AFTER COMMENT BY THE FRNL SCIENCE TEAM

Recommendations for the implementation of plantain in Overseer

Author: Mark Shepherd

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1. Executive Summary

Background

Plantain-rich pastures are increasingly used by New Zealand farmers. Predominantly, plantain is sown with ryegrass/white clover, but can also be sown as a specialist crop (with or without clover and other herbs). In grass-dominant pastures and pure stands it is commonly observed to diminish in abundance after about 2-3 years. It is important that the use of plantain in pastoral systems can be captured in Overseer, especially as there is increasing evidence that plantain-rich pastures can decrease nitrogen (N) leaching.

The aim of this report is to describe the changes in Overseer required to build the known effects of plantain[1] into the model, with supporting evidence for the changes, for review by the FRNL science team[2]. Following review, the finalised list of recommended changes will then be agreed by the FRNL science team and approved by the FRNL Programme Management Committee, and this report will form the Change Document for Overseer Ltd.

Key model areas

Despite the in-depth research on plantain completed in the FRNL programme, and further supplemented by other available information and expert opinion, the challenge still remains of implementing plantain in Overseer so that it can be modelled across a diversity of farm enterprises, farm systems and environments. The approach therefore has been to identify changes where the consensus of the FRNL science team is that there is enough information to justify a change (or evidence that change is not needed); and also, to identify other aspects where change might be needed in the future but more evidence is required first.

The model review identified some key areas that require decision on (a) whether change is justified (i.e. is different to standard pasture) and (b) how the change should be converted to an Overseer algorithm. In summary:

- The **short-term nature of plantain** is a potential issue, with persistence only 2-3 years. How this is dealt with by the farmer, e.g. resowing, could have implications for soil N mineralisation and subsequent leaching estimates if resowing includes cultivation.
- **Pasture intake characteristics** (ME, %N and utilisation) – industry literature indicates plantain offers higher quality feed. Our databases don't fully support this.
- **Pasture production** - Interpretation of yields and productivity is made difficult by lack of country-wide data and the fact that experiments tend to establish new swards, which might skew positive effects due to simply the process of renewal.
    - Relativity – if plantain pastures or crops grow more feed then this could increase the amount of N eaten and, therefore, urine production excreted and negate some of the benefits
    - Temporal distribution of growth patterns – will potentially impact on N leaching
- **Partitioning of eaten N in milk/meat** – is more N diverted to protein in these products, thus reducing the amount excreted?

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[1] Most New Zealand research on plantain used the cultivar Ceres Tonic. This is a relatively winter-active, prostrate, large- but narrow-leaved plantain type (*Plantago lanceolata*), with a coarse root structure. Further characteristics of this type observed in the various FRNL trials, relevant to the effects described in this report, are its lower dry matter content and higher water soluble carbohydrate/nitrogen ratio compared with perennial ryegrass.

[2] The FRNL science team involved in plantain research and implementation of plantain in Overseer consisted of Mark Shepherd, Diana Selbie, Mike Dodd (AgResearch), Racheal Bryant, Keith Cameron (Lincoln University), Elena Minnée and Ina Pinxterhuis (DairyNZ).

- **Partitioning of N in excreta** – is there enough evidence to support greater diversion of excretal N to dung, thus decreasing urine N load, driven by plantain pasture nutritive characteristics compared with standard pasture?
- **Urine patch N load** – is the dilution effect real (thus reducing the urine patch equivalent N load)? And how much is it decreased by? And is this a sliding scale related to plantain proportion in the sward?
- Effect of plantain metabolites **on soil processes**, e.g. nitrification. What is the size of this effect on N leaching reduction and how reliable (across soil-types and climates) is the effect?

This report aims to address each of these areas. These components tend to be considered at a component scale. However, when scaled to a farm level, some of the decision points around algorithm changes in Overseer might be shown to have minimal impact on N leaching estimates. Completion of a development version will allow sensitivity testing of the model to help understand the impacts of interactions of a 'plantain block' with other parts of the Overseer model. This is an important next step because, as the plantain model will be constructed from individual component research, some of the interactions may modify N leaching estimates.

Summary of recommendations

Plantain block(s)

- Plantain should be implemented as:
    - ***A pasture block type***, which means that it is a long-term pasture where plantain supplements ryegrass/white clover. Plantain levels are maintained by oversowing, direct drilling and/or good grazing management. The block is not cultivated to reseed it. As with other pasture blocks it can be fully grazed, fully cut and carry or a mix of grazing and cut and carry. It can also be an effluent block.
    - ***A specialist forage crop***, in place for up to two or more years. We need to agree with the FRNL science team how this is best modelled, e.g. as a forage crop rotating through the pasture platform or as a forage crop in a crop block. Whatever the final choice, cultivation of such a crop will result in N mineralisation which may offset some or all of the benefits of the crop.
- Plantain should also be available as a ***supplement type***, or a number of supplement types depending how they are used commercially. This ensures that farm systems using plantain can be fully represented in an Overseer model set-up. However, unless fresh cut and carry, there is insufficient data to assume that any effects from metabolites on, say urination, are carried through in the supplement.
- Plantain should be grazable by all enterprise types. This is based on the assumption that the effects observed in experiments based on dairy cattle and dairy pastures is reproducible in other ruminant enterprises.
- For pragmatic reasons, a sliding scale of effects on N cycling based on levels of plantain in the sward should be adopted. This encourages farmers to try plantain compared with, saying, only implementing change if a pasture has a high proportion of plantain. The challenge then becomes how algorithms are best developed for this sliding scale – is it a linear relationship with plantain proportion, for example?

Pasture ME and N concentration:

- There is no strong evidence of consistent relative differences in pasture N concentration or ME content between standard and plantain-rich pastures: use the current Overseer defaults for both pasture types.

Pasture digestibility

- Use the same digestibility calculation as for all other pasture types.

Pasture utilisation

- Use the current Overseer default values for pasture utilisation by animals.

Production

- Changes in animal production are captured by user input changes in the model. This is important because these inputs are used in Overseer to back-calculate pasture production (Overseer does not model pasture growth directly).

Block relativity

- For plantain/clover swards, set a default relativity of 1.1.
- For plantain/pasture blocks, set a relativity of 1

Seasonality of growth

- There is more work to do to understand the FRNL data and differences between N and S Island
- We would expect the growth differentials to be clear in plantain vs pasture: and less of a differential between plantain/pasture and standard pasture
- Evidence doesn't yet support this?

Urine N partitioning

- Partition more N to dung than the current Overseer calculation. To do this, adjust the Ledgard equation, using a linear sliding scale for the adjustment factor:
    - For zero plantain, use Overseer default proportion of urine:
    - For a plantain sward (>60% plantain), urine proportion = 0.8* Overseer value, remaining N moved to dung
    - This means that for plantain (30% of sward DM, urine proportion = 0.9* Overseer value, remaining N moved to dung
- Longer-term, consider developing a new Ledgard algorithm that includes factors such as water-soluble carbohydrate (Feed <u>quality</u> characteristics), rather than just N <u>quantity</u> alone

N in product

- No change to N concentration in animal products
- Any increases in N removal in product should be captured by changing the farm yield of milk or meat.

Drainage model

- There is some indication from lysimeter studies of decreased drainage volume under plantain (attributable to lower water use efficiency). However, further evidence of the size of effect at the paddock level is required. Until then, use existing drainage model values for plantain-rich pastures

Background model

- Use existing background model values for plantain-rich pastures

Urine patch N load

- Modify N loads in a standard urine patch on a linear sliding scale depending on proportion of plantain in the sward.
- For zero plantain, UP N load = default 750 kg N/ha
    - For a plantain content >60%, N load = 60% of ryegrass UP, i.e. 450 kg N/ha
    - This means that for plantain-rich pasture (30% plantain), N load = 80% of ryegrass UP, i.e. 600 kg N/ha
- Further sensitivity testing will demonstrate if these are the best numbers to use

Pasture N uptake

- Any increased pasture N uptake potential will be captured by adjusting seasonal growth rates

Miscellaneous

- Written guidance should be provided to end-users to
    - describe what comprises a plantain pasture block type and its typical management and thresholds for plantain content
    - clarify that increases in animal production resulting from plantain-rich pastures need to be reflected in the user inputs: Overseer will not automatically change these
- *Clover content* - No change to estimation of clover content for plantain-rich pasture blocks.
- *N fixation* - No change to current calculation of symbiotic N fixation for plantain-rich pasture blocks

Other issues

- Inclusion of other pasture species is out of scope If a pasture mix also includes other species (i.e. other than ryegrass, white clover or plantain) the model for now should treat these other species similar to ryegrass/white clover.

- We assume that the energy sub-model is satisfactory and does not need to be modified to accommodate practices associated with plantain management, i.e. everything up to and including calculation of ME requirement is satisfactory.

- Overseer will not name specific cultivars: the benefits are assumed to be applicable to all cultivar types with the specific properties of lower DM%, higher WSC/CP ratio and less soluble and degradable N, i.e. properties that affect the parts of the model that we suggest should be changed to accommodate Plantain: namely, affecting urine patch N dilution and urine N partitioning.

- **The report has identified gaps that need addressing:**

    - There is some indication of higher pasture ME values on S Island than are used in Overseer. This needs to be followed up, although out of scope for this project. It might be that a further S Island pasture needs to be created, relating to well-managed, irrigated pasture.

    - More information is required on if and how plantain-based supplements are used-on-farm and how this affects their nutritive value.

- o Assess the evidence for decreased drainage at the paddock level under plantain. Decreased drainage could be one of the mechanisms for reduced N leaching.
- o Issue where pure plantain swards are used as these are less winter active than standard pastures – or plantain/pasture mixes – and this will affect soil mineral N uptake: effects are likely to be small for the background model
- o Consider whether it is justified to build in deep recovery of N by plantain, as this would reduce N leaching by capturing some of the N that had moved below the nominal rooting depth of 60 cm for standard pastures
- o Some experiments have shown a nitrification inhibition effect from grazed plantain but there is insufficient evidence to support implementing this across all situations.
- o Given that the priority is N, use the current Overseer standard pasture default values for other nutrient concentrations of plantain-rich pastures until the databases have been interrogated to update these other nutrient values.

Preliminary analysis of size of effect

A preliminary estimate of size of effect was run through the Overseer FM science model, focusing on changes to urine partitioning and urine patch N load. Based on the recommendations in this report, changing these two components resulted in N leaching reductions of 20-40% at a block level. Assuming 20% of the farm was put into plantain, this would equate to an overall farm-level reduction of c. 4-8% (Central plateau, pumice soil), less than other farm level modelling with diverse pastures.

However, these are very preliminary numbers and more detailed sensitivity testing is required, as described below.

Next steps

Once agreement has been reached in the FRNL science team, sensitivity and sensibility testing will be conducted using an Overseer Science version prepared for this work. Sensibility testing will focus on (a) do the results look about right based on other modelling results and expert opinion and (b) is the model responding appropriately to changed inputs. Sensitivity testing will focus on the main drivers that we have identified as key to modelling plantain.

Based on identification of the key decision points around Overseer changes documented in this report the following list of variables should be included in sensitivity testing.

- Relative area of plantain on the farm
- Environment: location, soil-type, climate – especially capturing differences between North and South Island environments
- Production (milk or meat) - impacts of more production and associated N removal in product at the same or lower N inputs
- N fertiliser inputs – if the same level of production can be achieved for less fertiliser input in a plantain-based system, what are the impacts
- Pasture ME – sensitivity of changes to ME, which will result in changes to estimates of N eaten and excreted
- Block relativity – the size of the effects of assuming more production from plantain blocks
- Seasonal growth patterns
- N proportion in urine
- Urine patch N load, due to the dilution effect
- Drainage volume

2. Background

This report provides recommendations for implementing plantain-rich pastures in the Overseer model, and provides the supporting information for those recommendations. Plantain-rich pastures are being increasingly used by New Zealand farmers and it is important that this management practice can be captured in Overseer. Stewart (1996) summarised the features and benefits of plantain:

- The most likely use of plantain on farms is as a component of mixed pasture swards. Its contribution is likely to be greatest where grass growth is less vigorous and where there are gaps in the sward. These conditions are likely to be found in low fertility dryland pastures. Whereas this *was* the case, the use of plantain/clover swards has increased more in rain-fed pasture systems, and is also used extensively in sheep farming in the lower North Island.
- It is unlikely to be the dominant species and could be expected to contribute less than 20% of the sward, except where the grass or legume growth is poor.
- The performance of animals grazing plantain has varied from excellent in mixed pastures to poor on nitrogen-fertilised pure swards
- Antimicrobial compounds present in plantain can inhibit rumen fermentation and change the volatile fatty acid composition of the rumen. These changes have potential to affect bloat, animal performance and milk composition.

More recently, there has been evidence of the value of plantain-rich pastures in decreasing nitrogen (N) leaching. The Forages for Reduced Nitrate Leaching (FRNL) programme has undertaken extensive research on plantain in field and animal studies, lysimeters and on monitor farms. The results form the basis of the recommendations in this document, supplemented with other data and expert opinion, where necessary.

The main driver for including plantain as a pasture type in Overseer is its potential for decreasing N leaching, and most of the research in the FRNL programme has focused on this aspect. An initial assessment of the FRNL plantain data and implications for modelling plantain in Overseer was made by Shepherd et al. (2019). They concluded that:

- The Overseer model structure was relatively easily adaptable to accommodate a plantain pasture type
- Plantain was best incorporated as a new pasture type on a pasture block, with suitable guidance for users on what type of pasture and management would justify selection of such a block-type. And has a longevity of 2-3 years. However, it is also necessary to accommodate a plantain crop block where plantain is grown as a single species or with clover
- The main mechanisms for N leaching reduction should initially focus on:
  - The 'animal N balance', i.e. N eaten and the partitioning of the excess protein N between urine and dung
  - The urine patch, mainly effects on N load (kg N/ha) per urine patch, due to dilution associated with extra water intake by animals eating plantain
- Other mechanisms that potentially reduce N leaching have also been identified, but more information around mechanisms and consistency of effect are required before these can be implemented in Overseer. These include: Nitrification inhibition, N immobilisation, reduced rate of mineralisation, and increased water-use and decreased drainage

3. What constitutes a 'plantain block'?

3.1 Background

Lee & Minnée (2012): "*Generally, farmers want to grow (chicory or) plantain to increase feed quality and/or supply during the summer and autumn, to provide a break in weed (e.g. yellow bristle grass) or pest cycles before pasture renewal or to utilise excessive nutrients (N and K) in effluent areas*[3]". Increasingly, plantain may also be sown as an option to reduce nitrate leaching.

From DairyNZ farmfact 1-78b ('Plantain management'):

- Plantain is an herb with a fibrous, coarse root system.
- Plantain yields recorded in New Zealand over a full year range from 10-19 t DM/ha/year (average = 16 t DM/ha). These yields are comparable to the annual yield of ryegrass pastures.
- Plantain tends to remain productive for 2-3 years. Plant numbers will decline over this time, with the rate of decline depending largely on weed control, N fertiliser application and grazing management (particularly during wet conditions to avoid pugging). Many weeds tend to invade plantain crops over time.
- Plantain is highly responsive to N fertiliser.
- Growth rates of Tonic[4] plantain between spring and autumn range between 25 and 80 kg DM/ha/day, potentially peaking at 140 kg DM/ha/day in summer. Growth rates during winter are lower (15-35 kg DM/ha/day).
- Typical composition is: 9-20% DM; 11-12 MJ ME/kg DM: 16-28% crude protein (2.6-4.5% N)

From Agricom (2019):

- High energy (average 11-12 MJ ME/kg DM) is a feature. This quality does not deteriorate to the extent ryegrass does over summer, so in late-summer and autumn, quality differences between the two species can be large.
- The high protein and digestibility of Tonic in summer and autumn is ideal to balance with high fibre and low protein forages (e.g. maize silage, ryegrass pastures and kikuyu).
- Tonic is suited to many soil types, with growth and persistence being maximised on soils with high fertility that do not frequently become waterlogged (e.g. poorly developed ex-swamp land).

3.2 Plantain in farm systems

Plantain can be mixed with grass and clover or sown as a pure sward, or mixed with clovers and other herb species. Choice of option depends on intended purpose.

- **Mixed with grass/clover pasture** – this is the most common (Stewart 1996). Plantain improves the summer quality and autumn recovery of perennial ryegrass pastures, especially in summer-dry environments. Swards can be established by conventional drilling or by seeding into existing ryegrass/white clover pastures, although establishment is slower and plant populations may not reach the density required to affect urinary N concentration (Anon. 2019). Optimal sowing rates are 2-4 kg/ha, any lower has a minimal benefit for herbage production. When plantain is in a pasture mix, the paddock should be

[3] This aspect probably is more relevant to chicory
[4] This is generally the main cultivar tested, hence it is referred to by name in much of the literature. Tonic was also the main cultivar used in the FRNL programme

managed as a normal grass and clover pasture (DairyNZ 2019). This means grazing at 2.5-3-leaf stage of the ryegrass component and to residuals of 1500-1600kg DM/ha.

- **Pure sward** – the main advantage is ease of management in that the farmer is tailoring management specific to plantain rather than balancing the needs with other species in the mix. The main disadvantages of a pure sward are poor winter growth compared with perennial ryegrass and the relative sensitivity to pugging and winter damage.
- **Special purpose crop** – mixed with clover and/or other herbs, this is essentially a high-quality forage crop. Such crops might last for c. 2 years and then will be replaced.

When plantain is sown as a pure sward or as a special purpose crop it requires different management (DairyNZ 2019). This involves grazing the crop for only a few hours per day so that the cattle only get c. 20-30% of their daily intake from plantain. Furthermore, grazing strategy has to be such that formation of stem mass is avoided, to maintain quality - grazing to 8 cm-plus residual heights with four-week intervals. For dairy cows, the main disadvantage of this forage type is the risk of bloat.

3.2.1 Other aspects to consider

The main features of plantain in farm systems, based on industry literature and advice are:

- A high-quality feed - high ME, and mineral content, highly palatable
- A better summer feed supply – maintaining quality and growth in drier conditions than standard pastures can withstand
- Improved rumen function

Productivity aspects have been an important driver of the use of plantain swards in the past, and there is evidence that pure plantain or plantain/other herb/clover mixes can improve productivity.

For example, Cranston et al. (2015) report that *“many farmers are sowing mixed swards containing chicory (Cichorium intybus), plantain (Plantago lanceolata), red clover (Trifolium pratense) and white clover (T. repens) (hereafter termed herb and clover mix)”*. These authors reported:

- Similar annual DM production as for ryegrass/white clover
- But different seasonal pattern, with greater production from the herb and clover mix in summer and autumn
- Best to avoid winter grazing to maintain the diverse mix of species.
- Other species can also be included in a diverse pasture mix, for example Lucerne. The composition will affect seasonal pasture quality and growth rates in comparison to ryegrass/white clover; and also, potentially, how it is managed on the farm.

In terms of productivity increases, these have been clearly demonstrated in sheep systems, particularly for plantain/other herb/clover mixed pastures. For example, Hutton et al. (2011) demonstrated that a herb sward mix can improve multiple ewe and lamb performance compared to a ryegrass dominant sward. Golding et al. (2011) compared four sward types: newly sown herb/clover; newly sown plantain/pasture (ryegrass/white clover); newly sown pasture; and old pasture. In the first year, the herb/clover treatment lambs were heavier (47 kg) than the new pasture (42 kg) and plantain/pasture treatment lambs (42 kg), which were heavier than the old pasture treatment lambs (40 kg) ($P < 0.05$). In the second year, the herb/clover treatment lambs were heavier (36 kg) than the new pasture treatment lambs (33 kg), which were heavier than the plantain/pasture treatment lambs (29 kg) ($P < 0.05$). It was concluded that a herb/clover mixed sward can increase post-weaning lamb liveweight gains during unrestricted feeding conditions compared with traditional perennial ryegrass-based pastures. However, the relativity of effect was also interesting: herb/clover > newly sown pasture with or without plantain > old pasture.

In terms of dairy systems, for example Box et al. (2017) measured similar milk production from cows grazed for 10 days in autumn and spring on perennial ryegrass-white clover pasture, or pure plantain or 50% perennial ryegrass-white clover or 50% pure plantain by ground area. In contrast, Bryant et al. (2018) measured a c. 10% increase in daily per cow milk solid production when comparing a forb mix vs ryegrass with or without Italian ryegrass ($P<0.05$), grazed in summer. Totty et al. 2013 measured increased milk production from cows grazed on diverse pasture compared with ryegrass/clover, but there was no difference in milk solids production. Navarrete et al. (2018) reported that milk production was similar from cows grazing (i) plantain, (ii) plantain-clover mix, or (iii) ryegrass/white clover for 10 days in autumn.

However, these dairy grazing studies have tended to focus on urinary N effects and, although milk production has been measured, experiment duration has tended to be days rather than weeks or months. It could be argued therefore that the system level effects of potentially increased summer milk due to better quality feed access might not be captured in these experiments. Especially as the experiments were aiming for similar N intakes between treatments.

In summary, taking sheep and dairy results combined, it looks like:

- Production benefits are larger when comparing plantain/other herb/clover swards with ryegrass/clover.
- Production effects are small to nil when comparing plantain/pasture with standard pasture
- Like with like comparisons need to be made, i.e. new swards with new swards, not new with old, due to the inherent benefit to production achieved by pasture renewal on its own.

Overseer needs to be able to capture these farm system effects, notably any implications on animal productivity in the farm system. However, Overseer input requirements should ensure changes in production are captured as user-entered values. These are then used to back-calculate pasture production, which in turn impacts on calculation of N eaten and N excreted (and ultimately N leached).

3.3 Challenges in deciding how we model plantain

3.3.1 Plantain/pasture vs plantain vs plantain/herb/clover

As described earlier, a common use is where plantain has been incorporated into a standard pasture mix. This mixture can be treated as a new pasture type in a pasture block, pending the implications of persistency, discussed below.

However, plantain can also be used as a specialist crop, either on its own or in a mix with clover and, sometimes, other herbs. How this short-term (2-3 years?) forage crop is modelled in Overseer needs to be clarified. Options include:

- As a 2-year forage crop on a crop block – currently there is no facility to do this (currently 1 year only)
- As a forage crop rotating through a pasture block – more feasible?

Either way, as discussed in the next section, we will have to consider how to deal with any N mineralisation flush resulting from a short-term crop if the soil is cultivated.

3.3.2 Persistence

From Agricom (2019): **“***On average Tonic will reliably survive as a productive stand for 2-3 summers. Exactly how long it lasts is often related to weed grass control, good grazing management of wet soils and allowing it to re-seed in the second and third years through the summer grazings*”.

This is further supported by Stewart (1996) who noted that it is unlikely to be the dominant species in a mixed sward and could be expected to contribute less than 20% of the sward, except where the grass or legume growth is poor. Experience in experiments and monitor farms within the FRNL programme confirm these challenges of both establishing and maintaining a plantain-rich pasture.

How sward persistence is dealt with in Overseer potentially has large consequences for N leaching estimates, particularly in terms of N mineralisation risk during pasture renewal. If pastures are cultivated to establish either a plantain/ryegrass/clover pasture or a speciality plantain forage, then the N mineralisation and subsequent N leaching risk must be captured. If swards are cultivated regularly to accommodate the short-term nature of the crop, this is likely to decrease (or negate) any benefits achieved from reduced leaching during grazing.

3.3.3 Defining plantain threshold levels

The next question is “how much plantain is ‘enough’?”. Focusing on plantain and implications for N leaching, a synthesis of information from the FRNL research programme suggests that a critical threshold for a statistically significant effect on within-animal N cycling and resultant urinary N production is c. >30% of intake. This was supported by the met stall study of Minnée et al., which showed a significant effect at 30% but not at 15% (Table 1). Table 1 also shows that increasing plantain levels beyond 30% has more effect. So, we have a lower boundary of 30% for defining an effective plantain-rich pasture. An upper boundary of plantain proportion in a sward is generally around 60% when sown as a plantain/clover sward.

Table 1. *Summary of the effects of different levels of plantain fed with ryegrass on average urinary N concentration and daily urinary N production (data adapted from Minnée et al., in prep.)*

	Feed composition			
	RG	**15%PL**	**30%PL**	**45%PL**
N concentration in urine (g/L)	7.5[a]	7.3[a]	6.0[b]	0.44[c]
Daily urine N (g N/cow/day)	263[a]	271[a]	224[ab]	197[b]

Bryant et al. (2017) suggest a threshold of c. 25%, broadly in line with the 30% observation for significant effects. Of course, this does not necessarily mean that there are no effects at <30% plantain, but just that they could be more difficult to measure, given the statistical power of the experiments.

After consultation with stakeholders, the preference was for a sliding scale of plantain levels with an associated pro-rata of effectiveness on N leaching. The thinking was that the initially suggested starting threshold of 30% plantain would not encourage adoption of the practice. This also supports the suggestion that there isn’t necessarily a nil effect at <30% plantain, but the power of the experiments has been insufficient to demonstrate statistical significance at lower plantain levels. We present later evidence of a linear effect on UP N loading rate and assume that this linearity also holds for effects on other properties.

3.3.4 Cultivars

Stewart (1996) reported that 20 years ago, two main productive upright cultivars were available in New Zealand: Grasslands Lancelot and the more erect winter active Ceres Tonic. Since then, plant breeding has continued. Recently, Ecotain^{TM} has become available, being a trademark for plantain cultivars that have properties similar to Ceres Tonic. Different cultivars can have different compositions, which might then affect their performance in a farm system, including effects on N leaching risk.

Tonic was the predominant cultivar used in the FRNL programme. However, rather than identify specific cultivars for use in Overseer, it is more meaningful to identify the specific properties that drive changes in N leaching compared with ryegrass/white clover. As described later in this report these include plantain having, compared with ryegrass:

- lower DM%,
- higher Water-Soluble Carbohydrate/Crude Protein (WSC/CP) ratio
- less soluble and degradable N fractions.

3.3.5 Other species

Some farms include other species in the mix to produce a more diverse pasture. For example, Cranston et al. (2015) report that *"many farmers are sowing mixed swards containing chicory (Cichorium intybus), plantain (Plantago lanceolata), red clover (Trifolium pratense) and white clover (T. repens) (hereafter termed herb and clover mix)"*.

Incorporation of these other species in a pasture mix is considered out of scope for this project. While there was early evidence of beneficial effects of diverse mixtures on reduced urinary N excretion (Edwards, Totty), there is little evidence that any other species/cultivar alone has the same effect as plantain. Until such evidence is presented in the research literature, it is assumed that the beneficial effects of diverse mixtures are attributable to their plantain content (Box et al. 2017; Dodd et al. 2019).

Plantain block(s) - Recommendations

- Plantain should be implemented as:
  - A pasture block type for grass and/or clover-based mixes, which means that it is a long-term pasture where plantain supplements ryegrass/white clover. Plantain levels are maintained by oversowing and/or good grazing management. The block is not cultivated to reseed it. As with other pasture blocks it can be fully grazed, fully cut and carry or a mix of grazing and cut and carry. It can also be an effluent block
  - A specialist forage crop, in place for two years. We need determine how this is best modelled, e.g. as a forage crop rotating through the pasture platform or as a forage crop in a crop block. Whatever the final choice, cultivation of such a crop will result in N mineralisation, which may offset some or all of the benefits of the crop.
- Plantain should be grazable by all enterprise types.
- Any effects of plantain on N leaching (e.g. urine patch N load) should be scaled depending on the proportion of plantain in the sward. It is assumed this scaling is linear.

- If a pasture mix also includes other species (e.g. plantain) the model for now should treat these other species similar to ryegrass/white clover, i.e. inclusion of other pasture species is out of scope.
- Written guidance should be provided to end-users to describe what comprises a plantain pasture block type and its typical management and thresholds for plantain content.
- Plantain should also be available as a supplement type, or a number of supplement types so that the farm system can be modelled. We discuss later the effects of supplement on plantain properties.

4. The ‘Overseer engine’ and implications for plantain modelling

4.1 The Overseer engine – a pastoral farm example

Watkins & Selbie (2015) provide a succinct summary of how the Overseer model engine estimates nutrient movement around a modelled farm, using a series of sub-models (Figure 1).

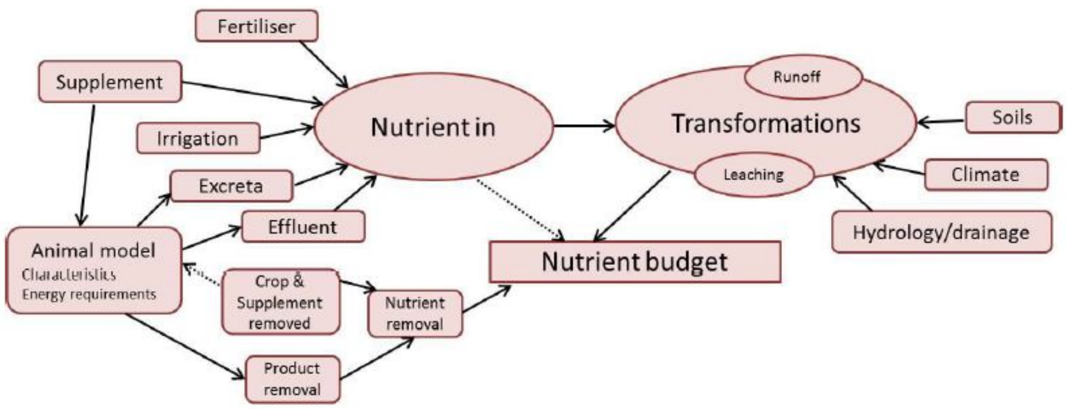


***Figure 1**. A summary of the sub-models making up the Overseer model engine for a pastoral farm (from Watkins & Selbie 2015).*

In summary (adapted from ‘Watkins & Selbie 2015):

- ‘component sub-models’ include Climate, Hydrology, Animal energy requirements, Animal intake and excreta, Urine patch model, Effluent additions and Crop growth.
- Component sub-models are combined to build ‘block sub-models’, e.g. Pastoral, Crop and Cut and Carry sub-models.
- Outputs from the block sub-models are then combined with ‘farm-based sub-models’, e.g. pad management, effluent system to produce the overall ‘farm sub-model’ for the particular farm being modelled in OVERSEER.
- Much of the OVERSEER modelling is about tracking nutrient flows, which means understanding the spatial (and often temporal) movement of nutrients.
    - The block nutrient budget captures the transfer of N in and out of the block.
    - The farm nutrient budget captures the transfer of N in and out of the farm.
        - This may include transfers in and out of block (e.g. fertiliser in, supplements exported), farm structure losses, and area weighted average losses such as N leaching or volatilisation.
        - Internal transfers such as effluent movement, or supplements grown and fed on the farm are shown in the individual block nutrient budgets but are not included in the farm nutrient budget as the nutrients do not cross the farm boundary.

4.2 Implications for modelling plantain

As described by Watkins & Selbie (2015):

"Grazing animals consume pasture containing N. The amount of pasture dry matter (DM) consumed depends on animal production (via the animal energy requirement sub-model), and the N content of the consumed pasture (pasture growth and pasture nutrient sub-models). Grazing animals also consume supplements containing N (supplement sub-model). Of the total N consumed, some is used to produce products (e.g. live weight, milk, wool, velvet) the rest is excreted as urine and dung (excreta sub-model). The excreted N can be deposited onto blocks, laneways or in the milking parlour and thus entering the effluent system and applied to the effluent block. The excreta N which is returned to the pastoral blocks can be taken up by the pasture again and/or a proportion can be lost to the air (e.g., via volatilisation and denitrification) or into drainage water (e.g., via leaching when the soil is draining)."

Therefore, to reiterate: the ultimate goal is a nutrient budget at the farm and the block level. To achieve that, we need to capture the effects of plantain on all of these nutrient flows. Nitrogen leaching is just one aspect of the budget and, while this is a priority, other aspects include: GHG emission effects; and a nutrient budget that reflects nutrient transfers and transfers of soil fertility, which in turn underpins fertiliser management plans. It is therefore essential that the information associated with implementing plantain in Overseer also is adequate for addressing the other aims of Overseer, i.e. beyond N leaching estimates.

Data, information and decisions that need to address the appropriate components within Overseer are summarised in Table 2.

Table 2. *Areas of the model needed to be addressed to implement plantain in Overseer.*

Question	Why important
What constitutes a 'plantain block'?	Important to clarify for the farmers and Overseer users when it is legitimate to consider a pasture as 'plantain rich' And to understand how plantain is used in a farm system so that it can be modelled in Overseer
Plantain pasture characteristics • Pasture ME content • Pasture digestibility • Pasture nitrogen concentrations • ME and N concentration interactions • Other pasture nutrient concentrations • Pasture utilisation by animals • Botanical composition	This information underpins how much dry matter and nutrient is eaten. This in turn supports subsequent calculations and modelling of transfers of nutrients in and around the farm
Accounting for production in Overseer	Annual production and seasonality of production is important: Contributes to calculation of DM eaten Amount of N removed in products affects what is left and returned as excreta Temporal effects on nutrients eaten and their transfer including deposition to pastures

Question	Why important
Animal nitrogen partitioning • Effects on nitrogen offtake and/or milk protein? • Partitioning between dung and urine • Urine distribution to blocks	Drives estimated production of excreta, partitioning into dung and urine and spatial/temporal distribution around the farm. All affect estimates of N leaching.
Adapting the Overseer urine patch model	The key calculation method of nitrate leaching risk from monthly deposition of urine. What factors does the UP model need to capture to be able to deal with plantain? And is there enough supporting evidence to make changes to the model?

4.3 What should success look like?

The Overseer plantain model is being built up from component pieces of information supported by component research studies. There are no results of studies yet that replicate an Overseer block (though, at the time of this report, two studies are in place – Ashley Dene and Massey). Therefore, we are relying on other model results and expert opinion to judge if the Overseer plantain model is satisfactory.

A part of the development process will be based on sensibility and sensitivity testing for N leaching:

- Sensibility testing – Do the results look about right in relation to current knowledge and results of farm system modelling with mechanistic models, and does the model respond sensibly to changes in user inputs?
- Sensitivity testing - What are the key model factors driving results from the Overseer plantain parameters in the model, what is the size of the change when inputs are changed, what are the interactions, does all of this make sense?

These form a key part of the acceptance criteria. But additionally – and as importantly:

- Is Overseer able to represent the way that farmers are using plantain in the farm system?
- Does Overseer capture reported productivity benefits, e.g. summer high quality feed for dairy systems, spring feed supply for ewes

> McCarl (1984): "*there is not and never will be a totally objective and accepted approach to model validation*"

5. Plantain pasture characteristics

From Watkins & Selbie (2015):

"*The Metabolic sub-model first provides an estimate of the animal's total metabolic energy (ME) requirement for maintenance, growth and production. The Animal intake sub-model estimates how much of this total ME requirement (mega-joules of metabolisable energy, MJME) is met by supplement and crop intake, and by difference, pasture. User-entered information entered into OVERSEER supplies data on the amounts and timing of feeding of supplement and crops. Next, pasture quality is used to estimate pasture DM intake. The pasture DM intake is combined with the nutrient contents of the feed, to provide an estimate of total animal DM intake and nutrient intake (Animal intake sub-model). Feed characteristics are derived from two databases: pasture characteristics and supplement characteristics.*"

According to Wheeler (2018) characteristics of pasture are described by the following inputs:

- Pasture type
- Pasture metabolic energy (ME) content[5]
- Pasture digestibility
- Pasture nutrient concentrations (for nutrient budgeting purposes)
- Utilisation by animals (default is 85%)
- Clover level (default is 'medium')

The input 'Pasture type' is used to set default pasture ME content, digestibility, and nutrient concentrations.

In the following sections, the default values used by Overseer for ryegrass/white clover pastures documented by Wheeler (2018) are described. The need for using values other than these for the new plantain-rich pasture types in Overseer is then discussed.

Much of the assessment is based on a database of key forage quality variables developed in the FRNL programme, comprising 34 studies (16 raw datasets and 18 from literature). Using this database, a meta-analysis was performed to compare the nutritional composition of plantain and perennial ryegrass pastures, and define key differences between the species (Minnée at al. 2019).

5.1 Selective grazing

Stewart's (1996) review indicated that, in mixed pastures, plantain is highly palatable to cattle, sheep, deer and horses, and is at times selectively grazed ahead of most legumes and grasses, though recent feedback from farmers indicate that at times plantain is avoided and grazed last or not at all. As well as the risk of overgrazing (Derrick et al. 1993) and resultant implications for persistence, this provides challenges for estimating nutritive value of mixed swards which are generally sampled by cutting and collecting the whole sward mix.

This was discussed by Wheeler (2018) in relation to Overseer and it was identified as a key issue in obtaining sufficient data on the nutritive value of what grazing animals actually eat.

[5] Based on the Technical manuals (Characteristics of pasture, Characteristics of crops, Supplements), Overseer uses both ME and digestibility. For pasture, there is the facility to use either or both, and there are equations to estimate ME from digestibility, or digestibility from ME. For pasture, the defaults are based on ME as that was the available published data, and digestibility is back-calculated. Supplements and crops database have both ME content and digestibility as inputs. ME content of pasture, crops and supplements, affects intake through the metabolisable energy model. Digestibility affects one term (NEactivity) in the metabolisable energy model and the amount of dung DM, and hence methane emissions.

Consequently, Wheeler (2018) noted: *"for the most part, animal behaviour has not been accounted for as pasture samples have been used instead of a truly representative sample of what was ingested"*.

The same will be true of plantain pasture characteristics values developed for Overseer.

5.2 Pasture ME content

5.2.1 Analysis

The ME value of pasture is a critical value for Overseer as this is used to back-calculate the amount of pasture eaten, based on the modelled energy requirements of the animals on-farm. The amount of pasture (and supplements eaten) drives the amount of nutrients eaten and ultimately recycled around the farm.

A monthly pasture ME value is used in Overseer, defined by region and month. For ryegrass/white clover, three regions are used: upper North Island; lower North Island; and South Island (Wheeler 2018). Also, to note: *"When calculating the default pasture ME content, other inputs that may affect pasture ME content have not been included, such as, clover content, irrigation (less dead matter) and grazing method"*.

Monthly values for ryegrass/white clover were based on the results of Litherland & Lambert (2007), using pasture samples submitted to commercial laboratories, and are summarised in Table 3. This suggests a trend for lower ME values from South Island pastures. There is also a seasonality to ME content, higher in late winter-spring on the North Island and in the autumn and spring shoulders on the South Island. Across all regions and months, values ranged between 10.3-11.7 MJ ME/kg DM.

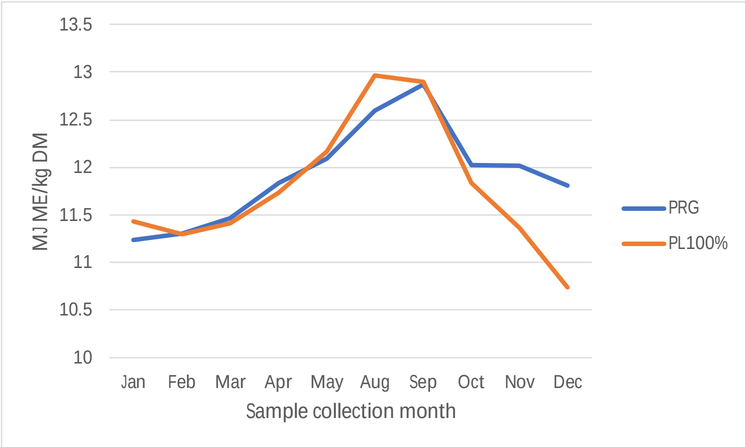
Table 3. *Summary of Overseer default monthly and regional ryegrass/white clover pasture ME values (from Wheeler 2018). Units: MJ ME/kg DM.*

	Mean	**Median**	**Min-max**	**ME ≥ 11 MJ ME/kg DM**
Northern North Island	11.0	10.9	10.4-11. 7	Jul-Nov
Southern North Island	11.0	11.0	10.3-11. 6	Aug-Dec
South Island	10.8	10.8	10.5-11.2	Apr-May, Sep-Oct
Mean	10.9	10.9	10.4-11.3	Aug-Dec

Direct comparisons of ME between ryegrass/white clover vs ryegrass/white clover/plantain pastures are few. The FRNL-established database of nutrient compositions for plantain-rich pastures included ME data. This was not reported in the paper of Minnée et al. (2019) However, a summary of the data was provided separately, and monthly ME values from this dataset are summarised in Figure 2. The North Island pasture types were ryegrass, ryegrass/white clover, pasture with up to 60% plantain (generally coded as PL50) or >60% plantain (coded as PL100). On the South Island, two pastures were compared: ryegrass and PL100. Pastures were grown at 4 annual N fertiliser rates grouped as: nil, low, medium and high.

Not surprisingly, there was a highly significant (P<0.001) interaction of island x month x species x N rate on measured ME values. ME values responded differently between the two Islands. At North Island sites, measured ryegrass/white clover ME values were in line with Overseer default values, with a strong seasonality. Values were generally unaffected by N fertiliser rate (data not shown). Plantain pastures had consistently lower ME values than the ryegrass/white clover pastures.

South Island:



North Island:

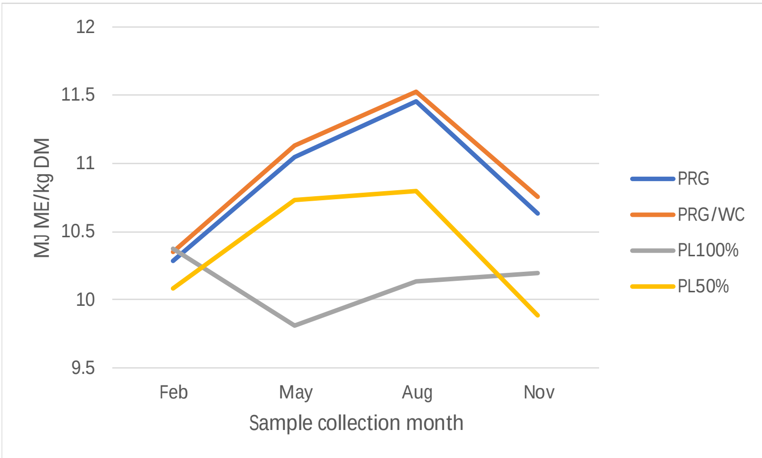


Figure 2. *Summary of measured ME values from North and South Islands, as affected by collection month (mean of nil, low and medium annual fertiliser regimes).*

These results contrasted markedly with samples from the South Island, where ryegrass again showed a strong seasonality in ME (as did plantain). However, overall, ME values were higher than on the North Island, and the differences between plantain and ryegrass were less marked. Plantain ME values were lower than ryegrass during spring. Table 4 summarises mean ME values across all months, which confirms the differences between Islands in absolute values and also relativity between species.

Table 4. *Average measured ME values (MJ ME/kg DM) from the FRNL-compiled database.*

Island	Perennial ryegrass	Perennial ryegrass/clover	Plantain/pasture mix	Plantain/clover
North	10.9	10.9	10.4	10.1
South	11.9			11.8

Box et al. (2017) undertook mid-late March (late lactation) and early to mid-October (early lactation) grazing studies in Lincoln, and summarised ME values from pasture samples taken during the study, concluding there was little difference (Table 5). Totty et al. (2013) reported a March grazing study at the same location and found no difference in pasture ME (12.3 MJ ME/kg DM). All of these reported values are in line with South Island data in Figure 2.

***Table 5**. Box et al. (2017). Reported pasture metabolizable energy from pastures sampled in March and October in Lincoln (MJ ME/kg DM).*

				50-50 Plantain/Pasture	
Month	**RG/WC**	**Plantain**		**RG/WC**	**Plantain**
March	11.2 ± 0.1	11.4 ± 0.2		10.9 ± 0.1	11.3 ± 0.1
October	11.7 ± 0.1	11.8 ± 0.1		11.7 ± 0.1	12.1 ± 0.2

Cranston et al. (2015) summarised literature comparing ryegrass/white clover pastures with herb and clover pastures. Although the latter included plantain and clovers, it also included chicory and there was no sown ryegrass. The comparison, therefore is not compatible with our comparison of rye/grass white clover vs ryegrass/white clover/plantain. Nevertheless, for the record, the conclusion was that "*the herb and clover mix generally has a lower fibre content, similar crude protein content and higher organic matter digestibility percentage and metabolisable energy content than rye/wc*". The reported values are in broad agreement with Table 3. The lowest reported values were associated with summer dry. Across the year ME values for ryegrass/white clover were in the range 8.9-10.6 MJ ME/kg DM. The herb mix ME range was 9.8-11.6 MJ ME/kg DM.

5.2.2 Discussion

The challenge is turning these disparate data into recommendations for default ME values for the new plantain block types. The initial intention was to describe the ME of plantain pastures relative to the Overseer defaults for standard pastures. This relies on data on the ME values for standard pastures collected in the FRNL programme first aligning with Overseer defaults.

For North Island sites, there is general agreement between FRNL collated data on ME of standard pastures and Overseer defaults (i.e. comparing Figure 2 and Table 4 with Table 3). Surprisingly, though, FRNL collated data on ME values for plantain/grass and plantain/clover indicates slightly lower average ME than for standard pasture (Table 4) and lower than the Agricom and DairyNZ cited values of plantain of 11-12 MJ/kg DM.

For the North Island we conclude that there is no evidence that the ME content of plantain-rich pastures is different to standard pastures and therefore we should use the current Overseer pasture ME defaults for plantain-rich pastures.

The data from the South Island also support, on average, no difference between pasture and plantain ME values: if anything, there is a bigger drop-off in ME in plantain in late spring – early summer than in ryegrass (Figure 2). The issue is, however, that the FRNL-collated values for pasture ME on the South Island are higher than Overseer defaults: mean 11.9 MJ ME/kg DM (Table 4) vs 10.8 MJ ME/kg DM (Table 3). This might be because the Overseer default values are drawn from a wider range of sites and/or that the FRNL population is drawn from more modern varieties, although this is only speculation at this stage. It's difficult to reconcile this difference without enquiring more closely into the relative conditions under which both data sets were derived.

Addressing the high ME values reported by FRNL and their misalignment with Overseer defaults should be a priority, although is out of scope of this project. Wheeler (2018) indicated that the current Overseer values do not take into account management options that could influence ME. However, without further evidence, we conclude there is inadequate evidence to change ME values of plantain, but also recognise the need to review ME values on the South Island generally.

Pasture ME - Recommendations:

- We assume that the energy sub-model is satisfactory and does not need to be modified to accommodate practices associated with plantain management, i.e. everything up to and including calculation of ME requirement is satisfactory.
- There is variability in both Overseer and FRNL data sets and, at this stage the recommendation is not to change plantain ME levels compared with standard ryegrass/white clover pastures.
- Red flag – high ME values on S Island need to be followed up, although out of scope for this project. It might be that a further S Island pasture type needs to be created, relating to high production, irrigated pasture.

5.3 Pasture digestibility

Digestibility (%) is defined as the proportion of the feed (in DM terms) that can be digested by ruminants. A digestibility value is used in Overseer to calculate the DM content of the dung fraction, and is used in GHG emission calculations.

From Wheeler (2018): "*Pasture digestibility is related to pasture ME content using the conversion from Feeding Standards for Australian Livestock (1994). Thus, digestibility (%) is estimated as:*

$$\text{Digestibility} = ME / 18.45 / 0.8 * 100$$

Where 18.45 is the energy content of digestible organic matter (MJ/kg DM), 0.8 is the ratio of metabolisable energy to digestible energy.

This equation is applied to all pasture types, including lucerne. Digestibility is constrained between the limits of 40% and 100% inclusive".

In their meta-analysis, Minnée et al. (2019) concluded that in comparing plantain and perennial ryegrass monocultures and mixed pastures "herbage digestibility did not differ significantly".

Pasture digestibility - Recommendations

- Use the same digestibility calculation as for all other pasture types.

5.4 Pasture nitrogen concentrations

5.4.1 Analysis

From Wheeler (2018): "*Within Overseer, pasture nutrient concentrations are used in the estimation of animal nutrient intakes and the amount of nutrient removed from the pasture when supplements are made… Pasture nutrient concentrations for N are required on a monthly basis, and on an annual basis for other nutrients*".

Pasture N concentrations are important as these affect estimates of N eaten, N deposited in excreta and its partitioning of excretal N between dung and urine and, all of which affect Overseer N leaching estimates.

Wheeler (2018) provides a detailed summary of the extensive and disparate datasets on ryegrass/white clover pasture protein concentrations used to generate Overseer default values, and explains how monthly values are estimated. The default values used in Overseer are based on data from Litherland & Lambert (2007), which has the advantage of aligning with Overseer ME values described above.

In summary, from Wheeler (2018):

"Base N concentrations for other animal types were made relative to 3.8% for dairy farms on flat land based on the [available data]. Thus, base N concentrations of 3.8, 3.7, 3.6 and 3.3 for dairy, dairy replacement, beef and other stock class-based pastures were used. Pasture N concentrations were then modelled by adding regional adjustments based on data from Litherland & Lambert (2007), and then adjusted to a monthly value based on the average curve of Litherland & Lambert (2007)".

Pasture N concentrations are increased to take account of inorganic N applied (N from fertiliser, irrigation, as well as inorganic N in effluents) using a split model that included total annual and application rate for a given month. It was assumed that the pasture was eaten 4-8 weeks after the N was applied [i.e. when maximal growth response was achieved].

On pastoral blocks only, the model also adjusts the pasture N concentration based on the clover content".

Thus, Overseer adjusts monthly ryegrass/white clover pasture protein contents by:

- Region (three, as for ME: upper and lower North Islands, and South Island)
- Enterprise (fertility level)
- N inputs as fertiliser, manure and irrigation water
- Clover content (high/med/low)?

It does not differentiate between irrigated and non-irrigated pasture.

Data from plantain-rich pastures are fewer but the analysis of the FRNL forage dataset (Minnée et al. 2019), provides useful insights. It was concluded after analysis of the data that "*generally, the herbage total N concentration of monocultures of plantain or grass was similar (mean 3.5%)*".

However, it was noted that whereas total N concentrations were the same, there were significant differences in the proportion of soluble N (12% of CP in plantain, 38% of CP in ryegrass).

5.4.2 Discussion

Early research on diverse pastures suggested that a reduced N intake relative to standard ryegrass/white pastures would be a key driver of reduced urinary N input (Woodward et al. 2012). However, there has been no consistent reduction in N intake demonstrated in the FRNL programme from grazing of plantain-rich and other diverse pastures, compared with standard ryegrass/white clover pastures; certainly, there is no consistent difference in crude protein content between pasture types.

Data on pasture protein concentration are variable and complex as demonstrated by the summary of Wheeler (2018). This makes drawing firm conclusions about differences between pastures extremely difficult. The FRNL-compiled database is probably the most comprehensive dataset and supports the conclusion of no consistent difference between pasture types.

Overseer captures the effect of N inputs on N concentration and assumes a spelling period sufficient to express the full yield potential of the applied N, resulting in only a small increase in N concentration from the fertiliser addition. This approach was supported by a separate survey of the literature by Shepherd & Lucci (2013) which showed low to no effects on pasture N concentrations from fertiliser addition, due to dilution of the extra protein by extra DM growth.

It is worth noting the lower overall average %N value for standard and plantain-rich pastures reported by Minnée et al. (2019), a value of 3.5%; this is at the lower end of the range of baseline values used in Overseer. However, the main point is that there is no difference in relativity between the pasture species.

Minnée et al. (2019) observed a difference in the proportion of water-soluble N between the pasture types and suggested that this might influence the partitioning of N between dung and urine. This is discussed further in Section 8. This ratio is currently not required by Overseer.

Pasture N concentration - Recommendation

- There are no relative differences in pasture N concentration between standard and plantain-rich pastures: use the current Overseer defaults for both pasture types.
- Facility to change pasture %N should be available as this will allow the effects of the inclusion of other pasture species in the diverse mix to be captured.

5.5 ME and N concentration interactions

Note: this section is redundant while Overseer FM doesn't allow users to override default values for pasture %N and ME, but it is worth reiterating should that functionality be reinstated.

The issue here is that *if* ME and N concentration values could be altered from the default values by users, there is a potential discrepancy in timescale for the changes: ME values previously could be altered for each month, whereas %N could only be altered as the annual average. Thus, if there was strong evidence that the relativity between ME and N concentration varied markedly through the year, this might not be captured by Overseer if the user could override default values.

Even using Overseer default values, we assume that this variation in relativity between ME and %N is captured. However, the variation in both measured %N and measured ME in various databases means that the data are extremely noisy and so it is difficult to identify exactly what is an 'average' relativity between ME and %N.

5.6 Other pasture nutrient concentrations

Other nutrient contents are required to allow the calculation of valid nutrient budgets (i.e. we are not considering just effects on N cycling, but other nutrients too). Many reports have compared the mineral composition of plantain with commonly used grasses and clovers (Stewart 1996). These show that "*plantain contains high levels of calcium, magnesium, sodium, phosphorus, zinc, copper and cobalt, at least as high as perennial ryegrass–white clover-based pastures and usually higher*". Box et al. (2017) measured the nutrient status of standard pasture and plantain pastures during a grazing experiment and reported that the mineral concentration was similar for pasture and plantain except for sodium and calcium. Sodium concentration was two times greater in plantain than pasture in the late lactation experiment only. Calcium concentration of the herbage was about three times. Wilman & Riley (1993) noted that plantain was high in sodium.

Other pasture nutrient concentrations - Recommendation

- Given that the priority is N, use the current Overseer standard pasture default values for other nutrient concentrations of plantain-rich pastures until the databases have been interrogated to update these other nutrient values for plantain blocks.

5.7 Pasture utilisation by animals

From Wheeler (2018):

"Utilisation is the proportion of total pasture grown that is eaten by animals on an annual basis. The default pasture utilisation for a block is based on animal type default values for the animal types that are grazing the block. Default animal type utilisation was estimated at 0.85 for dairy, 0.75 for dairy replacements, and 0.7 for sheep, beef, and deer. Utilisation is expected to be higher on finishing blocks, and lower on merino blocks where extensive management systems are used. Thus, utilisation is increased by 15% on beef or deer finishing blocks, and decreased by 5% on merino sheep blocks. Utilisation is not affected by pasture type or time of year".

Agricom (2019) states that, on dairy farms, Tonic can regularly be utilised to 85% of pre-grazing mass without any impact on future regrowth and this is a higher utilisation rate than ryegrass pastures. Presumably this relates to plantain swards rather than plantain/ryegrass/clover swards. However, this is the same value as used by Overseer for standard pasture. The observation of FRNL monitor farmers was also that there was no difference in utilisation / post-grazing residuals on standard and plantain-rich pastures (Ina Pinxterhuis, Pers Comm).

It is concluded that there is insufficient data to justify changing Overseer default values for plantain-rich pastures. End-users are able to enter their own utilisation values, if required.

Pasture utilisation - Recommendation

- Use the current Overseer default values for pasture utilisation by animals.

5.8 Clover content

Clover content is used to estimate the amount of N fixation for the nutrient budget (see next Section). According to Wheeler (2018):

- Clover content is defined as the annual average clover content (as a proportion of DM) of pasture where fertiliser N inputs are not applied.
- Clover content is defined for each animal type and clover level, being higher for cattle, lower for sheep and deer.
- However, clover level cannot be changed from the default values in Overseer FM,

Clover content - Recommendation

- No difference in the default clover content values for plantain-rich or standard pasture blocks.

5.9 Symbiotic N fixation

Overseer estimates annual N fixation as part of the nutrient budget. Wheeler (2018) provides detailed equations of how N fixation is calculated. In summary, calculated N fixation is adjusted for:

- Estimated dry matter production (i.e. calculated by Overseer)
- Estimated clover content (as described in the previous section)
- N fixation rate (kg N fixed/kg DM)
- A reduction factor due to inorganic N inputs

N fixation - Recommendation

- No change to current calculation of symbiotic N fixation for plantain-rich pasture blocks.

5.10 Supplement feeding

Stewart (1996) noted that the antimicrobial compounds in plantain could interact with the fermentation process in silage. Isselstein (1993) found that silage pH values remained over 5, protein degradation was insignificant and there was little lactic or acetic acid produced. However, the silage "smelled OK and did not deteriorate in storage". Similarly, Bariroh et al. (2018) reported that "*the fermentation characteristics of plantain did not follow conventional rules for adequate fermentation yet the odour characteristics indicated that the silage was not 'spoiled'*" and that *additives and fertilisers, which improved conditions for lactic acid bacteria, did improve the preservation characteristics*". The authors concluded that the poor quality of the resultant plantain silage would not be suitable as a supplement in early lactation, but it could be fed to cows in autumn to reduce N intake (assuming it was a lower N content than pasture, perhaps not always the case) and to aid drying-off.

The above literature relates to pure plantain swards. Although no specific reference could be found to silage made from plantain-rich (as opposed to 'pure' plantain) swards, it is probable that this silage will be more like 'conventional' pasture silage. Then, if we assume that nutritive value of plantain-rich pastures is similar to standard pasture, as discussed earlier, then it is logical to use similar nutritive values for standard silage and silage made from plantain-rich pastures until more data are available.

DairyNZ (2019) recommend using pure plantain swards as a 20% supplement to diet. The advice is to restrict grazing of a plantain sward to 2-3 hours. However, if farms also decide to cut fresh plantain and feed this, as an alternative approach, this management practice would also need to be captured in Overseer. In this case, we would use the nutritive value of the fresh plantain.

The outstanding questions relating to using plantain or plantain-rich pastures as a supplement: What contribution does this have to any mechanisms that decrease N leaching? Similarly, if non-plantain supplements are fed while grazing plantain-rich pastures, how do these interact with the plantain in delivering benefits to N leaching?

Judson & Edwards (2016) tested whether 'the plantain effect' could be delivered with conserved plantain rather than fresh, by supplementing dairy heifer winter feed with baleage made from either perennial ryegrass or plantain. Diet was 2.5 kg DM/day as kale plus 3 kg DM/day as supplement. At similar N intakes, spot measurements of urine N over winter showed a significant decrease in urinary N concentration: 0.36% (plantain) vs 0.53% (ryegrass), i.e. a 32% decrease. There was no firm conclusion as to why this effect was noted but the authors indicate increased frequency of urination due to a diuretic effect from the plantain; but no data was presented on water intake, urine volumes or secondary compounds.

Regarding plantain as a conserved (ensiled) supplement there is evidence (current PhD studies on plantain silage) that the ensiling process breaks down the secondary compounds such as Aucubin and catalpol which were below detectable limits in a plantain silage study (R Bryant, Pers Comm).

In a grazing study offering plantain silage to late lactation dairy cows (Bryant, Welten et al. unpublished), lower urinary N excretion ($P<0.10$) was recorded when plantain silage was fed, but this was linked to lower N% of plantain silage and lower apparent N intake ($P<0.1$); urine volume and frequency was similar.

Given the general lack of consistent data on this topic, it is suggested that the model is adjusted to include plantain-based supplements so that the farm systems can be modelled in Overseer. This will require developing default nutritive values for plantain-based supplements. However, it is suggested plantain supplement effects on N partitioning are not included without further evidence - unless the supplement is fresh cut and carry.

Supplements - Recommendations

- More information is required on how plantain-based supplements are, or might be, used-on-farm and their nutritive value and these practices need to be able to be represented in Overseer.
- Plantain effects on N partitioning and excretion should not be included until there is evidence of a consistent effect of plantain metabolites carried through into the supplement
- The exception is where that supplement is fresh cut and carry plantain pastures or plantain

6. Accounting for production in Overseer

Three scales of production (milk/meat) need to be considered on the farm because these affect both spatial and temporal distribution of nutrients:

- Farm-level production – drives calculation of nutrients eaten, and nutrients removed in product
- Relativity of the contribution of individual blocks to the total, farm-level, production
- Temporal distribution of pasture eaten within a block

The amount of produce is entered at the total farm level. This enables Overseer to calculate the total annual amount of pasture (and supplements) that need to be eaten by the animals to support this level of production. The annual pasture DM eaten is then distributed across the year based on standard production curves for milk and meat. As the pasture eaten (and its nutrient content) drives estimates of nutrient deposition, routines are then applied to:

- Identify any relative differences in pasture production between blocks,
- Identify the temporal distribution of pasture production within a block.

Relative differences in production between blocks

For example, are some blocks more productive due to better growing conditions? The default assumption is that relativity is 1 between blocks, i.e. all blocks contribute the same kg DM/ha to the total requirement. However, if for example, plantain is a more productive pasture, then this needs to be recognised by allocating more DM production from this block relative to ryegrass/white clover pasture blocks.

The result of this adjustment is that Overseer assumes that more kg DM/ha will be eaten on this block compared with others and, depending on pasture N concentration, more excretal N could be produced relative to other blocks.

Temporal distribution within a block

This is important because nitrate leaching from urine deposition has a temporal element with different months of deposition having different risks of leaching. Thus, if the pasture growth curve across the year differs in shape compared with standard ryegrass/white clover, this different distribution has to be accounted for.

The N sub-model requires an estimate of monthly production to estimate N uptake. The distribution of pasture growth is based on a simple growth model used in the crop sub-model. Thus, the distribution of pasture production across the year relative to standard pasture is required.

6.1 Annual production and seasonality of production

Any increase in production will be captured by user inputs about production of milk or meat. Overseer will back calculate the amount of DM eaten (and produced based on utilisation). Overseer will calculate N removed in product; thus, increasing production for the same or lower N inputs will decrease the amount of N entering excreta. Partitioning of N into milk would affect the N available for excretal output – see Section 7.

Production - Recommendations

- Changes in production are captured by user input changes in the model (animal production).
- Users have to understand that increases in production resulting from plantain-rich pastures need to be reflected in the user inputs: Overseer will not automatically change these (guidance needed?)

6.2 Block relativity: difference in production potential between blocks

There is limited data on like-for-like comparisons of DM production from ryegrass/white clover plantain-rich swards. Moorhead & Piggot (2009) reported DM production in Northland, comparing standard ryegrass/white clover pastures with pastures supplemented with plantain. Six sites were monitored over three years. While at first sight, this looks like a useful dataset to make the comparison, all sites compared newly sown plantain rich pasture with generally old ryegrass pastures (On-farm Research 2012). Consequently, there was a large yield difference in year 1 (c. 6 t DM/ha), which could possibly be attributed to the 'new sward effect' but this declined to c. 1 t DM/ha in years 2 and 3.

Even where different sward types are established at the same time, it is probably inadvisable to only consider yield differentials in year 1, given the difficulty in maintaining plantain in a sward. A fairer estimate is to average 2-3 years of data.

Taking the data of Moorhead & Piggot (2009), and focusing on years 2-3 of their sward comparisons (i.e. avoiding the first-year flush) suggests a yield benefit of an additional 10-15% from plantain. On-farm Research (2012) identified a lack of comparative data but concluded that "*in general, total yields of plantain have been similar to other pastures*".

Table 6. *Estimates of annual DM production based on monthly average daily growth rates provided from the FRNL-compiled database. PRG = perennial ryegrass monoculture; PRG/WC = standard ryegrass/clover mixture; PL50 = mixed-species pasture containing plantain <60%; PL100 = plantain monoculture and plantain/clover mixture with >60% plantain.*

		N Island				**S Island**	
		PRG	**PRG/WC**	**PL50**	**PL100**	**PRG**	**PL100**
Nil N	t DM/ha	5974	8649	12010	7876	3910	5946
	relativity to RGWC			1.39	0.91		1.52
Low N	t DM/ha	7078	8463	14558	7571	5406	7024
	relativity to RGWC			1.72	0.89		1.30
Med N	t DM/ha	9953	10833	16068	10965	7577	9881
	relativity to RGWC			1.48	1.01		1.30
High N	t DM/ha	16599	15140	15656	15899	11453	12766
	relativity to RGWC			1.03	1.05		1.11
mean	t DM/ha	11210	11478	15427	11478	8145	9891
excl nil N	relativity to RGWC			**1.3**	**1.0**		**1.2**

However, data provided from the FRNL database on pasture growth rates further complicate interpretation. The daily pasture growth rates averaged by month from North and South Islands provided from FRNL were used to estimate annual production (Table 6) and the plantain production relative to the standard ryegrass/white clover (N Island) or ryegrass (S Island) because there was insufficient data for ryegrass/white clover.

Results show increasing yields with increasing N inputs as would be expected. On the North Island, there was generally no difference in annual yield between plantain and ryegrass/white clover. There appeared to be a 20% yield benefit over ryegrass on the South Island and, here, the size of effect decreased with N input possibly because the lack of clover in the ryegrass sward was compensated for by the N input.

Similarly, on the North Island, size of benefit between plantain-rich and ryegrass/white cover pastures decreased with increased N input. Nevertheless, the benefit was large at low-medium N inputs. Without further understanding of the database, it is difficult to assess if this effect is real.

DairyNZ (2019) state that "*Plantain yields recorded in New Zealand over a full year range from 10-19 t DM/ha/year (average = 16 t DM/ha). These yields are comparable to the annual yield of ryegrass pastures*".

Instead of pasture growth rates, a better indication might be data on actual animal production. Productivity gains were analysed in Section 3.2.2 of this report and it was concluded that:

- Production benefits are larger when comparing plantain/other herb/clover swards with ryegrass/clover.
- Production effects are small to nil when comparing plantain/pasture with standard pasture
- Need to compare like with like, i.e. new swards with news swards, not new with old, due to the inherent benefit to production achieved by pasture renewal on its own.

An analysis of the liveweight gains reported by Golding et al. (2011) suggests over the two years of the experiment a benefit of the plantain/herb/clover sward of c. 13%. Bryant et al. (2018) reported an increased milk yield of c. 10%. A conservative estimate of relative productivity for plantain/herb/clover or plantain/clover blocks might therefore be 10%, i.e. a relativity of 1.1 compared with 1 for ryegrass/white clover. To some extent this aligns with pasture production data from the South Island in Table 6.

Data for plantain/pasture is less clear and the recommendation is to leave this as for ryegrass/white clover

Block relativity - Recommendations

- **For plantain/clover swards set a default relativity of 1.1 at 60% plantain), with a sliding scale for lower proportions (1 at 0% plantain).**
- **For plantain/pasture blocks, set a relativity of 1**

6.3 Relativity within a block: seasonal distribution of pasture growth

AgriCom (2019): "*Daily growth rates are around 80-100 kg DM/ha/day in summer and autumn, but can be as high as 120 kg DM/ha/day over Jan/Feb*"

DairyNZ (2019): "*Growth rates of Tonic plantain between spring and autumn range between 25 and 80kg DM/ha/day, potentially peaking at 140kg DM/ha/day in summer. Growth rates during winter are lower (15-35 kg DM/ha/day*)".

Laws & Genever (2019): "*The growth pattern of plantain is similar to that of PRG, exhibiting low to medium growth in winter, with the main growth periods occurring in spring and autumn. Reports from New Zealand suggest that the growth rate for plantain mix pastures can vary between 30 and 75 kg DM/ha/day".*

Data from the FRNL-compiled database do not replicate the high growth rates reported by AgriCom (2019) or DairyNZ (2019). Data for South Island are summarised in Figure 3. This is expressed as average daily growth rate by month and also the monthly proportion of the total annual growth based on these monthly values. These data support the suggestion of improved growth (of a pure plantain pasture) in summer, compared with ryegrass.

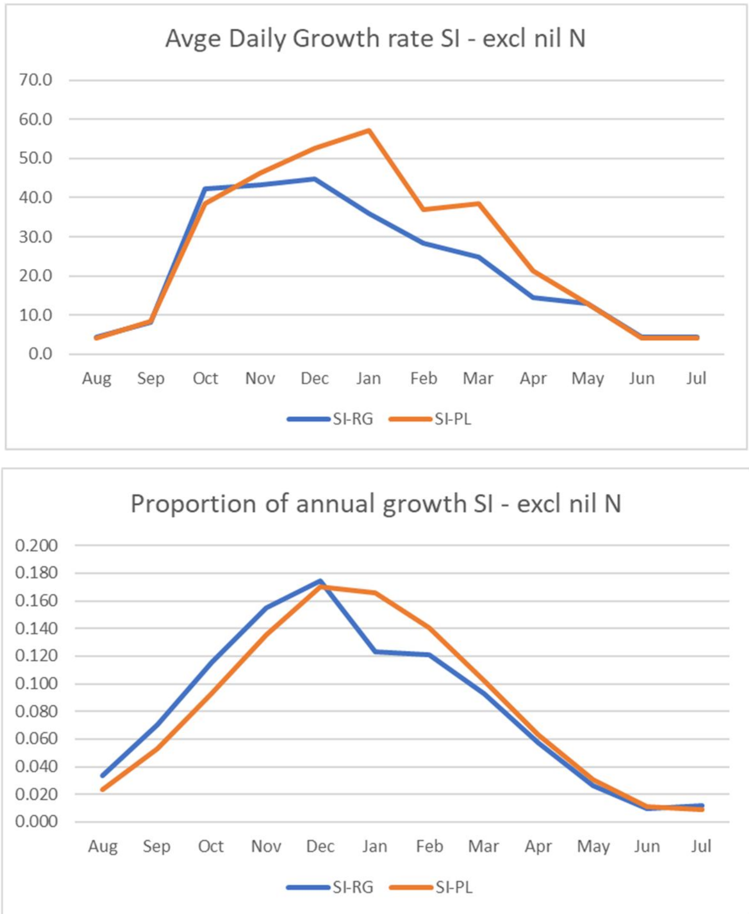


Figure 3. *From the FRNL-compiled database. Summary of South Island pasture growth rates (kg DM/ha/day) averaged by month (top) and the calculated proportion of annual DM production each month. Ryegrass (SI-RG) vs plantain (SI-PL). Each is a mean of low, medium and high N annual N fertiliser inputs.*

Data on seasonality of plantain/pasture and standard pasture DM production in Northland were reported by Moorhead & Piggot (2009). These data have been reworked to report average daily growth rates and proportion of total DM yield in each season (Figure 4). A criticism of the data is that it is not comparing like with like (i.e. new plantain pasture vs old standard pasture). However, it does provide some comparison of seasonality. These data also support a greater proportion of production in the summer months from plantain-rich pastures.

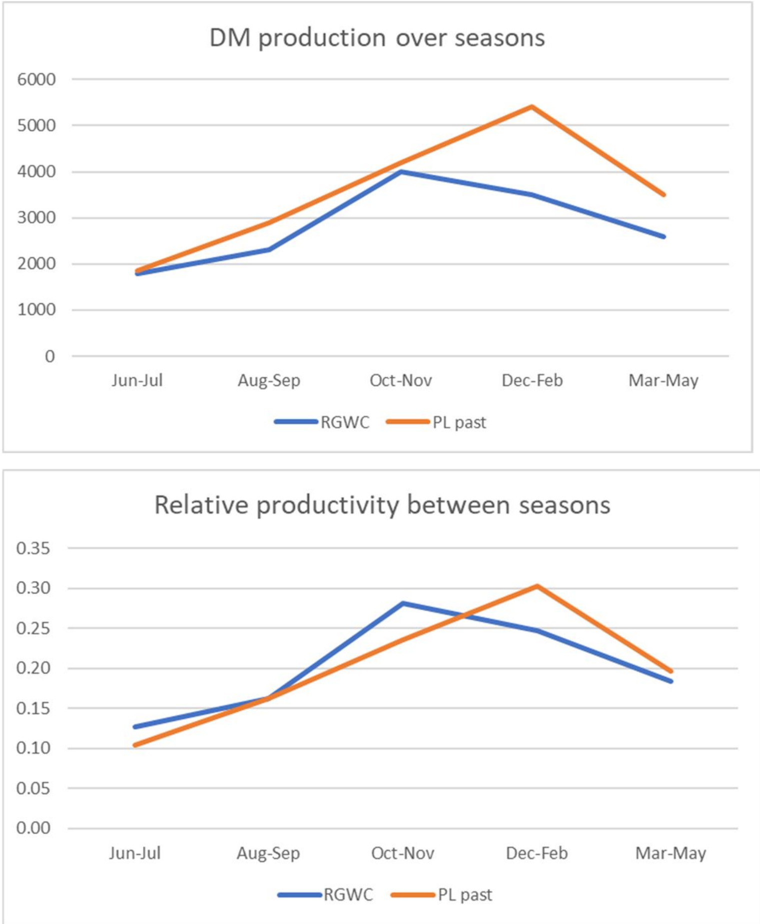


Figure 4. *Adapted from Moorhead & Piggot (2009). Summary of Northland pasture growth rates (kg DM) by season (top) and the calculated monthly proportion of annual DM production each season. Old ryegrass/clover pasture (RGWC) vs new plantain/ryegrass/clover pasture (PL past).*

However, evidence for differences in seasonal growth in the FRNL-compiled database for the North Island is less clear. Figure 5 shows equivalent data as for Figure 3, i.e. monthly average growth rates and monthly proportion of annual production. The data have more noise. Plantain/pasture appears to perform better than plantain alone. And the benefit to production appears to be in spring rather than summer/autumn, which is counter to other data and also to industry literature.

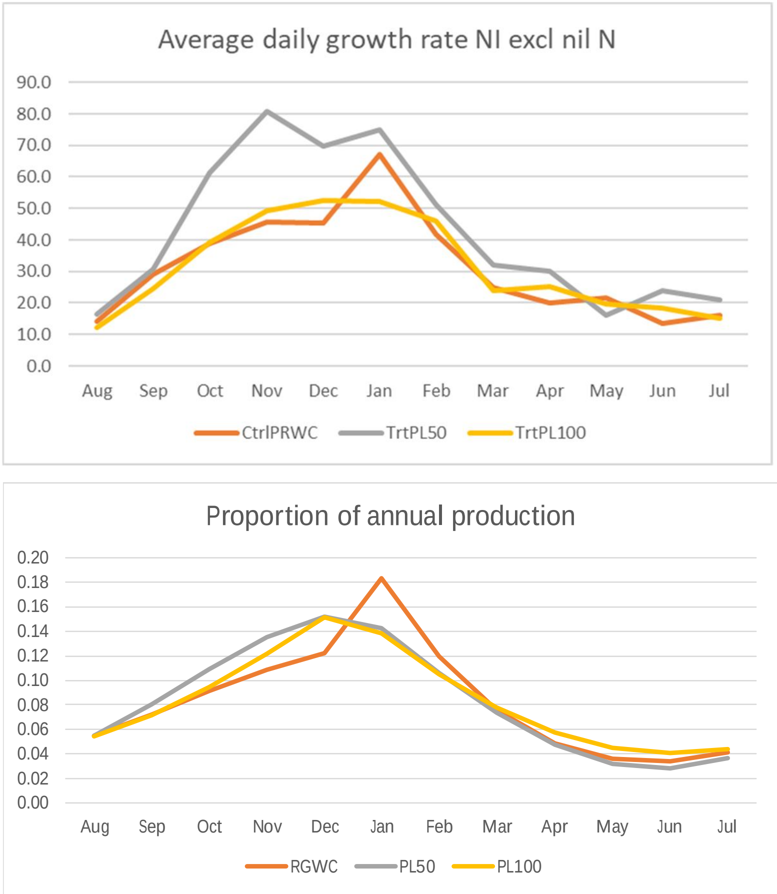


Figure 5. *From the FRNL-compiled database. Summary of North Island pasture growth rates (kg DM/ha/day) averaged by month (top) and the calculated proportion of annual DM production each month. Ryegrass/white clover (RGWC) vs plantain/pasture (<60% plantain: PL50) vs plantain/pasture (>60%plantain: PL100). Each is a mean of low, medium and high N annual N fertiliser inputs*

Seasonality of growth - Recommendations

- More work to do to understand the FRNL data and differences between N and S Island
- Would expect the growth differentials to be clear in plantain vs pasture: and less of a differential between plantain/pasture and standard pasture
- Evidence doesn't yet support this?

7. Animal nitrogen partitioning

Watkins & Selby (2015) summarise how Overseer calculates excretal N:

"The Excretion sub-model uses an animal N balance, where N excreted is N intake less N in product. Product N includes N used to produce live weight gain and milk during animal growth and lactation. Product N is estimated using a combination of user inputs, other sub-models (e.g., live weight gain) and scientific literature on the N content of animal products. Note that N removed as product from a block is the N removed in milk or live weight sold. The N in live weight sold may be gained over several years. Total N excretion is then partitioned between urine and dung based on dietary N content, with the partitioning based on scientific literature".

7.1 Partitioning between dung and urine

Partitioning of the excretal N to urine and dung is driven in OVERSEER by the relationship developed by Ledgard et al. (2003) and is a function of the dietary N concentration:

Proportion N in urine = 30 + 11.9 x %N feed

Thus, the current relationship is based on total N. An initial analysis by Shepherd et al. (2019), compared Overseer estimates with measured urine N production from grazing and metabolism stall studies (Figure 6). Results suggested there was a reasonable fit overall for plantain-rich pastures, ryegrass/white clover and fodder beet, albeit with a group of outliers that were difficult to explain. On the basis of no significant deviation? of the fitted regression from the 1:1 line, one option would be to retain the current Overseer N partitioning relationship based on the equation of Ledgard et al. (2003).

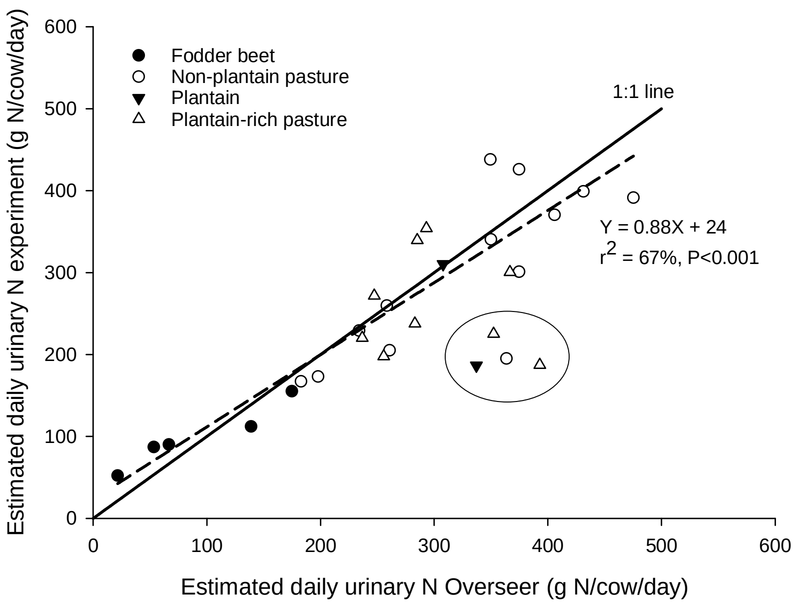


***Figure 3:** Comparison of Overseer modelled and experiment estimated daily urinary N production from plantain and fodder beet diets. ALL data. Regression excludes 4 outliers.* Note: non-significant intercept, slope of fitted line changes to 0.96 (r^2 = 68%, P<0.001) when forced through zero.

However, Minnée et al. (2019) argue that it is not just total N, but the composition of the N fraction that affects the partitioning between dung and urine. When comparing plantain and ryegrass, there was no difference in total herbage N concentration but plantain pastures contained significantly less soluble and degradable N compared with ryegrass pastures. Increased undegradable N can result in more N being partitioned to faeces (Bryant et al. 2012). Minnée et al. (2019) also found that plantain had a larger ratio of non-structural carbohydrate to N and argue that his would also increase partitioning of excretal N to dung, compared with ryegrass. Moorby (2014) found that the proportion of the dietary N excreted as urine decreased as the ratio of water-soluble carbohydrate to N increased.

All of this points to a need to recognise the importance of the type of N and C in the diet, for allocation of urine partitioning. Table 7 shows that as the proportion of plantain increased in the diet, for the same N intake there was a smaller proportion of excretal N as urine.

Table 7. *Nitrogen intake and N partitioning from dairy cattle offered diets of perennial ryegrass only (RG) or RG with 15, 30 or 45% of total feed offered as plantain (PL). Source:* Minnée et al. (in prep)

Parameter	RG	15PL	30PL	45PL	SED[1]	*P*-Value
N intake (g/cow/day)	548	573	540	522	23.2	0.224
N output (proportion N intake)						
N to urine	0.50[a]	0.48[ab]	0.43[bc]	0.39[c]	0.017	< 0.001
N to faeces	0.29[c]	0.30[c]	0.33[b]	0.37[a]	0.009	< 0.001

While Overseer has modelled only ryegrass pastures in the past, using total N has been less of an issue. However, introducing other pasture types will require this to be addressed. To introduce a WSC factor into the N partitioning is probably a step too far at the moment. An alternative short-term solution could be to apply an adjustment factor multiplier post-calculation of urine and faeces proportions in Overseer (Table 8).

Table 8. *Calculated changes in the proportion of excreta N partitioned to dung and urine with increasing proportion of plantain in the diet. Based on results reported in Table 7.*

			Feed composition			
			RG	**15%PL**	**30%PL**	**45%PL**
From Table 7	Prop of N intake as	N-urine	0.5	0.48	0.43	0.39
		N-faeces	0.29	0.3	0.33	0.37
		N-total	0.79	0.78	0.76	0.76
Calculated	Proportion of excreta as	N-urine	0.63	0.62	0.57	0.51
		N-faeces	0.37	0.38	0.43	0.49
Multiplier	Relativity to ryegrass	N-urine	-	1.0	0.9	0.8
		N-faeces	-	1.0	1.2	1.3

Table 8 indicates that the proportion of urinary N from ryegrass and low plantain diet (15%) was consistently around 63% and decreased with increasing plantain proportion above 30%. Calculations in Table 8 suggest a 10% reduction in urine proportion at 30% plantain and 20% at 45% plantain.

This fits with the concept of a sliding scale of effectiveness depending on the proportion of plantain in the sward.

Urine N partitioning - Recommendation:

Partition more N to dung than the current Overseer calculation. Adjust the Ledgard equation on a sliding scale based on proportion of plantain in the pasture

For zero plantain, urine proportion = default for standard pasture

For a sward rich in plantain (>60%), urine proportion = 0.8* Overseer value, remaining N moved to dung

This means that for a plantain sward (30% plantain): urine proportion = 0.9* Overseer value, remaining N moved to dung

7.2 Urine distribution to blocks

From Watkins & Selbie (2015):

"Distribution of excreta is an important part of the N model as it uses input information to determine where and when excreta-N is deposited around the block and farm. Key steps in determining N distribution are:

- *Accounting for transfers (nutrient eaten in one place and distributed in another).*
  - *Allocation of excreta-N to farm structures (dairy shed, feed pads, lanes) using time-based formulae,*
- *Accounting for transfers between blocks and farm structures (e.g. nutrients fed in-shed but deposited as excreta on the block, or nutrients eaten on a block and but excreted on the wintering pad).*
  - *Excreta deposited on wintering pads (place of consumption).*
  - *Remaining excreta N is assumed to be deposited on the blocks where the animals are grazing. This is done by assuming that the distribution to blocks is based on feed consumption in each block.*

The final outcome of the Distribution sub-models is an estimate of the amount of N as dung, urine and effluent deposited on each block, each month. The nutrient deposited on farm structures (e.g. wintering pads) enter the effluent management sub-model, where the nutrients may be applied back onto a block as effluent. The calculation for the proportion of N leached combines this quantity of N deposited on a block with an estimate of leaching risk or 'proportion leached"'.

Recommendation:

- No changes to the way N is distributed between blocks are required

7.3 Partitioning between product and excreta

Overseer uses the N in product as an output in the nutrient budget but also uses this to construct an animal N balance, the surplus being equivalent to excretal N output (then partitioned between dung and urine, as explained above).

Thus, the estimate of N removed in product affects the amount of N estimated to contribute to excretal and urinary N load. There are two aspects to N removal in product

- Higher product yield, resulting in more N removed in the extra milk or meat protein produced
- Possibility of increased N concentration in product, especially for milk

While the higher product yield effect should be captured by user N inputs (annual production), the question is whether the plantain diet affects the concentration of N in milk? Either way, it is possible to input protein and fat production instead of total kg MS. We assume there is no effect on the protein content of animal tissues.

Table 7 shows that the proportion of N intake measured in milk increased with increasing plantain proportion in the diet. However, the milk N concentration was consistent across treatments (0.61 g N/100 g milk), which suggests that the response in N offtake was solely due to increased milk production.

Milk composition data from Box et al. (2017), Totty et al. (2013), Nkomboni (2017), Bryant et al. (2018) or Dodd et al. (2019) showed no significant difference in milk protein concentration with different diets (P>0.05). It is concluded therefore, that differences in N offtake in product are due to increased yield, for example due to a better quality of diet arising from the diverse pastures. Bryant et al. (2018) explain this effect being found in various experiments as being due to factors such as improved digestibility in warm environments.

N in product - Recommendation

- No change to N concentration in animal products
- Any increases in N removal in product should be captured by changing the farm yield of milk or meat.

8. Adapting the Overseer background and urine patch models

From Watkins & Selbie (2015):

"Nitrogen leaching is modelled from urine (urine patch sub-model) and non-urine (background sub-model) areas. Both models are based on a transfer co-efficient approach which uses drainage to estimate the proportion of the 'available' N that is leached.

A good estimate of drainage is essential to utilise the transport coefficient/drainage model approach to N leaching. Drainage is based on a daily soil water balance model which is up-scaled to a monthly time step for the monthly N model calculations. A database of typical long-term regional rainfall distributions is used for this purpose.

Leaching of N - Background

- *Estimates the proportion of available N that is susceptible to leaching. Available N is the net difference between inputs from dung, fertiliser, soil, effluent and irrigation sources, and removals (N uptake, volatilisation and denitrification).*
- *Assumes that the pasture behaves according to a cut and carry system, which is generally characterised by efficient pasture uptake of available N and low N leaching loss.*

Leaching of N - Urine patch

- *Estimates the proportion of deposited urine N that is susceptible to leaching using a N balance approach where multiple processes remove available N.*
- *Removal processes must be estimated adequately: uptake, ammonia volatilisation, and nitrous oxide emissions/denitrification.*
- *A transport mechanism is used to model N moving below the root zone".*

8.1 Drainage model

Overseer requires a reliable estimate of drainage, both in terms of amount and its distribution through the year. The challenge is that Overseer uses a small number of climate input parameters to calculate drainage; as a minimum, annual rainfall is a compulsory input, and annual PET and seasonal distribution of rain and PET can also be (optionally) modified by the user. The user also has facility to enter monthly data.

The Overseer drainage model has previously been compared with an independently developed and validated drainage model, IrriCalc. Th comparison was favourable. Wheeler & Bright (2015) previously compared drainage estimates from Overseer and the IrriCalc model for a number of scenarios. In the absence of irrigation, there was a strong linear relationship between the drainage volume predicted by Overseer and IrriCalc. There was also good agreement between the estimates of average annual drainage under irrigation for the two models.

Shepherd (2019) compared Overseer drainage estimates with the daily water balance model of Woodward (2001) and similarly found good agreement across a range of soil-type and climate combinations (pasture, unirrigated). Shepherd (2019) also compared Overseer drainage estimates with a dataset of c. 30 lysimeter studies (pasture, irrigated and unirrigated); agreement between measured and modelled was reasonable, given the challenge of setting up Overseer to replicate annual experiments. There was some indication that agreement was not as good at very high levels of drainage (Figure 4).

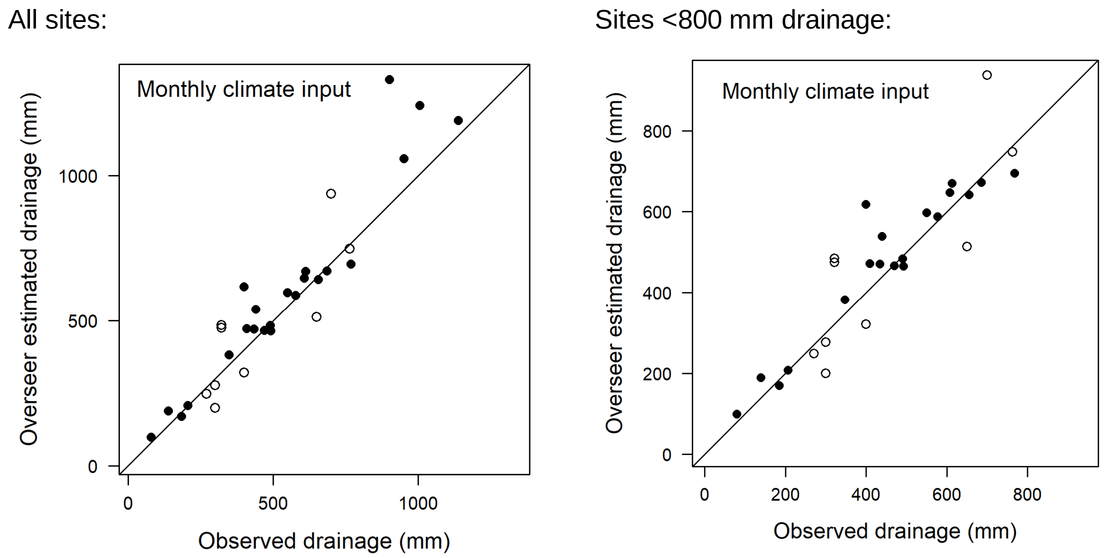


***Figure 4**. Comparison of observed and Overseer estimated annual drainage using monthly climate data input. Includes all sites (left) or sites <800 mm drainage (right). Irrigated sites open circles, unirrigated sites closed circles.*

8.1.1 Analysis

The question then is: is there any indication that the drainage model would need to be modified for plantain-rich pastures? Woods et al. (2018) measured N leaching from urine applications in lysimeters growing either perennial ryegrass/white clover (PRWC) or Italian ryegrass/plantain/white clover (IRPWC). There was a difference in total drainage due to forage type, averaged across urine-N application rates: 333 mm for standard pasture vs 256 mm for the mixed sward (a 23% reduction) and, in general, there was less drainage from the IRPWC during the winter months (June-August).

Malcolm et al. (2014) compared 4 pasture mixes over two drainage seasons: perennial ryegrass/white clover (PRWC); tall fescue/white clover (TFWC); Italian ryegrass/white clover (IRWC); and 'Diverse' (perennial ryegrass/Italian ryegrass/white clover/red clover/chicory/plantain). Though the authors didn't specifically comment on drainage differences, year 1 showed distinct treatment effects: IRWC (c. 450 mm), TFWC = Diverse (c. 515 mm) < PRWC (c. 550 mm). In year 2, differences weren't so large and grouped as Diverse/IRWC (c. 470 mm) < TFWC/PRWC (c. 500 mm). This is a c. 7% reduction, somewhat less than the 23% reduction measured by Woods et al.

Both of these studies focused on pasture mixes and it is probable that much of the reduction in drainage volume was due to inclusion of Italian ryegrass, which has been shown to be more winter active than other species (Cullen et al. 2008).

In contrast, Welten et al. (2019) compared drainage from lysimeters growing single species: Lucerne, plantain or ryegrass, with urine applied either in summer, autumn or winter. As an average of all urine treatments, there was a significant difference between forages; ryegrass (482 mm) > Lucerne (409 mm) > plantain (347 mm). The size of the difference between plantain and ryegrass is surprising (a 28% reduction), given only moderately higher winter growth rates reported by the authors.

Carlton et al. (2019) compared lysimeters growing ryegrass/ white clover and ryegrass/ white clover/ plantain. Treatments were 3 irrigation types and 2 urine application rates. Across all irrigation treatments, drainage from pasture with plantain forage was 21% less than that from the standard pasture when urine was applied in December, and 28% less when urine was applied in February. The authors attributed this to greater water uptake by plantain, arguing that plantain has a lower water-use efficiency. This was supported by Neal et al. (2011), who estimated much lower production per mm water use by plantain compared with ryegrass (Table 9). Averaged over three different watering regimes, plantain water use efficiency was 25% less than ryegrass.

Table 9. *Estimated water-use of ryegrass and plantain under different irrigation regimes (Neal et al. 2011).*

	kg DM/ha/ mm water use			
	I1	I2	I3	Mean
Ryegrass	20.9	18.2	16.0	18.4
Plantain	16.2	12.6	12.6	13.8
Plantain - % of ryegrass	78	69	79	75

I1 - maintaining optimal soil water status; I2 - water applied to achieve 66% of I1; I3 - water applied to achieve 33% of I1

8.1.2 Discussion

Drainage is a key driver of N leaching (as well as aquifer recharge). If plantain (or other pasture species) does decrease drainage, effects on N leaching need to be captured. The observations of reduced water-use efficiency warrant further attention, therefore. Other modelling of plantain pastures in FRNL has not factored in any drainage effects (Beukes et al. 2014, Bryant et al. 2019). Beukes et al. (2014) noted that their modelling approach (using the Whole Farm Model, WFM) has no climate-driven model for diverse pastures and that:

"It will also be important to model systems over different climate years to evaluate the potential of diverse pastures with deeper and more complex root system to outperform standard pastures during dry seasons. This will require the development of a climate driven diverse pasture model for the WFM, which presents a considerable challenge because of the complex interactions between species and the dynamic nature of the mix within and between years. By not modelling the root structure of diverse pastures it is likely that an important positive trait of these pastures is missed".

Even so, the authors here look to be considering effects of root architecture and drought tolerance rather than water-use efficiency per se. Until there is further information and evidence, it is not possible to consider this aspect of lower water-use efficiency and implications for drainage in Overseer. All of the lysimeter studies used high N application rates to simulate urine application; the question is, what is the overall effect at the paddock level when the between urine patch areas are also factored in?

Drainage model Recommendation

- Use existing drainage model values for plantain-rich pastures

- Longer-term: if there is sufficient evidence, look to modify the drainage model to reflect on lower water-use efficiency of plantain. This will decrease drainage, and N leaching.

8.2 Background model

The Overseer pastoral background nitrogen (N) leaching model estimates losses from fertiliser, manure, dung and soil sources of N. This represents the 'between urine patch' areas of the paddock and, when combined with estimates of N leaching from the urine patch (provided by the urine patch model), a block level estimate of N leaching results.

Shepherd (2019) reported an evaluation of the background model. Experimental datasets and literature were interrogated to identify key drivers for N leaching from fertiliser, manure and dung N sources that the model needs to capture. The model was evaluated by (a) comparing with lysimeter/small plot measurements of N leaching where manure or fertiliser N had been applied and (b) running a number of fertiliser or manure application scenarios through the model for sensibility testing.

It was found that:

- Overseer correctly estimated that N leaching losses are small from nil-N cut and carry pastures
- Overseer estimates annual N leaching losses of 5-10 kg N/ha from annual fertiliser N loads of 200 kg N/ha (applied in multiple doses across the year), which are in line with the literature.
- The leaching risk profile for individual fertiliser applications through the year suggests highest losses in the winter but, particularly under dry conditions, some risk also from carry-over of summer applications. There are few experimental data with which to compare this summer carry-over effect.
- The leaching risk profile for individual manure applications through the year is in line with the risk profiles published in the international literature

Many reports state that leaching from cut and carry grass/clover pastures is 'low' (e.g. Simmelsgaard 1998; Ball & Ryden 1984; Grignani & Laidlaw 2002). There is little data specifically from plantain-rich pastures. However, Welten et al. (2019) included control lysimeters of Lucerne, plantain and ryegrass/white clover. They reported "*Leaching losses of inorganic-N across the nil-urine control pasture treatments were relatively low (<2 kg N/ha)*". Woods et al. (2018) similarly noted < 1 kg N/ha leaching from control lysimeters of diverse and standard pastures.

There is no evidence to indicate that the current Overseer background model needs to be modified for diverse pastures, particularly as most nitrate leaching will result from urine patches.

Background model - Recommendation

- Use existing background model values for plantain-rich pastures
- Issue where pure plantain swards are used as these are less winter active than standard pastures – or plantain/pasture mixes: effects likely to be small for the background model

8.3 Urine patch model

8.3.1 Urine patch N load

8.3.2 Analysis

There is considerable evidence that plantain-rich diets decrease the urinary N concentration, with data from a number of papers summarised in Table 10.

From Bryant et al. (2017):

“The reason for the reduction in urinary N concentration on plantain-based pastures could be driven by a number of factors but one of the initial theories is thought to be associated with water diuresis caused by low DM containing plantain. Diuretics are substances which cause an increase in the production of urine and whose presence interferes with homeostatic mechanisms (i.e. anti-diuretic hormone or ADH) for maintaining body water balance (Merrill 2008). Two common forms of diuresis are water diuresis which is caused by excessive consumption of water (inhibiting ADH), and osmotic diuresis which is caused by the presence of high concentration of solutes restricting the reabsorption of water in the convoluted tubules of the renal system (Mathisen et al. 1981)”.

Some authors have also reported increased water intake from consuming the lower DM content of plantain, compared with standard pasture (e.g. Dodd et al. 2019).

In nearly all experiments summarised in Table 10, there was a significant effect of plantain on urinary N concentration. In the majority of cases, dietary N intake was similar and the explanation of effect was given as frequency of urination. The experiments have solely focused on dairy cattle. However, other experiments with sheep have reported a diuretic effect in these animals too (O’Connell et al. 2016; Lindsay 2016)

Comparison of wetted area of urine patches from cows on plantain and ryegrass-based diets, have shown no effect of pasture type on urine patch area (Bryant et al. 2017). Therefore, this is one less variable to concern ourselves with when looking at relativity between standard pastures and plantain.

As a first approximation to the relativity of UP N load from grazing different forage types, data from Table 10 were separated into three comparisons. These comparisons were only made if measurements were made in the same experiment:

- ‘standard’ pasture vs pasture including plantain. Standard pasture was generally ryegrass/white clover; one comparison used Lucerne instead of clover in the pasture.
- ‘standard’ pasture vs plantain. Generally, this is where plantain was planted as a pure sward or with clover. One treatment where plantain was >45% was also included.
- ‘standard’ pasture vs plantain/clover/herbs. This is where the experiment was testing more diverse pastures and was used as a check of relativity with the first comparison, above.

Table 11 summarises the results.

***Table 10**. Summary of urine N concentration data (g N/100g) collected from cattle grazing studies feeding plantain-rich diets. US = urine sensor; RG = Ryegrass; WC = white clover; PL = plantain*

Study	Treatment	RGWC	RGWC/PL	PL	PL/Other	Method	P<0.05	Notes
Box et al. (2017)	Autumn	5.4	3.6	2.4		US mk1	Y	
	Spring	4.7	3.4	2.2		US mk1	Y	
Bryant et al. (2018)		5.2			4.0	US AgR	Y	herb mix; note also with/without IR
		6.3			6.0	US AgR	N	
Cheng et al. (2017)		3.5		1.4		spot	Y	
Bryant et al. (2017)	Spring	4.2			2.9	spot	Y	
	Summer	3.8			4.1	spot	Y	only small amount of PL
	Autumn	5.7			5.3	spot	Y	
Mangwe et al. (2019)		4.8		1.3		spot	Y	also, chicory
Navarette et al. (2018)	Mar	3.2		1.3	1.5	spot	Y	Other = clovers, red and white
	Apr	2.8		1.5	1.8	spot	Y	
Nkomboni (2017)	0PL	4.5				spot	Y	
	15PL		4.1			spot		
	30PL		4.0			spot		
	60PL				3.0	spot		
Totty et al. (2013)		5.7			3.4	spot		incl herbs
Minnée et al. (2017)	0PL	7.0				met stall	Y	
	20PL		6.7			met stall		
	40PL		5.0			met stall		
Edwards et al. (2015)		6.1			4.9		Y	
Dodd et al. (2019)	RG+L	7.0				spot	Y	legume is Lucerne (L), not clover
autumn	RG+L+PL		3.8			spot		
	TF+L	6.3				spot		TF = tall fescue

Study	Treatment	RGWC	RGWC/PL	PL	PL/Other	Method	P<0.05	Notes
	TF+L+P		4.5			spot		
	RG+L	6.2				spot	Y	legume is lucerne
spring	RG+L+PL		4.9			spot		
	TF+L	6.1				spot		
	TF+L+PL		4.8			spot		
Waghorn et al. (2018)		7.0	4.5			Met stall		
Minnée et al. (in prep)[1]	0PL	7.5				Met stall?	Y	
	15PL		7.3					
	30PL		6.0					
	45PL			4.4				

Notes:
[1] These data were not used in the metadata analysis but were used to test the conclusions drawn from that analysis (see text)

***Table 11**. Summary of urine N concentration from grazing different pastures and comparison between forage type (g N/100g).*

	Standard pasture	pasture+ PL	High PL	Diverse+PL	PL relativity
standard vs plantain-rich	6.2	4.7			0.75
n	10	11			
standard vs plantain	4.6		2.1		0.45
n	7		7		
standard vs diverse+PL	4.8			3.7	0.78
n	10			10	

8.3.3 Discussion

The daily urinary excretion will be affected by N intake, N in product and partitioning to urine and dung. All of these aspects, and implications for Overseer modelling, have been addressed earlier. Here we are trying to develop an appropriate scalar to catch the relativity between a ‘typical’ urine patch N load for standard pasture, pasture-rich plantain and a specialist plantain crop.

It’s well recognised that the effective N load of a urine patch will be driven by urine patch size, urine concentration and urination volume. Factor in also the diurnal variation in urine concentration and the interaction of frequency and chance of urine patch overlap, and it can be seen that the use of a single value needs to capture all of these interactions.

Many of the urinary N concentration data in Table 10 were collected by spot sampling. The challenge in using spot samples to calculate daily loads is well-recognised (Bryant et al. 2019), but they might give us an indication of relativity.

Table 11 suggests a 25% reduction in N concentration by grazing plantain-rich pastures, with a similar reduction when comparing standard pasture with standard plus plantain, or standard with diverse including plantain. This compares well with the estimated decrease of 32% reported by Judson & Edwards (2016) when kale grazing was supplemented with plantain (urine = 0.36%N) or ryegrass (urine N = 0.53%N) baleage. Similarly, when Woods et al. (2018) sampled urine from cows grazing the two different pasture types they determined a typical urine patch load was 664 vs. 508 kg N/ha, i.e. a 25% reduction from plantain. Table 11 supports the fact that a higher proportion of plantain has a larger effect, i.e. a c. 50% reduction.

Bryant et al. (2017) summarised similar data (Figure 5). The average urine N concentration for control pastures was 5.52±0.23 g N/L compared with 4.43 ± 0.24 g N/L for pastures offering less than 50% plantain and 3.01 ± 0.23 g N/L for pastures containing 50% or greater plantain. This equated to a 20% reduction for plantain<50% and 45% for plantain >50%. The size of these reductions was confirmed in a metabolic stall trial (Minnée et al. in prep.): with 30% plantain urine N concentration was reduced by 20% and with 45% plantain by 41%.

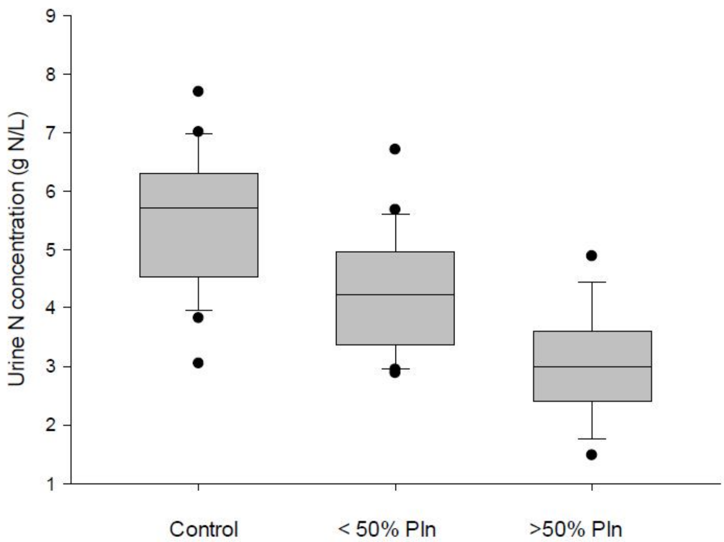


Figure 5. *Distribution of urine N concentration of mid-stream spot samples (average of am and pm sampling) from dairy cows grazing pastures without plantain (control), or pastures containing 5-40% (<50% Pln) and 50% or greater plantain (> 50% Pln). From Bryant et al. (2017)*

Furthermore, the three median values in Figure 5 approximate to a linear relationship in effect, depending on proportion of plantain in the sward.

Urine patch N load - Recommendation

- Modify N loads in a standard urine patch on a sliding scale that is linear between 0 and 60% plantain
- For zero plantain, UP = 750 kg N/ha
- For plantain >60%, UP N load =60% of standard = 450 kg N/ha
- Further sensitivity testing will demonstrate if these are the best numbers to use

8.3.4 Nitrification inhibition

Secondary metabolites within plantain have potential to slow nitrification via urine or directly in the soil. For example, Carlton et al. (2019) measured lower populations of ammonia oxidising bacteria under diverse pastures with plantain. However, Navarette et al. (2016) showed that the levels of inhibitory compounds vary through the season. Welten et al. (2019) measured reduced N leaching in lysimeters sown with plantain but results suggested seasonal variation in the contribution of inhibition to the reduction.

More information is required on:

- that the active compounds/mechanisms responsible for the effect
- the consistency of effect, and the interaction with environmental factors,
- the fate of the ‘saved’ N

Nitrification inhibition - Recommendation

- Some experiments have shown a nitrification inhibition effect from grazed plantain but there is insufficient evidence to support implementing this across all situations.

9. Evidence of expected size of effect

There are no data with measured N leaching losses at a block scale. The nearest scale is paddock and these results are not yet available. The Overseer estimates of effects on N leaching will be built up in the model from component studies and then tested to see if the resultant combination of components yields a reduction in N leaching that feels 'about right' based on, any measurements, modelling and expert opinion. Previous modelling done in the FRNL programme provides some indications of size of expected effects.

9.1 Literature review

Beukes et al. (2014) used a combination of models to estimate farm-level effects of incorporating 'diverse pasture' into 20% or 50% of the farm. DairyNZ's Scott farm in the Waikato was used as the baseline. The diverse pasture comprised herbs (chicory and plantain), red clover and prairie grass added to the standard pasture. The models were able to capture the lower N concentrations in the urine because of a combination of lower total UN excreted and larger urine volumes. Key findings were:

- The animal model predicted urinary N concentration reductions of 23% and 17%.
- Farm-scale model scenarios, where 20% or 50% of the farm was sown with diverse pastures, resulted in 2% and 6% reductions in urine deposited onto paddocks.
- This reduction was smaller than expected with some system interactions related to seasonal feed supply, diet composition and total N intake being likely to play a role.
- The reduction in urinary N onto paddocks, together with a dilution effect from larger urine volumes per cow per day as a result of lower DM% of diverse pastures, resulted in N leaching reductions of **11% and 19%** for the two scenarios, respectively.

Romera et al. (2017) used different modelling approaches to simulate the effect of diverse pastures, but came up with reductions in N leaching of the same order: reductions in N leaching of about 40% were predicted here when all the sward area on the farm was sown to diverse sward mixtures, compared with standard mixtures. The reduction was mainly derived from a reduction in the concentration of N in urine and, to a much lesser extent by a reduction in the total amount of urinary N excreted by the cows. These authors noted that the need to understand and improve the persistence of diverse swards is important to reduce the cost of pasture establishment.

Bryant et al. (2019) undertook modelling at the block scale rather than the farm using APSIM to estimate size of reductions in N leaching. The modelling was done across two environments: Canterbury and Waikato. Furthermore, 3 scenarios were tested:

- S1 – forage only effect, as for standard perennial ryegrass/white clover mixture, except diuresis increases urination frequency from 11 to 15 events/cow/day, with associated dilution or lower N load.
- S2 – forage + management effect, as for S1 except a higher WSC/CP ratio of the pasture was assumed.
- S3 – forage + management + systems effect, as for S2 except the amount of fertiliser was reduced by 50 kg N /ha /year.

APSIM aimed to capture effects through diuretic effects, resulting in reduced urine patch N load but increased number of urine patches with increased risk of urine patch overlap. There was further interaction with stocking rate, which differed between the two sites:

Key results:

- Baseline losses were estimated to be (a surprisingly high)148 kg N/ha (Canterbury) and 29 kg N/ha (Waikato). The large values at the Canterbury site meant that treatment effects were small when expressed as a % of this base.
- Urine patch N load was reduced by 30% which is of the order suggested in this report.
- This resulted in a 20% reduction in N leaching at the Waikato site – in agreement with our preliminary estimates (see next section)
- Canterbury effects were much less, as a result of high baseline (6%). We have not run Overseer scenarios for a Canterbury environment yet, but would expect reductions to be of a similar order to those at Waikato.

Overseer does not factor in increased overlap risk (other than by adjusting the ‘standard’ urine patch to capture this) and therefore would not respond to the differences in stocking rate identified in the APSIM modelling.

9.2 How Overseer should respond to the recommended changes

Modifications to the Overseer model to accommodate plantain-rich pastures will mean that:

- The model will be able to capture any effects of differences in the N concentration of different pasture types. HOWEVER, the default position is that there are no consistent differences between pastures. Users would need to over-ride these default settings.
- The model will be able to capture any increases in production, but this requires users to enter revised production estimates (the model does not do this automatically).
- The model will capture increases in N offtake in product based on user inputted production data. Overseer will not assume any extra N is partitioned to product (i.e. no change in N concentration) – increased N offtake will solely be due to changes in production.
- The model will reduce the amount of urinary N production due to (a) increased N removal in product (if product output is changed) and (b) slightly more excretal N partitioned to faeces.
- The model will reduce the amount of N leached from a urine patch by using a lower default value for a standard urine patch. This is likely to be the main driver of reduction in N leaching (see example below)
- The model will not try to represent the interaction between increased frequency of urination and increased chance of urine patch overlap, this is beyond the scope of the current model structure. All of this variation needs to be captured in a representative number for a standard urine patch.
- The model will not account for ‘deep recovery’ of N
- The model will account for any interactions between productivity, and increased pasture grown, for example.
- The model will not be able to account for other effects on the UP N leaching: nitrification inhibition; reductions in drainage
- The model will be able to calculate the contribution of the new plantain pasture-type blocks to the whole farm estimate of N leaching

9.2.1 Indicative size of effects

As a very early indication of possible size of effects, the Overseer FM science model was used to run a couple of scenarios. Using existing farm files, it was imagined that the pasture block on those farms included either 30% or 60% plantain. The assumption was that nutritive value and growth patterns were the same as standard pasture and all of the effects on N leaching were due to change in partitioning of urinary N and reduced urine patch N load. Scenarios tested were:

- Plantain 30% - change excreta N partitioning by 10% more N going to dung and urine patch N load decreased by 20%
- Plantain 60% - change excreta N partitioning by 20% more N going to dung and urine patch N load decreased by 40%

The farms selected were in the Central Plateau on a pumice soil. Figure 6 shows the estimated change in N leaching arising from the separate components (UP N load and proportion of urine N) and combination of the two.

The result suggests that the main effect is from UP N load rather than change in the amount of urine N deposited. This result is in agreement with Beukes et al. (2014). Combined, the result was a 20% reduction for plantain 30% and a 40% reduction for plantain 60%. Note that these are very simplistic runs and take no account of changes in productivity, or anything else.

Proportioning these reductions across the farm allows an estimation of the farm-level impacts on N leaching (Table 12). These results show that the highest estimate of block-level reduction of 40% would achieve similar estimates to Beukes et al. (2014) and Romero et al. (2017). However, the more likely proposed 20% reduction at a block level would yield farm-level reductions of about half of those. Note also that this scaling up assumes no crop blocks on the farm. High N leaching losses from grazed forage blocks would further erode the contribution of plantain-rich pastures at the farm level.

However, a more detailed analysis through structured sensitivity testing will guide final decisions on choice of parameters and likely size of effects.

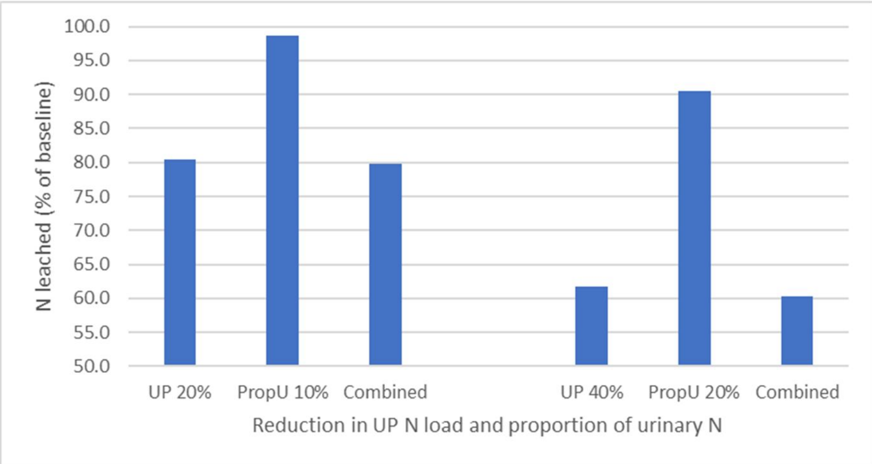


***Figure 6**. Estimated reduction in block-level N leaching as affected by changing proportion of urinary N and reduction in urine patch N load.*

***Table 12**. Estimates of farm-level reductions in N leaching based on different proportions of the farm being converted to pasture with plantain*

Proportion of farm	% Reduction in N leached	
In diverse	Plantain 30%	Plantain 60%
20%	4	8
50%	10	20
100%	20	40

10. Next steps

- Finalise these recommendations with the FRNL scientists and get sign-off from FRNL. This may well be an iterative process of revision and agreement. The decision process and any changes to the recommendations will be captured in this document
- This document then becomes the Change Document for Overseer Ltd
- Based on this Change Document, a Development version of the model will be delivered for testing.
- A testing protocol will be developed, covering both sensibility and sensitivity testing. Results will form the basis of an iterative process of testing, revising and finalising the model.
- Following sign-off of the development model, two supporting documents will be prepared to accompany public release:
    - A revised version of this report summarising the approach and the supporting evidence for changes
    - Results of the sensitivity and sensibility testing

10.1 Sensitivity testing

Based on identification of the key decision points around Overseer changes documented in this report the following list of variables should be included in sensitivity testing.

- Relative area of plantain on the farm
- Environment: location, soil-type, climate – especially capturing differences between North and South Island environments (e.g. fine and coarse textured soils in high and low rainfall environments)
- Production (milk or meat) - impacts of more production and associated N removal in product at the same or lower N inputs
- N fertiliser inputs – if the same level of production can be achieved for less fertiliser input in a plantain-based system, what are the impacts
- Pasture ME – sensitivity of changes to ME, which will result in changes to estimates of N eaten and excreted
- Block relativity – the size of the effects of assuming more production from plantain blocks
- Seasonal growth patterns
- Urine proportion
- Urine patch N load
- Drainage volume

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