

Appendix 1 Paraquat-containing products registered in New Zealand

Product label	g a.i./1 litre	Mixed w/ diquat?	Year of registration
PDQ	135	Yes	2018
Paraquat 200SL	200		2014
Agpro Paraquat 200	200		2014
Speedy 250	135	Yes	2013
Kuatout	135	Yes	2013
Parable 250	250		2021
Uniquat 250	250		2011
Genfarm Paraquat 250	250		2006
Flash Herbicide	250		2006
PQ 200	200		1993
Preeglone	135	Yes	1965
Gramoxone 250	250		1962

Source: https://eatsafe.nzfsa.govt.nz/web/public/acvm-register;jsessionid=F56E2CEAD423371F71464B811E0060FF

Source: Sapere diagram based on NZIER (2015)

Appendix 2 Paraquat application rates

Crop	Min application rate (g a.i./ha)	Max application rate (g a.i./ha)	Frequency of application
Apples	256.5	378	1
Brassicas	202.5	270	2-3
Clover seed crop	300	400	1
Green beans	256.5	378	1
Kumara	100	500	2-6
Lettuce	270	270	2-3
Lucerne	400	600	1
Onions	135	600	1.5
Pea seed crop	256.5	378	1
Pears	265.5	378	1
Potatoes	135	405	1-2
Spinach and silverbeet	270	270	2-3
Stone fruit	256.5	810	1-2
Strawberries	27	499.5	1-3
Sweet corn	270	270	2-3

Source: EPA CFI responses from paraquat users, and own estimates

Appendix 3 New Zealand scale factor

Recall from section 3 above that the herbicide contribution to crop yield is an important parameter in estimating the economic value of paraquat use. No such data exists for New Zealand so we use overseas data translated to its New Zealand equivalent, on average.

	NZ (estimated by Sapere)	**USA (estimated by Sapere)[2]**	**USA (estimated by Deloitte AccessEconomics,2018)**
Total CPP use (million USD)	129.45[1]	12,330.42	8,640
Total crop area (million ha)	3.3	126.4	161.1
Total crop production (million USD)	7,117.06	201,434.32	195,036
CPP use/ha (USD/ha)	39.4	97.57	53.63
CPP use/$ production (USD)	0.018	0.06	0.04
Scale factor - ha		0.4	0.73
Scale factor - production		0.3	0.41
Average scale factor		0.35	0.57
Average scale factor used	**0.46**		

Data is average for 2007-2016. CPP = Crop Protection Products. Includes herbicides, insecticides and fungicides

[1] Based on Manktelow et al (2005) and adjusted for 2016 dollars

[2] Based on data from the USDA National Agricultural Statistics Service Information

Appendix 4 Crop yield attributable to herbicide use

Crop	% crop yield attributable to herbicides	% crop yield attributable to paraquat (high)	% crop yield attributable to paraquat (low)
Apples	7%	0.22%	0.07%
Brassicas	6%	0.2%	0.06%
Clover seed crop*	50%	1.59%	0.5%
Green beans	9%	0.29%	0.09%
Kumara	50%	50%	50%
Lettuce	6%	0.19%	0.06%
Lucerne*	20%	20%	20%
Onions	20%	0.63%	0.2%
Pea seed crop	25%	0.8%	0.25%
Pears	39%	1.24%	0.39%
Potatoes	15%	0.47%	0.15%
Spinach and silverbeet	23%	0.73%	0.23%
Stone fruit	5%	0.16%	0.05%
Strawberries	14%	0.44%	0.14%
Sweet corn	12%	0.37%	0.12%

* For kumara and lucerne, we did not have separate data for total herbicide contribution to crop yield. Nevertheless, our interviews with paraquat users suggest that there are no suitable alternatives for these two crops in particular.

Appendix 5 Aquatic acute risk assessment results

Species	Concentration applied 2x at 28 days interval	Concentration applied 4x at 28 days interval	Acute RQ	Trigger value
Algae – diatom (Navicula pelliculosa)	400g a.i./ha (clover)		7.94	>0.5 High risk >0.05 High risk for threatened species
	600g a.i./ha (Lucerne)		11.85	
		600g a.i./ha (barley grass control)	23.35	
	1,000g a.i./ha (forestry)		19.84	
		1,500g a.i./ha (barley grass control)	58.6	
		1,500g a.i./ha (non-crop)	58.6	
Aquatic plant (Lemna gibba)	600g a.i./ha (Lucerne)		0.067	>0.05 High risk for threatened species
		600g a.i./ha (barley grass control)	0.13	
	1,000g a.i./ha (forestry)		0.11	
		1,500g a.i./ha (barley grass control)	0.33	
		1,500g a.i./ha (non-crop)		
Algae (Selenastrum capricornutum)		1,500g a.i./ha (barley grass control)	0.1	>0.05 High risk for threatened species
		1,500g a.i./ha (non-crop)		