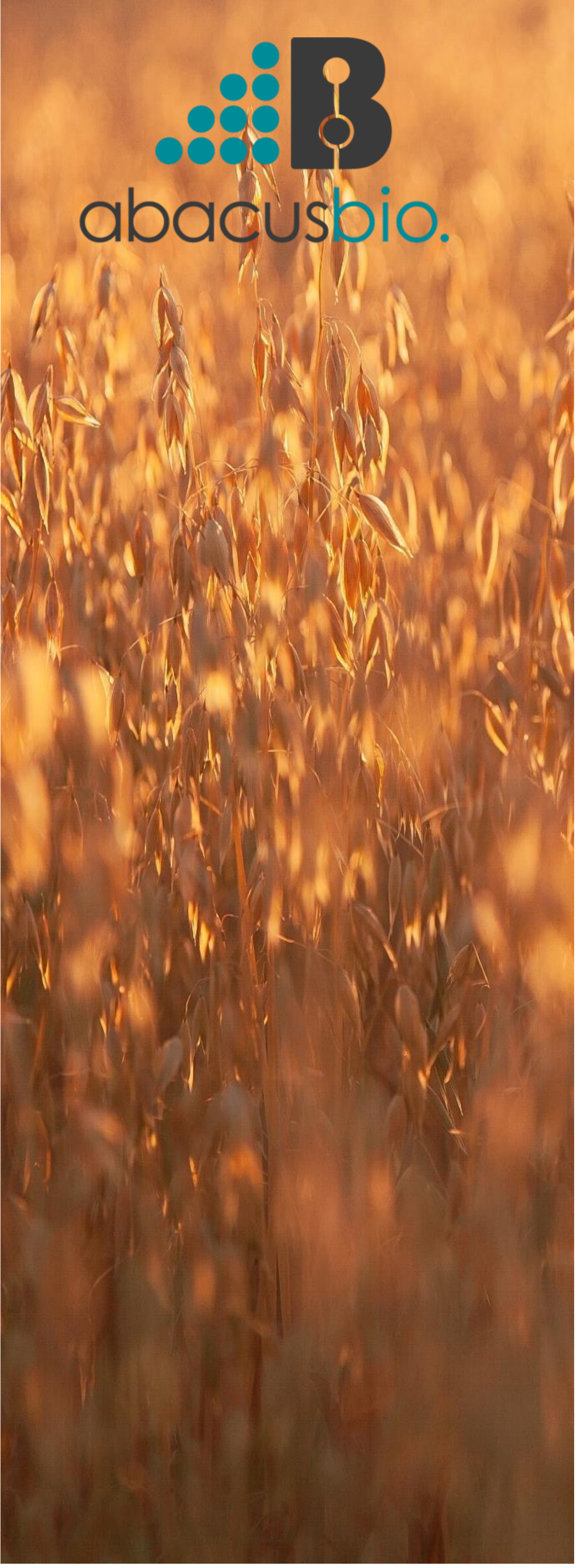

Oat milk supply chain literature review

Prepared for:

Thriving Southland

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AbacusBio

Contents

Purpose of literature review

To provide Thriving Southland with an independent review of existing literature pertaining to the following elements of oat milk production:

- Production needs - agronomic requirements, including soil and water needs, weed and pest management;
- Market analysis of oats for milk - costs and margins, competition, product mix and innovative opportunities, carbon neutrality.

Oat agronomics

Commercial oat varieties have long been recognised as a high-quality food for humans and feed for livestock. Modern oat varieties, *Avena sativa L.*, are hexaploid and originate from 30 ancestral species (diploids, tetraploids and hexaploids)[1]. Improved genetics have played a significant role in improving yield and other agronomic characteristics. Crop management, eg nitrogen levels and climatic conditions, also have significant influences on enhancing oat composition and yields.

Optimal climatic and environmental conditions for oat crops

Oats are mostly grown in cool, moist climates with optimum growing temperatures of 20-21°C[2]. Oats can be sensitive to hot, dry weather, especially during emergence of the head and maturity. For these reasons, world oat production is generally concentrated across latitudes of 35-65°N and 20-46°S[3].

Temperature has a significant impact on the growth and development of oats, as shown in a controlled environment trial across three genotypes in the United States. In this trial, grain-filling rate was 45% greater at 15°C daytime temperature than at 31°C[4].

These data are supported by data from a North Dakota study showing that warm, bright (high solar radiation) spring weather, and cooler summer weather, without excessive rains during grain filling, generated the best oat yields with high quality grain[5].

In further support of this, trials assessing impact of root zone temperature and phosphorus concertation on oat plant growth showed that height response and root yield (with added phosphorous) was greatest at 15°C and least at 25°C[6].

Oats thrive in well drained soils but are adapted to grow in many soil types when the pH is between 5.5 and 7.0[7]. Oats do not perform well in acid soils and have an intolerance to aluminium toxicity[8], although they will perform better than other small-grain cereals in acid soils[9]. In more acidic soils, lime can be applied to soil prior to sowing to increase pH to optimum levels.

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1 https://www.nature.com/articles/s41598-018-22478-4
2 https://plantvillage.psu.edu/topics/oats/infos
3 http://www.fao.org/3/y5765e/y5765e06.htm#:~:text=Oats%20are%20mostly%20grown%20in,and%2020%2D46%C2%B0S.
4 https://acsess.onlinelibrary.wiley.com/doi/abs/10.2135/cropsci1996.0011183X003600030017x
5 https://acsess.onlinelibrary.wiley.com/doi/abs/10.2135/cropsci2001.4141066x
6 https://acsess.onlinelibrary.wiley.com/doi/abs/10.2136/sssaj1964.03615995002800030032x
7 https://plantvillage.psu.edu/topics/oats/infos
8 https://acsess.onlinelibrary.wiley.com/doi/abs/10.2134/agronmonogr33.c6
9 http://www.fao.org/3/y5765e/y5765e06.htm#:~:text=Oats%20are%20mostly%20grown%20in,and%2020%2D46%C2%B0S.

Oat in Southland, New Zealand

Southland climate

The total amount of oats grown in New Zealand is estimated to be 12,000T grain oats and 10,000T of general feed oats (2020 data[10]).

Southland is the main oat growing region of New Zealand with the region producing ~50% of total oat production in 2017[11] (Figure 1).

The Southland climate and location (45.8°S) fits well within the parameters for optimal oat crop production. However, the Southland climate can be marginal during critical times of the growing season. For example, a summary of five years of field trials in Southland found that spring sown oats had a higher risk of late season moisture stress during grain fill, compared with autumn sowing[12]. Late season weather conditions (storms) also negatively impacted on lodging and yield.

A classification of Southland soils shows that 10,700ha are suitable for oat production (high versatility for production potential and management) however, much of this class of land is in high competition with dairy production (Figure 2[13].

The areas circled in Figure 2 are historical grain growing areas within Southland and include most of the moderately versatile land. In total, 117,700ha of the 186,100-ha was rated as “moderate versatility for arable farming” and is not suitable for dairying due to structural compaction and waterlogging susceptibility. This land is currently utilised across all land classes (dairy, dry stock and arable).

The proposed Makarewa based oat milk factory has initial plans to produce 40 million litres of oat milk annually[14], with the ability to add a further 20 million litres processing capacity when needed. One litre of oat milk requires approximately 230 grams of raw oats[15], therefore, to meet the production forecast the milk factory would require approximately 1,200 additional hectares of oats produced (based on grain yield of 7.5 T/ha), or an extra 20% of grain oats grown in Southland.

[10] Personal communication with Ivan Lawrie from Foundation of Arable Research

[11] https://figure.nz/chart/t8u1syzhCpY1m5eH-qn9IUv3xbXXoiYmy

[12] https://www.far.org.nz/assets/files/uploads/C181_Oat_Review.pdf

[13] Source: Great South

[14] https://countrytv.co.nz/oat-milk-plant-to-be-built-near-invercargill/

[15] Justin Riley (CEO NZ functional foods) personal communication

Figure 1. Area of oats harvested (hectares) in New Zealand year end June 2017 (source: StatsNZ)

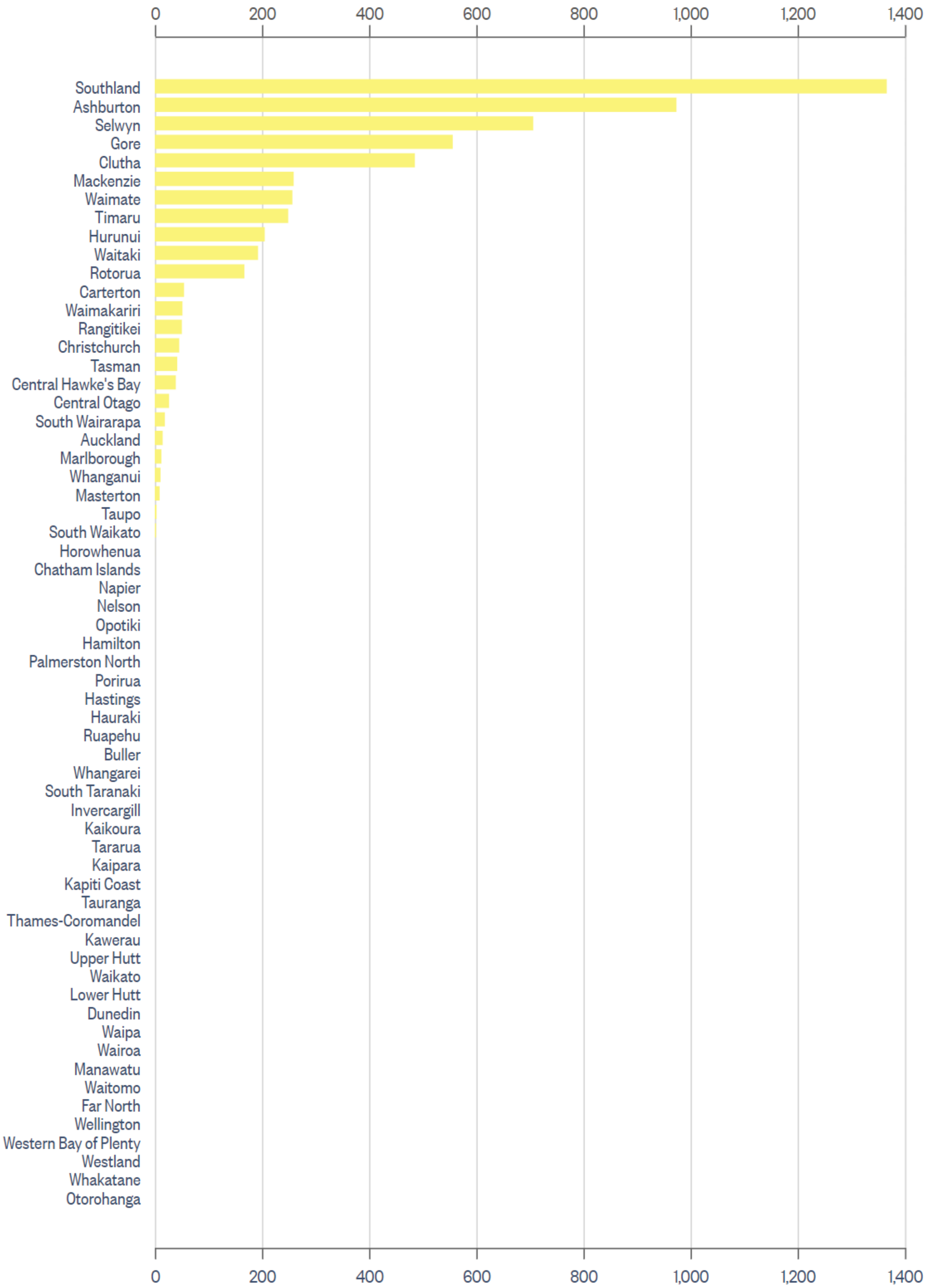
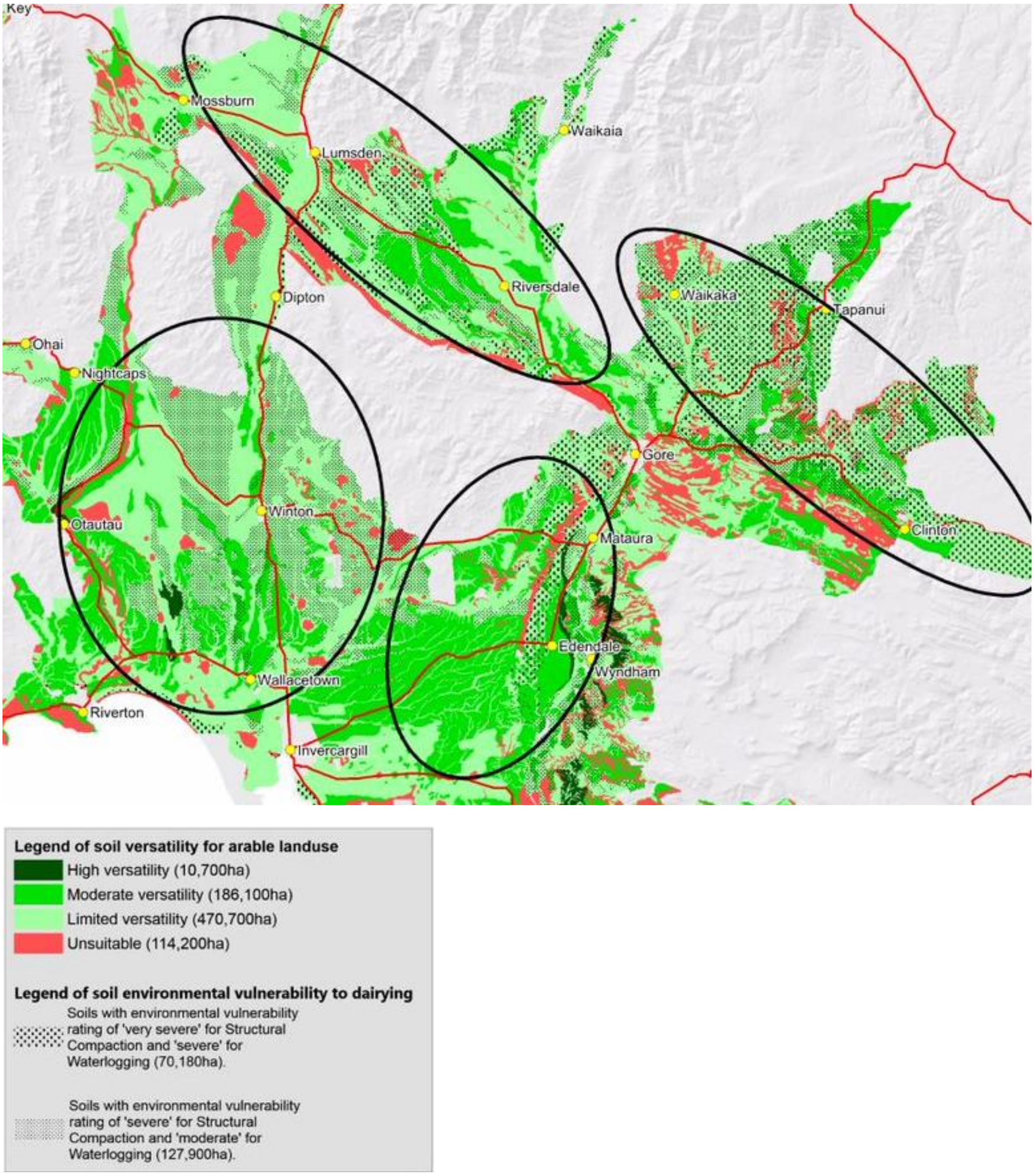


Figure 2. Southland map highlighting areas of versatility and environmental volatility[16].



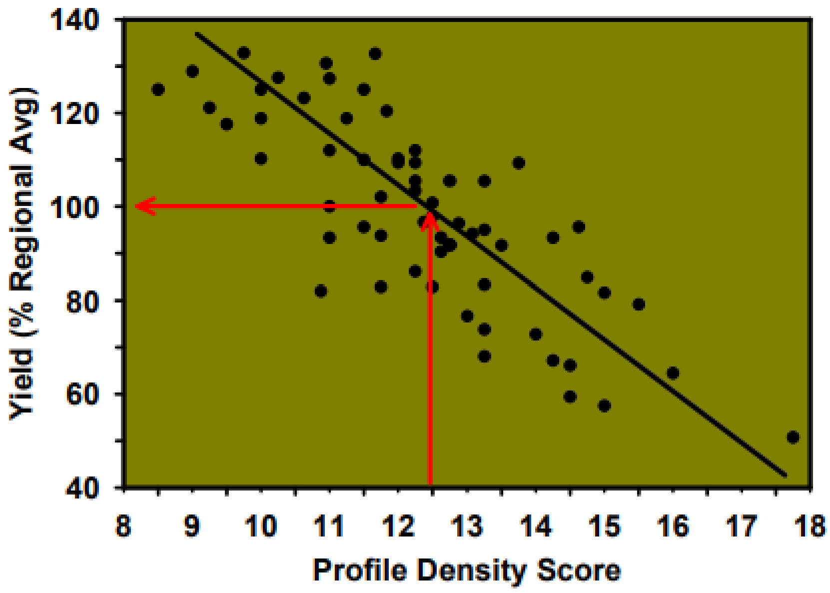
Southland soils

Soil monitoring sites in Southland show that crop yields decrease as soil density increases (Figure 3). The main cause for this is the decreased ability of the soil to hold water and air and reduced rooting depth[17].

[16] Great South

[17] https://www.far.org.nz/assets/files/blog/files//070f33ba-e94c-534b-a73f-6c6cc771b420.pdf

Figure 3 – Relationship between profile density scores and relative crop yields in Southland[18].

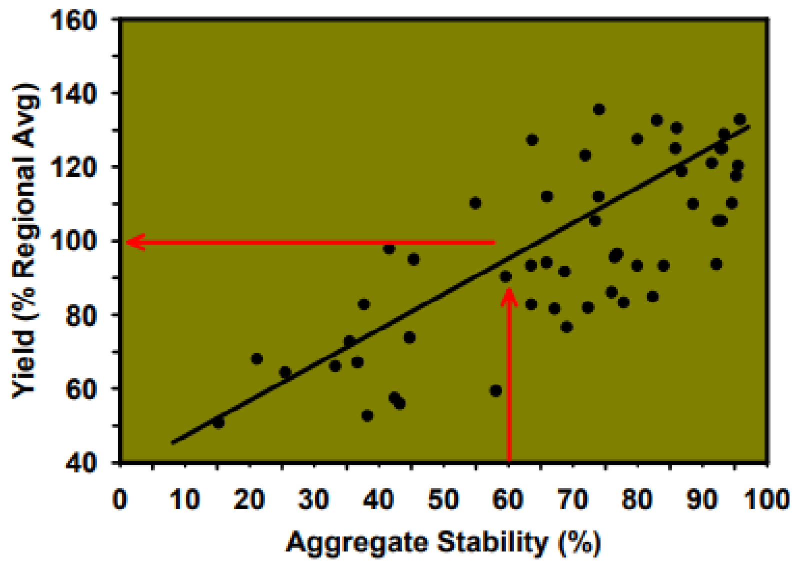


Some New Zealand soils have naturally compact subsoil. There are also management factors which will increase the breakdown of soil structure and increase soil density. These practices include continuous cropping with conventional cultivation, cultivating in wet soils and removing crop residues, resulting in reduced organic matter in the soil.

Soil structure and aggregate stability also have a significant impact on relative crop yield. Southland soils become unstable when organic matter levels fall below 2.5% (or 1.25% total carbon). A Southland monitoring programme has shown that crop yields tend to increase as aggregate stability increases[12] (Figure 4).

[18] https://www.far.org.nz/assets/files/blog/files/070f33ba-e94c-534b-a73f-6c6cc771b420.pdf

Figure 4 – Relationship between aggregate stability and relative grain yield in Southland[19]



Aggregate stability is promoted through adoption of minimal tillage techniques, maintaining high organic matter content (cover crop, addition of green manure, retaining crop residue, permanent pasture) and use of autumn sown crops. Generally, increasing plant root mass is more effective than above ground cover crops for improving soil organic matter[12].

Table 1. Organic matter returned by roots of various crops[20].

Crop	Organic matter added in top 20 cm soil (kg/ha/crop)
3 year old grass	6000 – 8500
1 year old grass	4000 – 5000
Farmyard manure (10 t)	4000
Winter cereals	2200
Red clover	2000
Spring cereals	1300
Forage cereals	~1300

Nutrient requirements

Milling oats are considered to need lower nutrient inputs than other crops[21] and tolerate a number of foliar diseases that other cereals do not[22], although this is not the case for other areas of New Zealand where crown rusts are an issue (not so much of an issue in Southland).

Nutrient requirements for crop growth must be supplied from the soil, or from added organic or synthetic fertiliser. Southland has good quality soils with excellent natural fertility, however, to maintain high crop

[19] https://www.far.org.nz/assets/files/blog/files/070f33ba-e94c-534b-a73f-6c6cc771b420.pdf

[20] https://www.far.org.nz/assets/files/blog/files/070f33ba-e94c-534b-a73f-6c6cc771b420.pdf

[21] https://acsess.onlinelibrary.wiley.com/doi/abs/10.2134/agronmonogr33.c6

[22] https://www.far.org.nz/assets/files/blog/files//174592e9-3329-5eeb-b1c3-285243c4a58a.pdf

yields there are some key nutrient requirements required including nitrogen, phosphorus, potassium, and trace elements.

Nitrogen

It is widely accepted that nitrogen is the most limiting nutrient for cereal crop production. Foundation for Arable Research (FAR) trials for milling wheat show that total nitrogen of 26kg is required for each ton of grain to maximise yield for feed wheat[23].

International trials on oats show that economic optimum nitrogen application rates range from 30-76 kgN/ha[24] while other trials show ranges greater than this, indicating that total nitrogen applied is not a strong indicator of optimal yield or optimal profit.

Total nitrogen required for plant growth comes from soil mineral nitrogen and applied fertiliser nitrogen. There is significant variation in soil nitrogen levels with FAR trials (across New Zealand for wheat cropping) showing that soil mineral nitrogen prior to planting can vary from 20 to 207 kg N/ha[25]. This extensive variability means it is imperative to measure soil nitrogen levels prior to growing any crop, including oats. There are no data regards requirements of autumn versus spring sown oats.

Generally, reduced fertiliser rates result in lower nitrogen loss from the soil profile, but crop yields can also be reduced proportionally. In the United States, across multiple crops, the use of nitrification inhibitors and split fertiliser applications has led to increased (~ 6%) crop yields and a reduction in nitrogen losses (~ 10%)[26].

In Southland, trials have shown that increasing rates of nitrogen have resulted in higher oat yields, but also higher levels of lodging which had an overall negative impact on the farmers' ability to harvest crops[27,28].

A major farming challenge and future impediment to nitrogen fertiliser use, is nitrogen leaching through the soil profile in all farming systems. A simulation tool, "The Agricultural Production Systems Simulator" (APSIM)[29], showed that higher rates of nitrogen use increased nitrogen loss in the Aparima catchment in Southland. There were significant benefits with altering the timing of nitrogen applications from a scheduled programme to a soil test-based programme, whereby nitrogen was only applied as soil tests indicated need[30]. This method of application may lead to more efficient use of nitrogen by plants and lead to less nitrogen loss to water and atmosphere. A UK study also showed that conventional tillage increased the total leaching loss of nitrate by 21 % compared with direct drilling in drained plots[31].

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23 https://www.far.org.nz/assets/files/blog/files/6e17b639-db58-4541-8594-113be7ac6a5b.pdf

24 https://www.tandfonline.com/doi/abs/10.1080/01904167.2019.1617311

25 https://www.far.org.nz/assets/files/blog/files/6e17b639-db58-4541-8594-113be7ac6a5b.pdf

26 https://www.sciencedirect.com/science/article/abs/pii/S0921818108002075

27 https://www.far.org.nz/assets/files/uploads/Copy_of_C136.pdf

28 https://www.far.org.nz/assets/files/uploads/C181_Oat_Review.pdf

29 https://www.apsim.info/

30 https://onlinelibrary.wiley.com/doi/abs/10.1002/jsfa.11063

31 https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1365-2389.1993.tb00432.x

Phosphorous and potassium

In addition to nitrogen, oats require phosphorus and potassium for optimal growth[32]. The optimum soil Olsen phosphorous range (available phosphorus) for high grain yields is 20mg/kg and annual maintenance requirements are 15-30kg P/ha/yr when producing oat grain yields of 7T/ha[33].

Most mixed cropping in Southland occurs on Pallic and recent soils, both of which generally exhibit low (0-30%) phosphorous retention[12].

Table 2 - Optimum soil quick test ranges for crops[34]

Crop	Olsen P	K	Sulphate-S
Pasture	20-30	5-8	10-12
Grass (seed)	15-25	6-8	6-10
Wheat	20-30	5-8	10-15
Barley	20-25	5-8	10-15
Oats	20-25	4-6	10-15
Maize (grain)	10-15	6-8	6-10
Maize (silage)	20-30	6-8	6-10
Brassica (seed)	20-30	6-8	10-15
Peas	20-30	5-8	8-10

In Waikato trials, the effect of root zone temperatures of 15°, 20°, and 25°C and phosphorous sources showed that height response and root yields to added phosphorous, was greatest at 15°C and least at 25°C. In both tops and roots the temperature effect was greater at higher rates of phosphorous application[35]. This would suggest that the Southland climate would lead to more efficient phosphorus use of oat crops.

Less potassium is required for oat grain than for other cereals, with maintenance requirements of 10-20 kg K/ha/yr, or up to 250 kg K/ha/yr, if crop residue is removed.

As above, the rates of application of all nutrients should be based on the results of a soil test.

Magnesium

Magnesium deficiency, "Grey Speck," is the most common micronutrient problem associated with oat production[36].

Organic fertilisers

An Indian study[37] showed biological fertilisers (composted poultry manure) are beneficial to crop yield and help reduce the environmental impact of cropping. When different nitrogen sources were examined: chemical nitrogen; organic nitrogen; and microbial nitrogen, it was shown that during critical stages of the crop, when most of the applied chemical nitrogen had leached from the top 20cm soil depth, substantial nitrogen came from organic matter mineralisation. In a Zimbabwean study[38], organic nitrogen combined

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[32] https://plantvillage.psu.edu/topics/oats/infos

[33] https://waikatoregion.govt.nz/assets/WRC/WRC-2019/Managing-Soil-Fertility-on-Cropping-Farms.pdf

[34] Adapted from Morton et al. 2000

[35] https://acsess.onlinelibrary.wiley.com/doi/abs/10.2136/sssaj1964.03615995002800030032x

[36] https://acsess.onlinelibrary.wiley.com/doi/abs/10.2134/agronmonogr33.c6

[37] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0213808

[38] https://link.springer.com/article/10.1007/s11104-011-0753-7

with chemical nitrogen proved to be effective in improving soil properties, ensuring less nitrogen loss and increased oat production.

Although overseas studies show some benefits from organic oats production[39, 40], there have been no trials of organic oat production methods in New Zealand that we know of and Harraways, the main New Zealand oat processor, imports their organic oats. The challenge with organic oat production in New Zealand is weed and disease control, and the lack of flexibility with fertiliser inputs to maintain consistent and profitable crop yields[41].

Pests, weeds, and disease

Damage from insects and disease is not generally a major factor for oat crops, however, significant damage can occur if insect populations build up. As the climate warms, insects may become more of an issue.

In New Zealand, fungal diseases for oat crops are a major issue in the North Island, generally ruling the crop out of production systems. Grain quality can also be an issue in the North Island.

A Southland field trial in 2020, showed that minimal fungicide treatments were required to control red leather leaf and other related diseases in oat crops, although there was no significant difference in yields from treated and control plots[42]. In contrast, the University of Wisconsin Arlington Agricultural Research Station studies showed seeds treated with fungicide (Rancona Crest) exhibited increased groat yield compared to untreated seeds by 187kg/ha[43].

Oat crops exhibit allelopathy[44] in relation to weed suppression. Trials in Canterbury showed the best weed suppression was observed in plots of rye corn, oats and peas, and oat and tares - 72 and 90% reductions in weed dry weight respectively[45]. This type of effect is important, especially for organic and regenerative systems, and is worth exploring further for Southland systems.

Most weed infestations can be controlled with strategic herbicide applications. However, there is increased tolerance of some weeds to group B[46] herbicides[47]. To slow the development of resistant weeds there needs to be a selection of herbicides which use different modes of action.

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[39] https://acsess.onlinelibrary.wiley.com/doi/full/10.2134/agronj2004.1288?casa_token=yVLrQcxEv7MAAAAA%3AQ4XGwMdlYBza2UNH6xJsxnhslnH-akU5LfOrPfZDsfROZRJvXHbYMLqoZLw-_65jLkfdg19m5cp9bo0a

[40] https://ageconsearch.umn.edu/record/134120/

[41] Personal communication with Foundation of Arable Research and cropping farmers

[42] https://www.far.org.nz/assets/files/blog/files//174592e9-3329-5eeb-b1c3-285243c4a58a.pdf

[43] Agronomic Management and Fungicide Effects on Oat Yield and Quality - Mourtzinis - 2015 - Crop Science - Wiley Online Library

[44] Biological phenomenon in which an organism produces one or more biochemicals that influence the growth, survival, and reproduction of other organism.

[45] https://www.agronomysociety.org.nz/files/2010_9._Cover_crops_in_organics.pdf

[46] https://www.crop.bayer.com.au/tools/mix-it-up/mode-of-action-search-tool

[47] https://www.far.org.nz/articles/77/c216-willow-weed-control-in-spring-sown-oats

Planning rotations to minimise pest carryover, timely sowing and adequate crop nutrition will all assist in reducing the likelihood of crop attack by insect pests and disease[48,49] and reduce resistance to weed and pest sprays.

Oat cultivars

Due to the commercial value of oats being lower than other cereal grains, oats have not had the same level of national investment to develop new cultivars over the past 20 years in New Zealand. However, in the past 12 years Plant Research NZ (a private plant breeding company based in Canterbury) have been working alongside a group of New Zealand farmers to develop new oat cultivars for oat production.

The oats bred by Plant Research NZ have been bred for a low-chemical input system. Plant Research NZ are collaborating with a North American breeding partner for organic production oats and are evaluating some of their germplasm here - there is a need to evaluate in a Southland environment[50] (note an opportunity for a Southland SFFF type bid).

Shorter strawed cultivars are grown for milling in Southland to reduce losses from lodging. However, management strategies such as reduced sowing rates and spraying with Chlomequat (growth regulator) also reduced to reduced incidence of lodging[51].

Southern Gold L5 has been released commercially with superior yields and water-use efficiency than older existing cultivars[52].

Field trials of a new variety in development are underway. The new variety is expected to deliver a superior yield to L5[53] (13% greater yield, greater ß-glucan and greater protein percentage). A 13% increase in yield is equivalent to 1T/ha for farmers which will increase the competitiveness of oats with other cereals, such as wheat. For the future of the Plant Research NZ breeding programme, the aim is to achieve 10T/ha yield (up from 7T/ha now)[54].

Other traits such as whiteness of the oats, which is important for the colour of oat milk, are also considered within the breeding programme line assessment.

Regenerative farming practices

Effects of land-use management on agricultural sustainability and greenhouse gas (GHG) emissions are major issues for consumers, regional councils, and farmers in New Zealand. Cropping systems in the future will need to reduce greenhouse gas emission per unit of production to increase food production while mitigating climate change.

Regenerative farming practices such as the use of cover crops, reduced tillage, reduced use of synthetic fertilisers and time control grazing are used to promote a more sustainable method of farming. Practitioners of regenerative agricultural practices claim to increase carbon sequestration, have better soil

[48] https://plantvillage.psu.edu/topics/oats/infos

[49] https://www.agric.wa.gov.au/oats/oats-insect-pests?nopaging=1

[50] Adrian Russell, Plant Research NZ Ltd, personal communication (July, 2021)

[51] https://www.agronomysociety.nz/files/1998_14._Chlormequat_sowing_rate_effects_on_oats.pdf

[52] https://www.odt.co.nz/rural-life/rural-life-other/new-oat-cultivars-developed

[53] https://www.stuff.co.nz/national/124201176/oat-boom-validation-of-lifes-work-for-southland-farmer

[54] Adrian Russell, Plant Research NZ Ltd, personal communication (July, 2021)

health, greater biodiversity, reduced water pollution and more resilience to drought, floods, pest incursions and to promote farmer and livestock welfare[55].

A practice encouraged in regenerative farming is no-till cultivation. No-till practices allow the soil structure to stay intact and protect the soil by leaving crop residue on the soil surface. Improved soil structure and soil cover increase the soil's ability to absorb and infiltrate water, which in turn reduces soil erosion and runoff and prevents pollution from entering nearby water sources. A recent study revealed that no till practices resulted in an 84% decrease in sediment loss of conventionally grown maize crop[56]. Supporting this is a NZ study showing sediment loss was 76% lower in a no-till compared to conventionally tilled corn crops[57].

No-till practices also slow evaporation, which means better absorption of rainwater, but increased irrigation efficiency, ultimately leading to higher yields, especially during hot and dry weather (note Table 3, and section on tillage trial in section below).

Soil microorganisms, fungi, and bacteria, critical to soil health, also benefit from no-till practices. When soil is left undisturbed, beneficial soil organisms can establish their communities utilising organic matter. A healthy soil biome is important for nutrient cycling and suppressing plant diseases. As soil organic matter improves, so does the soil's internal structure—increasing the soil's capacity to grow more nutrient-dense crops[58].

International modelling shows that no-till cultivation leads to greater carbon storage and when combined with nitrification inhibitors can lead to reduced GHG emissions of ~ 50% and increased crop yields of ~ 7%[59].

An Environment Aotearoa report[60] stated that waterways in farming areas are polluted by excess nutrients, pathogens, and sediment. Early practice monitoring shows that regenerative agricultural practices provide environmental benefits and suggest that widespread adoption of regenerative agriculture could help to reverse negative trends[61]. However, it is worth noting, there have been no control trials done in Southland comparing regenerative practices to conventional, so the majority of data quoted in New Zealand is anecdotal, rather than scientifically verified.

A United States based study found that crop pests were 10 times more abundant in insecticide-treated corn fields than on insecticide-free regenerative farms. The same study found that while the regenerative farmers had lower yields, they reported 78% higher profits over traditional crop production systems, due to a reduction in input costs, and higher value end markets[62].

Overall, there is some evidence which indicates that regenerative farming practices can deliver some benefits, reducing pest/disease incidence while reducing environmental risk. There is considerable debate around this in New Zealand[63] as regenerative farming practices are relatively new to commercial business

[55] https://pureadvantage.org/insight-into-regenerative-agriculture-in-new-zealand-the-good-the-bad-and-the-opportunity/

[56] https://link.springer.com/article/10.1007/s13593-018-0545-z

[57] https://www.sciencedirect.com/science/article/pii/016719879400427G

[58] https://regenerationinternational.org/2018/06/24/no-till-farming/

[59] https://www.sciencedirect.com/science/article/abs/pii/S0921818108002075

[60] Ministry for Environment, 2019

[61] https://pureadvantage.org/insight-into-regenerative-agriculture-in-new-zealand-the-good-the-bad-and-the-opportunity/

[62] https://peerj.com/articles/4428/

[63] https://geneticliteracyproject.org/2020/06/11/plant-scientists-want-new-zealand-to-fact-check-mythology-surrounding-regenerative-farming/

and more studies/field trials are required to provide evidence-based feedback regarding their benefits and impact on farm productivity and profitability in the Southland environment.

New Zealand Merino have elected to develop their own regenerative programme[64], ZQ^{RX}, in recognition that there are no hard and fast rules around regenerative farming and the programme will be viewed by buyers as a commitment to improvement across multiple business areas.

Nitrogen management

Oats are considered to be very effective at mopping up excess nitrogen (fertiliser and urine) which would otherwise leach through the soil profile following a winter crop grazed by cattle/sheep. Catch crops are effective in removing excess nitrogen from the soil but also provide additional cost-effective feed to the farm system.

A New Zealand study showed that oats as a catch crop, planted after a winter kale crop, led to a reduction in nitrogen leaching by 25%[65], which is consistent with other field trial results. A field trial in Illinois using oats as a cover crop, after corn, showed a fivefold reduction in N_2O emissions, also indicating a significant reduction in GHG emissions, decrease in residual soil nitrogen, and no negative effects on subsequent crop yields.

New Zealand trials (2018) showed that August sown oats produced 3.7TDM in 100 days at a cost of $0.15/kgDM[66], however, crop yields would have been significantly improved if taken through to the heading stage for whole crop silage. Figure 3 shows the biomass accumulation of oats sown in late June in Southland in 2017, which reached 14TDM by mid-December. Early spring sown oats has the flexibility of being harvested as green feed, whole crop silage of taken through to gain harvest.

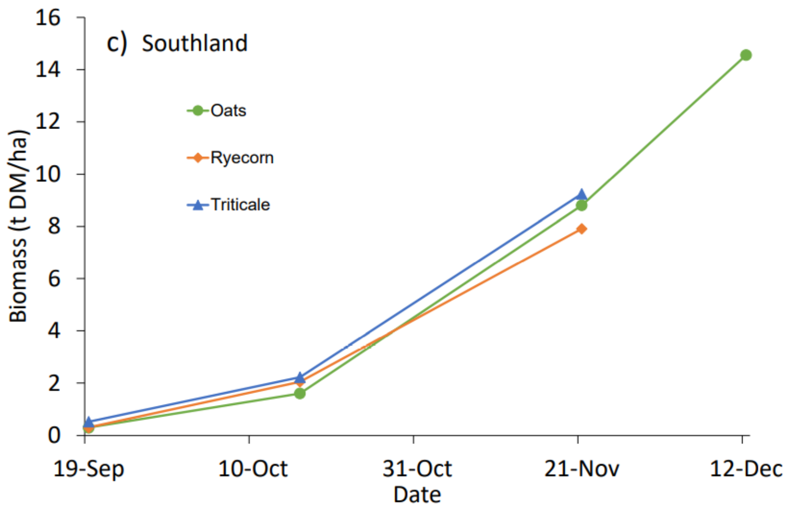
Figure 3 – Cumulative biomass of June sown oats grown in Southland in 2017[67]

[64] https://www.discoverzq.com/

[65] https://www.tandfonline.com/doi/full/10.1080/00288233.2017.1336103,

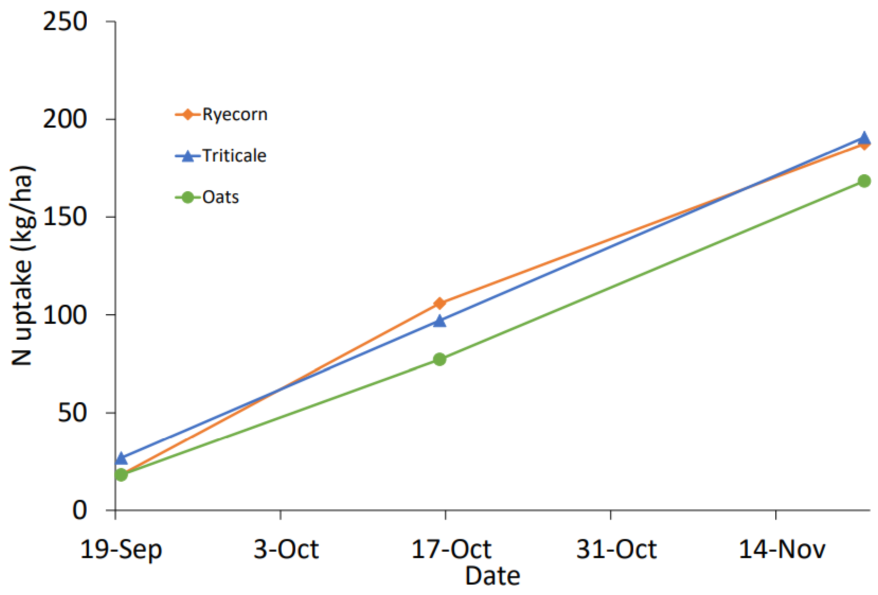
[66] Winter forages for reduced nitrate leaching, Guidelines for catch crops MBIE, 2018

[67] https://www.far.org.nz/assets/files/blog/files//f1f6b00f-b669-5ef0-8ecc-897f0da8deee.pdf



Uptake of nitrogen by oats catch crops can be as high as 150 kgN/ha in Southland soils as shown by trial data (Figure 4). This is supported by other trials[68,69] where nitrogen loss has been shown to be reduced by 50% using oat catch crops compared to fallow post winter grazing.

Figure 4 – Cumulative nitrogen uptake for June sown catch crops in Southland post crop winter grazing[70]



An MPI Sustainable farming fund project showed that early sown catch crops grown on commercial farms in Southland reached 10TDM/ha yields and captured 100-150 kgN/ha. The project also showed that best results were achieved when crops were sown as early as possible and with minimum tillage techniques[71].

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[68] Catch crops after winter grazing for production and environmental benefits

[69] Performance of Winter-Sown Cereal Catch Crops after Simulated Forage Crop Grazing in Southland, New Zealand

[70] https://www.far.org.nz/assets/files/blog/files//f1f6b00f-b669-5ef0-8ecc-897f0da8deee.pdf

[71] https://researcharchive.lincoln.ac.nz/bitstream/handle/10182/11744/Carey%20catch%20crops%20to%20mitigate%20loss%202019.pdf?sequence=1&isAllowed=y

Integrating farming systems and crop rotation management

Crop rotations have many benefits for cropping and livestock systems particularly with reducing incidence of pest and disease infestation of crops and animals and maintaining soil characteristics (physical and biological). Intensity and frequency of tillage have a significant impact on the rate of soil quality decline after cropping. Results from the Southland soil monitoring programme showed that on average the use of minimal tillage resulted in better soil structure and higher earthworm populations (Table 3).

Table 3 – Soil quality indicators under different tillage practices[72]

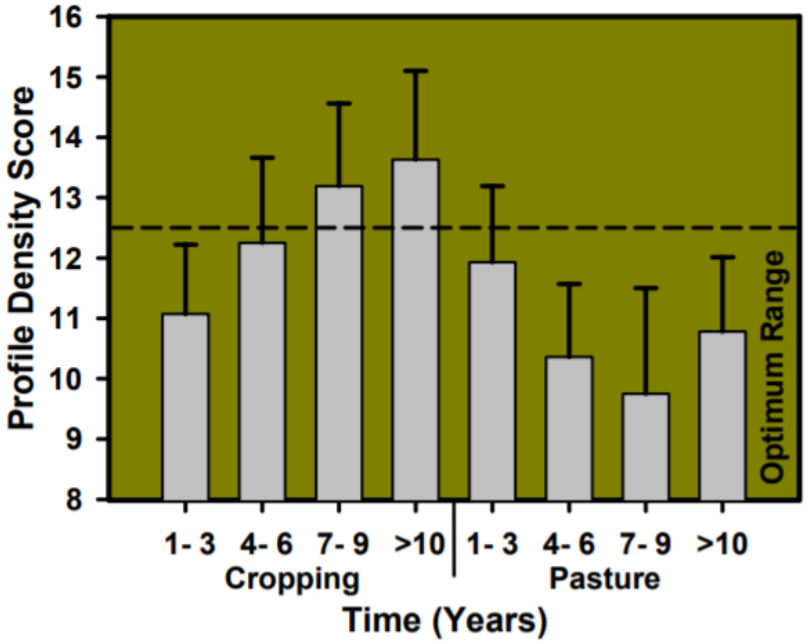
Management/Tillage Type	Aggregate Stability (%)	Structural Condition Score	Profile Density Score	Earthworms (No./m^2)
Pasture	94	4.1	10.5	1030
Minimum Till	70	2.8	11.8	266
Conventional Till	59	2.0	13.0	199
Intensive Till	48	1.5	14.3	94
Optimum range	60 - 100	2.5 – 5.0	8 – 12.5	> 200

For arable farming, rotations involving 8-10 years of cropping are not uncommon and are generally associated with a gradual decline in soil quality (physical and biological). Results from the Southland soil monitoring programme (Figure 5) showed soil conditions declined below optimum range after 6-7 years of continual cropping, however, improvements in soil quality occurred quite quickly to about 60% by year three of continuous pasture management[73].

[72] https://www.far.org.nz/assets/files/blog/files//070f33ba-e94c-534b-a73f-6c6cc771b420.pdf

[73] https://www.far.org.nz/assets/files/blog/files/070f33ba-e94c-534b-a73f-6c6cc771b420.pdf

Figure 5 – Relationship between time and soil structure under cropping or pasture in a mixed cropping rotation[74]



In support of an integrated farming system, general crop meta-analysis from North and South America has shown[75]:

- Strong positive production outcomes of crops grown following pastures;
- Enhancement of soil organic matter with perennial pastures, particularly in the surface soil;
- Improvement in water infiltration and water quality.

The benefits of using catch crops to improve environmental outcomes suggest that oats could be valuable tool for livestock farmers (dairy and sheep & beef) to mitigate negative environmental outcomes (N-loss & GHG emissions) for their farms while maintaining financial viability. There would need to be further investigation into crop rotation options when integrated into a livestock system, particularly with potential management limitations.

Greenhouse gas (GHG) emissions

There is contrasting evidence regarding the impact on farm profit when pursuing management strategies to reduce GHG emissions for cropping. Modelling in North and South American systems show that GHG emissions per kg DM decrease with increasing gross margin in grain and oilseed crops, suggesting that crop producers have economic incentives to reduce GHG emissions[76].

In a different study, a modelling exercise incorporating oats into a dairy system in Otago (7% of milking platform sown in oats) and showed that N_2O-loss increased by 2% and methane production increased by 1%[77]. However, the model was built around spring-sown oats and we believe there is likely to be greater environmental benefit within a dairy system from autumn-sown oats (which we may model as part of the larger Thriving Southland project, still to be determined).

[74] https://www.far.org.nz/assets/files/blog/files/070f33ba-e94c-534b-a73f-6c6cc771b420.pdf

[75] https://www.sciencedirect.com/science/article/abs/pii/S0167880913003265

[76] https://www.sciencedirect.com/science/article/abs/pii/S0308521X12000595

[77] Explore your options – Participatory research, Advanced research adoption project, Dairy NZ, MPI, Ag-research 2021.

Land use change from livestock to plants will reduce GHG emissions (particularly methane), where low emissions farming options (such as oat growing) can be incorporated into agricultural sectors with restrictions being imposed, such as dairy.

Data from multiple sources (Table 4, Figures 6 & 7) show that the intensity of GHG emissions from dairy, grain, sheep and beef and cropping systems are vastly different. These studies have determined the carbon footprints in different manners, so cannot be used as a strict comparison. However, they do indicate oats have a lower carbon footprint than livestock agricultural sectors.

New Zealand GHG mitigation modelling shows that the costs of mitigation may be significant for dairy farmers, with reductions in operating profit ranging between 2–8, 8–30, and 13–67% for GHG-e reductions of 10, 20, and 30%, respectively[78]. With this in mind, developing an integrated farm system which supports GHG mitigation and profitability is paramount. He Waka Eke Noa[79] is a primary sector climate action group designed to work with farmers to develop a framework to reduce agricultural emissions and build the agricultural sector's resilience to climate change.

Other strategies for reducing GHG emissions on farm can be achieved through management techniques which generate lower GHG outputs. For example, direct drilling and reduced tillage results in lower GHG emissions than conventional tillage, also noting that CO_2e emissions produced in the cultivation of oats are recorded as being lower in organic (regenerative) farming systems, both when converted to an area unit and when converted to a production unit[80, 81].

Comparative water use for plant milks versus cows' milk is also an issue for consumers (Figures 6 & 7). In Southland, where most water-use for crops is watered through rainfall, this is less of a concern.

[78] https://link.springer.com/article/10.1007/s10705-014-9608-y
[79] https://hewakaekenoa.nz/
[80] http://www.eemj.icpm.tuiasi.ro/pdfs/vol17/full/no4/16_368_Moudry_17.pdf
[81] https://www.sciencedirect.com/science/article/abs/pii/S0167880909001297

Figure 6. Environmental comparisons of different milk types[82]

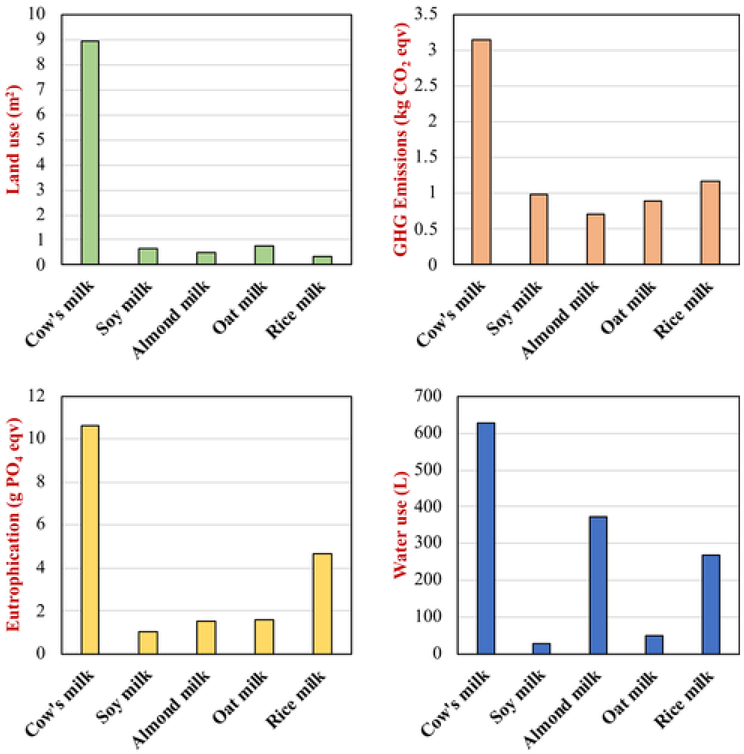
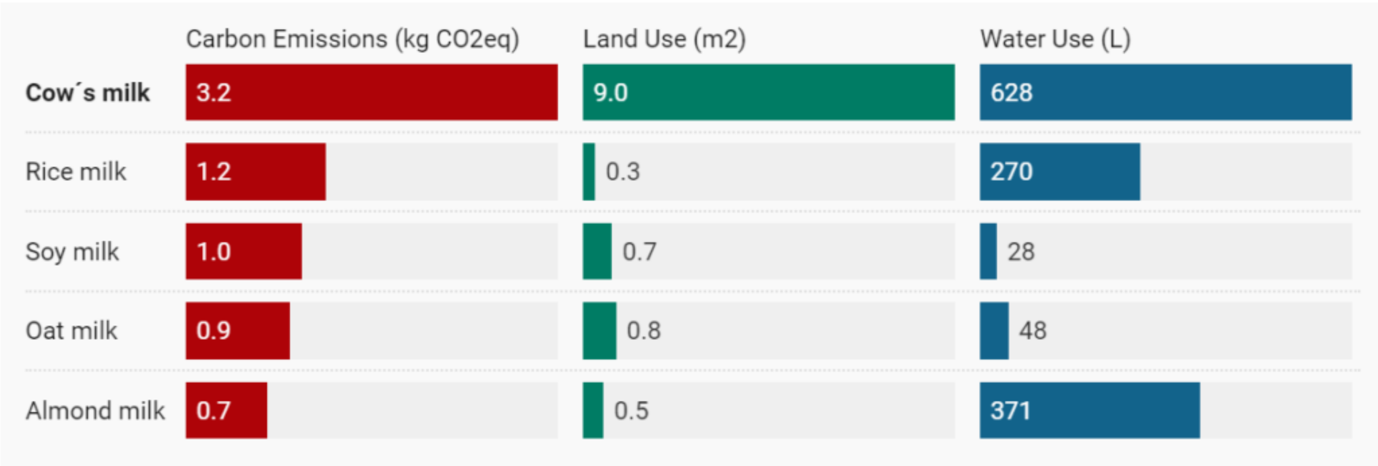


Figure 7. Environmental comparisons of different milk types (adapted[83]*)*



[82] https://onlinelibrary.wiley.com/doi/full/10.1111/1541-4337.12505

[83] https://science.sciencemag.org/content/360/6392/987.abstract

Table 4. Carbon dioxide equivalent (CO_2e) comparison across different farming systems, taken from multiple sources (note different methodologies have been used in determining CO_2e amounts, so this is an indicative (not direct) comparison only).

System	tCO_2e/annum	tCO_2e/cow	tCO_2e/ha	tCO_2/t product
Dairy	0.7 -5.8[84]	6.9	12.6 8.4 – 10.5[85] 9.6[86]	8.5 – 9.4[87] 3.1 – 18.8[88]
Oats			1.8[89]	
Cereal grain	0.2 - 0.34[90]		0.1 – 0.2[91] 2.8[92] 1.93[93]	0.04 – 0.15[94]
Beef			3.9 – 5.1[95]	
Sheep			2.8 – 4.3[96]	

[84] https://www.sciencedirect.com/science/article/abs/pii/S0377840111001659

[85] https://www.sciencedirect.com/science/article/abs/pii/S0377840111001647

[86] file:///C:/Users/kwilson.ABACUSBIOLTD/Downloads/Mitigation%20of%20on%20farm%20GHG%20Emissions%20-%20FINAL.pdf

[87] https://www.sciencedirect.com/science/article/abs/pii/S0377840111001647

[88] file:///C:/Users/kwilson.ABACUSBIOLTD/Downloads/Mitigation%20of%20on%20farm%20GHG%20Emissions%20-%20FINAL.pdf

[89] https://www.researchgate.net/profile/Hannu-Mikkola-2/publication/264892275_Greenhouse_gas_emissions_from_oats_barley_wheat_and_rye_production/links/546de5e60cf2193b94c60057/Greenhouse-gas-emissions-from-oats-barley-wheat-and-rye-production.pdf

[90] https://www.mpi.govt.nz/dmsdocument/4018/direct

[91] https://www.sciencedirect.com/science/article/abs/pii/S0377840111001647

[92] https://www.mpi.govt.nz/dmsdocument/4018/direct

[93] https://www.researchgate.net/profile/Hannu-Mikkola-2/publication/264892275_Greenhouse_gas_emissions_from_oats_barley_wheat_and_rye_production/links/546de5e60cf2193b94c60057/Greenhouse-gas-emissions-from-oats-barley-wheat-and-rye-production.pdf

[94] https://www.sciencedirect.com/science/article/abs/pii/S0377840111001647

[95] https://www.sciencedirect.com/science/article/abs/pii/S0377840111001647

[96] https://www.sciencedirect.com/science/article/abs/pii/S0377840111001647

Oat products

Health properties of oats

Nutritionally, oats have the highest protein level among commercially grown cereals, although lower than in foods derived from animals or legumes:

- 12-20% in the dehulled kernel;
- 9-15% in the whole grain[97].

Some wild diploid ancestors of modern oat varieties have protein levels greater than 20%, which is of relevance for future breeding, with the growing demand for plant-based protein (note as stated above, Plant Research NZ is selecting for breeding lines with greater protein percentage).

Oats are a good source of macronutrients, vitamins, minerals, and other phytochemicals, but the actual dietary intake of these depends on the part of the grain that is consumed and how it has been processed, i.e., endosperm vs. bran (Figure 8). Oats have a superior amino acid profile compared with other cereals wheat, barley, and maize, with higher levels of all the essential amino acids[98], although these are still very low in comparison with cows' milk[99,100,101].

β-glucans

Consumption of sufficient quantities of oat products has been shown to reduce host cholesterol and modulate cardiovascular disease risk. The effects are largely attributed to the gel-forming properties of oat β-glucans. β-glucans are strongly hydrophilic, non-starchy polysaccharides (Figure 9), which, when incorporated in food, alter functional characteristics such as viscosity, rheology, texture, and sensory properties.

β-glucans have been shown to influence immune response in humans, downregulate inflammatory pathways and exhibit antioxidant properties. β -glucan may also help to prevent sharp rises in blood sugar and insulin levels after eating a meal. It has been established that people with mildly elevated cholesterol levels have to consume at least 3g of β-glucan per day (~100 grams whole grain oats per day) to observe a significant reduction in their serum total- and low-density lipoprotein- (LDL) cholesterol levels[102].

Oat β-glucans have been shown to modulate the gut microbiota, particularly those bacterial species that influence host bile acid metabolism and production of short chain fatty acids, factors which are regulators of host cholesterol homeostasis.

β -glucans have also been shown to have a positive impact on weight control and contribute to bowel regularity. The fibre attracts water and increases the viscosity (or thickness) of digested food, which increases the volume of food in the gut and makes stool easier to pass. This also slows down digestion and the rate that nutrients are absorbed, which in turn increases satiety. Short-chain fatty acids produced

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[97] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4325078/

[98] Histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine.

[99] https://link.springer.com/chapter/10.1007/978-3-540-34389-9_5

[100] Amino acid composition of novel plant drinks from oat, lentil and pea (2000), Foods, 429.

[101] https://onlinelibrary.wiley.com/doi/full/10.1111/1541-4337.12505

[102] https://www.hsph.harvard.edu/nutritionsource/food-features/oats/

from bacteria that ferment beta-glucan fibres may also increase satiety through a chain reaction of events that regulate appetite hormones[103].

Figure 8. Structural representation of the oat grain presenting different oat tissues (i.e., the bran, germ and endosperm) and the nutrient distribution/organisation within these tissues[104].

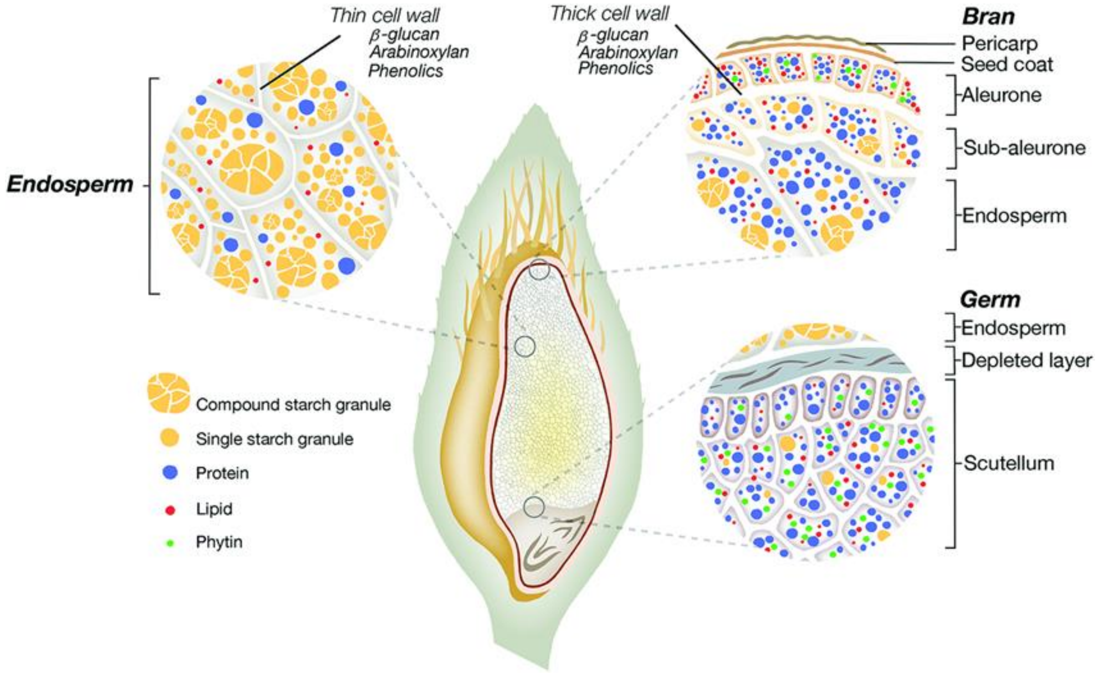
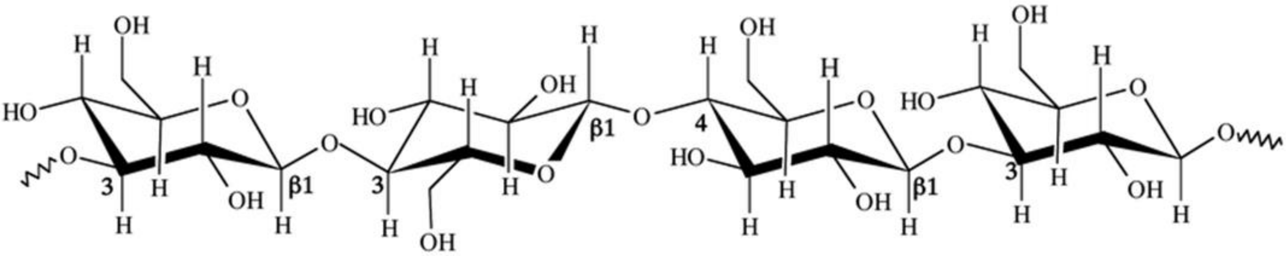


Figure 9 Chemical structure of oat beta-glucan showing the beta 1,4 and beta 1,3 glycosidically linked glucose polymer structure[105].



Properties of oat milk compared with other milks

Plant milks in general are nutritionally poor in terms of amino acids and protein amount as well as other nutrients such as calcium compared to cows' milk[106,107]. Bioavailability of nutritional elements in cows' milk is often superior to plant milks as well. Often plant milks are fortified with nutrients, especially

[103] https://www.hsph.harvard.edu/nutritionsource/food-features/oats/

[104] https://pubs.rsc.org/en/content/articlehtml/2018/fo/c7fo02006f

[105] https://www.researchgate.net/publication/227527409_Anti-Wrinkle_Therapy_Significant_New_Findings_in_the_Non-Invasive_Cosmetic_Treatment_of_Skin_Wrinkles_with_Beta-Glucan

[106] https://www.mdpi.com/2071-1050/11/18/5046/htm

[107] https://link.springer.com/article/10.1007/s00394-019-01936-3

calcium, to make them more comparable to cows' milk. Allergenicity of cows' milk is one of the factors driving consumers towards plant milks.

We have summarised the properties of the different milks in Table 5. It is worth noting, there are few direct comparisons of the various plant and cows' milk in the literature, so some of the data comes from different sources and should be indicative only when used for comparative purposes. We have not included data from livestock milk from other species, e.g. sheep and goats. There is evidence that sheep and goat milk have lower allergenicity because of lower lactose levels[108], although welfare and environmental issues still come into play regards consumer concerns.

Oat milk has more calories, carbohydrates and fibre than other plant milks such as soy and almond. Commercial oat milk is often fortified with vitamins A, D, B2 and B12 as well as minerals like calcium.

In terms of direct comparisons of the different milks post consumption, again, there is not much available in the scientific literature. One study compared plasma lipids, glucose, insulin and antioxidant status in humans after drinking oat, soy or cows' milk[109]. Oat milk consumption resulted in a reduction of plasma cholesterol (4%) and low-density lipoprotein (LDL) cholesterol (9%) levels as compared with baseline, but no changes in high-density lipoprotein cholesterol (HDL) and triglyceride values. Likewise, Soy milk consumption resulted in decreased LDL cholesterol (positive for health) concentrations. The only significant plasma lipid change observed during consumption of cow's milk was an increase in HDL cholesterol (negative for health). No consistent changes in body weight, fasting blood glucose, serum insulin and antioxidant status occurred after consumption of any of the milk treatments.

[108] https://www.sciencedirect.com/science/article/pii/B9780128097625000358

[109] https://www.karger.com/Article/Abstract/12736

Table 5. Plant milk comparison

Categories	Cows' milk	Oat milk	Soy milk	Coconut milk	Cashew milk	Hemp milk	Almond milk	Rice milk
Description	A nutrient rich liquid food produced by the mammary glands of mammals (cows). Primary source of nutrition for young mammals.	Derived from whole oat grains by extracting the plant material with water (often in an enzymatic process). Oat milk has a creamy texture and oatmeal-like flavour, is manufactured in various flavours eg sweetened & unsweetened, vanilla or chocolate.	Soy milk is produced by soaking and grinding soybeans, boiling the mixture, and filtering out remaining particulates. It is a stable emulsion of oil, water & protein. Its original form is an intermediate product of the manufacture of tofu.	Coconut milk is the liquid that comes from the grated pulp of a mature coconut. The opacity & rich taste of coconut milk are due to its high oil content, most of which is saturated fat.	Cashew milk is made from whole cashews & water. It has a creamy, rich consistency & is loaded with vitamins, minerals, healthy fats, & other beneficial plant compounds. Available in unsweetened and sweetened varieties.	Hemp milk is made by blending water & seeds from the hemp (*Cannabis sativa*) plant. It has an earthy, nutty flavour & a creamy consistency.	Almond milk is manufactured from almonds, has a creamy texture & nutty flavour. Some types or brands are flavoured in an imitation of dairy milk. It does not contain cholesterol, saturated fat or lactose & is often consumed by those who are lactose-intolerant.	Rice milk is sourced from rice whole grains produced through an enzymatic process. Commercial rice milk is typically manufactured using brown rice & brown rice syrup & may be sweetened using sugar or sugar substitutes, & flavoured by common ingredients, such as vanilla.
Health claims [110] [111] [112]	High in protein Processed for lipids, note milk from grass-fed is higher in long-chain fatty acids Calcium Vit A & D Minerals Lactose free & lower fat versions available via processing technology	Vegan, lactose- soy & nut free Gluten free but concerns re the avenin protein & cross-contamination with wheat, so often avoided by gluten intolerant consumers Often fortified with B vitamins and minerals Good for bone health ß-glucan content may lower blood cholesterol 100% wholegrain Can reach up to 36% of the daily recommended calcium intake Insulin regulation	Cholesterol free Low in saturated fat Lactose free Good source of protein, calcium, and potassium Can be fortified with Vit A, B-12 & D	Safe for most people with nut allergies Can be fortified to be a good source of calcium, Vit A and D Helps to improve the immune system and control blood pressure	High nutrient content May boost heart health Good for eye health May aid blood clotting May improve blood sugar control Good for skin May have anticancer effects Boosts immune health Lactose free	Commercial hemp milk is often fortified with calcium, phosphorus, and Vit A, B12 and D Most of the fat in hemp milk is unsaturated essential fatty acids, including linoleic acid (omega-6) and alpha-linolenic acid (omega-3) Provides protein that the body can easily digest and use Free of soy, lactose, and gluten Skin health & protection against heart disease	Low in calories Supplemented with calcium, Vit A and D to Lactose free High Vit E content	Least likely of all milk products to cause allergies Naturally sweeter than other milk products Fortified to be a good source of calcium, Vit A and D

[110] https://link.springer.com/article/10.1007/s13197-016-2328-3

[111] https://practicalgastro.com/wp-content/uploads/2019/07/Moo-ove-Over-Cow-Milk-Rise-of-Plant-Based-Dairy-Alternatives.pdf

[112] https://www.healthline.com/nutrition/best-milk-substitutes#TOC_TITLE_HDR_8

Categories	Cows' milk		Oat milk	Soy milk	Coconut milk	Cashew milk	Hemp milk	Almond milk	Rice milk
Nutritional composition selected brands (per 240mL cup)[113], *may be fortified	Energy (kcal)	122	130	100	70	60	101	41	130
	Protein (g)	8.0	4.0	8.0	0	1.0	2.0	1.0	1.0
	Fat (total g)	4.8	2.5	4.0	4.5	2.5	7.0	2.5	2.0
	Saturated fat (g)	3.0	0	0	4.5	0	0.5	0	0
	Carbohydrate (g)	11.7	4.0	8.0	8.0	9.0	8.0	4.0	27
	Fibre (g)	0	4.0	1.0	1.0	0	0	1.0	0
	Sugars (g)	12.4	3.0	6.0	7.0	7.0	6.0	3.0	14.0
	Calcium (mg)	293	451*	451*	101*	451*	300*	451*	300*
	Iron (mg)	0.05	1.8	1.1	0	0.4	1.1	0.7	1.1
	Magnesium (mg)	27	n/a	39	41	17	41	n/a	n/a
	Potassium (mg)	342	120	299	41	29	n/a	180	n/a
	Sodium (mg)	115	149	119	0	170	0.4	149	60
	Riboflavin (mg)	0.5	0.4	0.5	n/a	0.5	0.4	0.03	n/a
	Vitamin B12 (mcg)	1.3	n/a	3.0*	3.0*	3.0*	1.49*	n/a	0.5*
	Vitamin A (IU)	464	499*	501*	499*	499*	499*	499*	499*
	Vitamin D (IU)	120	101*	119*	101*	101*	101*	89*	101*
Size/value projection[114]	Volume of dairy market worldwide = 225 metric T in 2019, projected to grow to 234 MT by 2021 US$718.9B in 2019 – US$1032.7B by 2024[115] Rev forecast (Products): US$ 574.3B (2027)[116]		US$3.7 billion in 2019	US$15.25 billion by 2024	US$2711.9 million by 2026	US$229 million by 2027[117]	US$666.24 million by 2027[118]	US$13.25 billion by 2025	US$2.6 billion by 2024[119]
Expected compound annual	4.7% (2020-2027)		9.8-13.4% (2020-2027)	6.82% (2021-2026)	17% (2021-2026)	7-12.8% (2019-2029)	15.3% (2020-2027)	14.3% (2019-2025)	14% (2020-2025)

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113 https://practicalgastro.com/wp-content/uploads/2019/07/Moo-ove-Over-Cow-Milk-Rise-of-Plant-Based-Dairy-Alternatives.pdf

114 https://www.grandviewresearch.com/press-release/global-oat-milk-market

115 https://www.statista.com/statistics/502280/global-dairy-market-value/

116 https://finance.yahoo.com/news/574-3-billion-global-dairy-173000283.html#:~:text=The%20Global%20Dairy%20Products%20Market,CAGR%20during%20the%20forecast%20period.&text=Moreover%2C%20the%20Covid%2D19%20pandemic,further%20boosted%20the%20market%20growth

117 https://www.reportsanddata.com/report-detail/cashew-milk-market

118 https://www.databridgemarketresearch.com/reports/global-hemp-milk-market#:~:text=Hemp%20milk%20market%20is%20expected,forecast%20period%20of%202020%2D%202027.

119 https://www.statista.com/statistics/1063078/global-rice-milk-market-value/

Categories	Cows' milk	Oat milk	Soy milk	Coconut milk	Cashew milk	Hemp milk	Almond milk	Rice milk
growth rate (CAGR)								
Factors driving demand	Rising consumption of dairy products Shifting consumer preference from meat to dairy products for protein enrichment Easy availability of products Significant product sales through online distribution during the pandemic Various health benefits (rich in calcium, riboflavin, Vit D, Vit A, Niacin, Potassium, Phosphorus)	Growing understanding of benefits of oat milk Increasing vegan diet popularity Increasing case of milk allergies (lactose intolerance) Increasing environmental impact awareness (lower carbon footprint) Better tasting/ more versatile than some other plant-based milk products Rising disposable income in Asian markets More durable (longer shelf life)	Population growth Health-conscious lifestyle Rising disposable income of people Lactose-free Veganism[120]	Downstream applications Increasing prevalence of lactose intolerance Health benefits of coconut milk Good source of lauric acid which is stored by the human body and used as energy[121] Consistency and taste	Nutrients and proteins Health benefits against blood clotting, anti-cancer evidence Increases antioxidant defences, lowers cholesterol level Easy to digest and rich in omega 6 fatty acid Suitable for lactose intolerance Rapid urbanization and changing lifestyles	Surging number of lactose intolerant population Increasing preferences of plant based, nutritious, healthy, and vegan products among the consumers Rising need to protect environment as well as animals (very sustainable crop) Growing demand from cafes for preparation of coffees	The rising cases of lactose intolerance and hypercholesterolemia Increasing health consciousness among individuals (numerous health benefits) Shifting consumer preferences towards vegan diets.	Increasing prevalence of non-dairy milk products Rising adoption of vegan diets are resulting in manufacturers substituting ingredients high in lactose content with rice milk Low fat and low cholesterol
Market segmentation (Type & Application)	**T:** Full cream, light (50%), trim, organic (unpasteurized/ unprocessed), A2 milk **A:** Milk, cheese yogurt, butter, ice cream, other **D:** Hypermarkets/ supermarkets, convenience stores, online, others	**T:** Organic, conventional, flavoured (sweetened, unsweetened), plain **A:** Food, beverages (cartons, bottles, others) **D:** Supermarkets, hypermarkets, grocery stores, online retail, other	**T:** Plain sweetened and plain unsweetened **A:** Food products like dessert, cheese and snacks, beverages like cold-pressed milk, flavours including vanilla and chocolate	**T**: Liquid, powder, conventional, organic **Packaging:** Bottles, cans, pouches, others **A:** Food & beverage, household, cosmetics	**T:** Milk chocolate cashew, Cashew coffee nut milk, Dairy free cashew milk, Cashew chocolate milk, (Plain vs flavoured) A: Cartons, bottles, jars, bottles, cans **D:** Drink to go, takeaway, restaurant service, personal use, supermarket, convenience stores, vending machines	**T:** Unsweetened, low sugar **D:** Supermarket, Online store, Other	**T:** Original almond milk, vanilla almond milk, non-dairy almond milk **D:** Hypermarkets, supermarkets, convenience stores, food and drink speciality stores	**T:** Powder rice milk, Fluid rice milk Source: Organic, conventional **A:** Snacks, Bakery & Confectionary, Beverages **D:** Supermarket/ hypermarket, convenience stores, food specialty stores, online retailers, and others

[120] https://www.gminsights.com/industry-analysis/soy-milk-market

[121] https://marketresearch.biz/report/coconut-milk-market/

Categories	Cows' milk	Oat milk	Soy milk	Coconut milk	Cashew milk	Hemp milk	Almond milk	Rice milk
Key international companies	Nestle S.A. (Switzerland) Danone S.A. (France) Kraft Heinz Company (U.S.) Fonterra Co-Operative Group Limited (New Zealand) Royal Friesland Campina N.V. (the Netherlands) Dairy Farmers of America Inc. (U.S.) Arla Foods Amba (Denmark) Saputo Inc. (Canada) Dean Foods Company (U.S.) Parmalat S.p.A. (Italy) Sodiaal (France), Unilever N.V. (U.K.), Inner Mongolia Yili Industrial Group Co Ltd. (China), China Mengniu Dairy Co., Ltd. (Hong Kong), Lion Pty Limited (Australia), Bega Cheese Limited (Australia), Freedom Foods Group Limited (Australia), Megmilk Snow Brand Co., Ltd. (Japan).	Oatly AB THE BRIDGE S.R.L Minor Figures Otis Oat M!lk Danone SA Nestle SA PepsiCo Panos Brands LLC Pureharvest Sanitarium The Hain Celestial Group Inc. Chobani, LLC Califia Farms, LLC Earth's Own Food Company Inc Elmhurst Milked Direct LLC Happy Planet Foods Mooala Brands, LLC SunOpta Inc Vitasoy International Holdings Limited Arla Foods amba PACIFIC FOODS OF OREGON, LLC Rise brewing Quaker Oat Silk Oat Yeah Thrive market	Whitewave Foods Hain Celestial Eden Foods Stremicks Heritage Foods Organic Valley PUREHARVEST American Soy Products Pacific Natural Foods Panos Brands Sanitarium SunOpta Vitasoy International Holdings Bowin International Limited	Theppadungporn Coconut ThaiCoconut Asiatic Agro Industry PT. Sari Segar Husada Sococo Ahya Coco Organic Food Manufacturing Heng Guan Food Industrial Whitewave Foods Coconut Palm Group Betrimex Goya Foods Renuka Holdings HolistaTranzworld UNICOCONUT	Russell Stover Candies (US) So Delicious Dairy Free(US) Britannia Industries Ltd.(India) Milkadamia (US) Hain Celestial Group (US) Silk (US) Godiva (US) Nutpods (US) WhiteWave Services, Inc. Blue Diamond Growers Provamel Dream blends So Delicious Dairy Free Forager Project VITASOY Cashew Dream Alpro	Good Hemp Hudson River Foods Pacific Foods Milkadamia Ecomil The Fay Farm Healthy Brands Collective Drink Daily Greens Waska Farms Wild Harvest Organics Braham & Murray	So Delicious Dairy Free Silk Pacific Foods Milkadamia Califia Farms Alpro Sanitarium PUREHARVEST Australia's Own	Pacific Foods Vitasoy Whitewave Foods Dream Costco Wholesale Fine Japan Ecoideas SunOpta Freedom Foods Pure Harvest Competitive Landscape God Karma Foods, Inc The Trader Joe's Company Nature's Choice
Regions & consumption	More than 6 billion people consume milk and milk products around the world	North America accounted for the largest share of 41.4% in 2019	Asia-pacific dominates soymilk market, followed by Europe (UK and Sweden) and the US	North America, South America, China (73.81% of total global consumption volume)	Brazil, East and West Africa, Vietnam, India, Europe[123]	Japan, China, US, Canada Latin American, Middle Eastern & African regions expected to grow	Almond milk is prominently used in the APAC countries, especially India and China[124]	The Middle East, Africa, South America, and Asia Pacific are increasing consumers[125]

[123] https://www.cbi.eu/market-information/processed-fruit-vegetables-edible-nuts/cashew-nuts/market-potential

[124] https://www.grandviewresearch.com/industry-analysis/almond-milk-market#:~:text=Asia%20Pacific%20dominated%20the%20almond,players%20in%20almond%20milk%20market%3F

[125] https://www.databridgemarketresearch.com/reports/global-rice-milk-market

Categories	Cows' milk	Oat milk	Soy milk	Coconut milk	Cashew milk	Hemp milk	Almond milk	Rice milk
	Leading consumers are China, India and the US[122]							
Market restraints	Availability of cholesterol free substitutes Number of allergies in population increasing Environmental awareness increasing Animal welfare awareness	Lack of understanding and awareness about plant-based food and beverages Lack of product penetration and awareness about oat milk Competition with animal and other plant-based milks	Other non-dairy milk products more readily available Adoption among consumers is high for other milk varieties esp. across developed markets	Fluctuating prices of coconut Overconsumption can cause certain types of allergies High amounts of saturated fat can increase cholesterol levels and health/weight concerns of consumers	High price of cashews Low shelf life Nut allergies Lack of awareness around the product	More preference given to cow milk Increasing cases of hemp allergy Lack of awareness/ knowledge among consumers	Negative environmental impact (high water usage) Nut allergies	Low market penetration of the product and lack of awareness The presence of competitive products Overall, less nutritious than other available options
Carbon footprint (GWP) Kg of CO_2/L of milk Land use (sqm)	2.76 [126] Varies between 1.14 in Australia and NZ to 2.50 in Africa ~0.3kg of CO_2e per 200 ml glass Requires 9 times more land than plant alternatives 8.9 sqm per year for every L of milk[127]	~0.9kg CO_2e per L 200ml glass of oat milk is responsible for around 0.18kg of CO_2e 0.8 sqm of land use per L per year 80% less land is required to grow oats compared to dairy milk	3.28[128] a 200ml glass of soy milk is responsible for around 0.195kg of CO_2e 0.75 sqm of land use per L per year 1 calorie of milk protein requires 14 calories of fossil fuel energy to produce. In comparison, it takes 0.26 calories of	0.42 (about half of soy emissions) Little water and energy required compared to other alternatives	2 kg CO_2e to produce 1 kg or 2.2 pounds of tree nuts[129]		3.86[130] 200ml glass of almond milk is responsible for ~ 0.14kg of CO_2e 0.5 sqm of land per L per year	1.2[131] 0.3 sqm of land used per L per year

[122] https://worldpopulationreview.com/country-rankings/milk-consumption-by-country

[126] Plant-based Milks: A Review of the Science Underpinning Their Design, Fabrication, and Performance - McClements - 2019 - Comprehensive Reviews in Food Science and Food Safety - Wiley Online Library

[127] https://theconversation.com/which-milk-is-best-for-the-environment-we-compared-dairy-nut-soy-hemp-and-grain-milks-147660

[128] Plant-based Milks: A Review of the Science Underpinning Their Design, Fabrication, and Performance - McClements - 2019 - Comprehensive Reviews in Food Science and Food Safety - Wiley Online Library

[129] https://healabel.com/c-ingredients/cashew-milk

[130]

Plant-based Milks: A Review of the Science Underpinning Their Design, Fabrication, and Performance - McClements - 2019 - Comprehensive Reviews in Food Science and Food Safety - Wiley Online Library

[131] https://earth911.com/how-and-buy/good-better-best-the-climate-impacts-of-milks/

Categories	Cows' milk	Oat milk	Soy milk	Coconut milk	Cashew milk	Hemp milk	Almond milk	Rice milk
			fossil fuel to make 1 calory of milk from organic soybeans.					
Downside	Whole milk is high in calories and fat Many people are lactose intolerant Ethical concerns around modern dairy farming practices (animal welfare, environmental footprint) 270 mil dairy cows worldwide currently – require a lot of land area per unit of product	Not the best option for those who are gluten intolerant or are dealing with Celiac disease (contaminated equipment) Side effects could include skin breaking out, intestinal inflammation and digestive discomfort[132] Compared to cow milk: less protein, lower in calcium, higher in sugar and carbs Can be expensive	Common allergen for both adults and children Most soy produced in US comes from genetically modifies plants Land use - parts of the Amazon rainforest are being deforested specifically to produce soy plantations Note: 85% of soyabeans are used to feed animals and produce oil, rather than to make soy milk	Not a good source of protein Contains more fat than other plant alternatives (may induce high cholesterol) May contain carrageenan – may cause digestive issues in some people Threatening Bisphenol-A in canned products and high sugar levels	Very little protein compared to cow's milk Not good for people with nut allergies Can contain high amounts of sugar and calories Sodium is commonly added to cashew milk Price can be higher than other alternatives Concerns around ethical labour	High cost Low in calcium and protein (although sometimes fortified) Can be heavily sweetened as the Natural taste is not always pleasant	Not a good source of protein May contain carrageenan – may cause digestive issues in some people A lot of water is required to cultivate almonds – largely depends on freshwater irrigation	High in carbohydrates – not good for diabetes Not a good source of protein Watery consistency which does not make it ideal for baking and cooking. May contain oil and thickeners.

132 https://simplyoatmeal.com/oat-milk-disadvantages/#:~:text=Consuming%20oat%20milk%20if%20you%20are%20gluten%20intolerance,then%20straining%20the%20liquid%20for%20a%20creamy%20beverage

Market Insights

There are a range of new oat products, led by oat milk, which are attracting consumers within the health and wellness sector. A number of diverse health claims can be attached to such products (as aligned with what is discussed in the previous section) and these have already been approved by the European Union and the Food and Drug Administration (FDA) in the United States. This means oats can be used as a base product for functional food and beverages which offers considerable opportunities for New Zealand manufacturers (domestic and export).

International Market Potential

Total sales of plant-based milks reached $1.83B in the US between August 2018 and 2019. It is possible for the international plant-based industry to be worth $2.4B by 2024, however it is facing challenges with companies struggling to keep up with the scale required to supply the demand[133].

Rising consumer awareness about the health advantages of oat milk, increasing popularity vegan diet, and rising cases of dairy milk allergies are increasing product demand.

In addition, owing to the Covid-19 pandemic, sales are rapidly increasing as consumers become more aware of the need to improve their immune systems and plant-based milks are seen as healthy options for that.

Consumers are buying supplies in bulk due to lockdown in many major cities across the globe. Being shelf-stable, most of the oat milk brands can be stored for a longer duration than the other non-dairy milk products.

The environmental credentials of oat compared with other milk products is another major factor driving industry growth (Figures 6&7).

Demand for organic oat milk

Oat milk sourced from conventional farming systems accounted for the largest market share, over 71% in 2019, and is expected to remain dominant[134]. The organic source segment is expected to have the fastest compound annual growth rate (CAGR) (2020 to 2027) on account of increasing disposable income levels and growing consumer awareness about the perceived health benefits of organic products (Figure 10). In recent years, large-scale retailers, such as Target and Walmart, have been responsive to increased demand for organic oat milk.

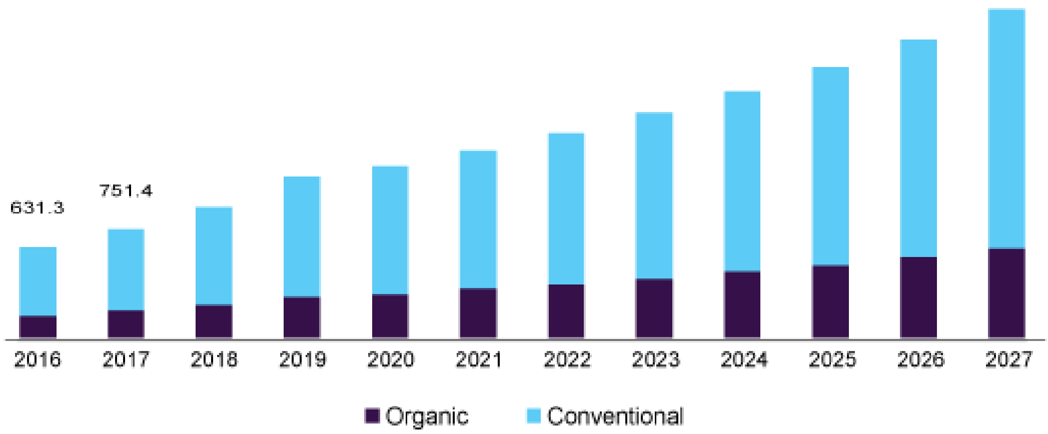
Improved standards of living, initiatives taken by government associations, and growing purchasing power of consumers are driving the market in emerging countries, such as India, China, and Brazil. The high price of organic oat milk products and lack of promotion is likely to hinder the organic segment growth in these markets.

Ultimately, price signals within the value chain will dictate the rate of organic milk production growth, particularly at the farm level where there are significant production challenges.

[133] https://www.grandviewresearch.com/press-release/global-oat-milk-market

[134] https://www.grandviewresearch.com/press-release/global-oat-milk-market

Figure 10. US oat milk market size, by source, 2016-2027 (USD million)[135]



New Zealand market

One in 10 New Zealanders say they are now vegetarian, or mostly meat-free[136]. The shift towards plant-based products in New Zealand is in-line with international trends.

The target market for oat milk products within New Zealand (and internationally) is medium to high income consumers. Consumers view oat milk as a cows' milk substitute and will assess the environmental impact of oat milk against cows' milk. One litre of oat milk can be made with a quarter of the land, water and emissions used for dairy milk[137], despite New Zealand being the lowest carbon international dairy producer[138].

Given there is a global movement to consume fewer products derived from livestock, and a New Zealand government initiative to increase agricultural value and reduce emissions, it is worth assessing new land-use options as to whether they can contribute to these goals.

Within New Zealand, supermarket chain Countdown, recently reported a surge in consumer demand for alternative proteins, with sales of dairy-free milk rising by 14% in the past six months, and dairy-free cheese sales by more than 300% (2019). Foodstuffs-owned, Pak 'n' Save, New World and Four Square, have also seen high growth in the plant milk category over the past year – almond milk sales were up by 32%, oat milk up by 26% and soy milk up by 7.8%[139].

When combined with cellular agriculture (meat and milk derived from cells), does this spell the end for dairy consumption? Fonterra media manager Philippa Norman stated "if we fast-forward 30 years, there will be two billion more mouths to feed around the world and dairy will be needed to feed them. We also know complementary nutrition sources will be required to meet this increased need for food, that's why we stay close to developments in that area[140]."

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[135] https://www.grandviewresearch.com/press-release/global-oat-milk-market

[136] https://static.colmarbrunton.co.nz/wp-content/uploads/2019/05/Colmar-Brunton-Better-Futures-2019-MASTER-FINAL-REPORT.pdf

[137] https://www.thebigq.org/2019/10/24/can-new-zealand-transition-to-a-plant-based-future/

[138] https://www.dairynz.co.nz/environment/dairy-sector-progress/nz-dairy-sectors-carbon-footprint/

[139] https://www.thebigq.org/2019/10/24/can-new-zealand-transition-to-a-plant-based-future/

[140] https://www.fonterra.com/nz/en/our-stories/articles/complementary-nutrition-what-it-means-to-us.html

In line with this thinking, the Southland move to oat production probably needs to align with the environmental benefits as much as the consumer demand, assuming returns are equivalent (to be determined).

Case studies

Oatly

https://www.oatly.com/int/

Oatly is a Swedish company which is the leading producer of oat milk on the market – mainly selling products in the United States. Oatly milk has gained market traction among coffee drinkers for its ability to froth (due to added canola oil) and among consumers for its health benefits and lower environmental impact (compared to other milks).

Sweden's traditional cows' milk production in 2018 was round 754,000 tons. In 1990, the Swedish consumed about 330lbs of cows' milk per person per year, compared to Americans at 233lbs per person per year. As cows' milk consumption grew so did lactose intolerance among consumers. This created the opportunity for plant-based alternatives in the market.

Oat milk was developed in the 1990s by Rickard Oste who studied as a food scientist at Lund University under the Professor known to have discovered the underlying cause of lactose intolerance in 1963.

Rickard Oste founded Oatly, with his brother, in 1994, but it took roughly 20 years for oat milk to gain traction.

Since 2015, cows' milk sales have dropped by ~3.4B dollars in the United States but are still much higher overall compared to plant-based alternatives. Between August 2018 and 2019 cows' milk sales were about $12B in the United States, whereas oat milk accounted for about $40 million dollars during that same time period (an increase from around $6 million the previous year – a 500% increase in market sales).

In 2018, Oatly generated more than $100 million in sales. There was a national shortage of oat milk in the United States in 2018 as the company struggled to meet consumer demand. A new CEO, Toni Petersson, joined the company in 2014 and rebranded the products, creating more variety in their products and completed a sustainability report in 2018 to demonstrate that oat milk is better for the environment than cows' milk[141].

When Oatly introduced its products to the US market in late 2016, they did so through one exclusive coffee partner, Intelligentsia, followed by chains of high-end speciality coffee shops in 2017. Their approach was to introduce the product in person rather than going though large grocery stores or supermarkets – they chose baristas to become their ambassadors.

The "new" milk quickly caught the attention of consumers as there was limited supply of the "exclusive product." At the end of 2017, oat milk was served in over 650 different locations and is now served in around 7,000 shops and 5,000 grocery stores across the United States.

In 2018, Oatly opened a 20,000 sqft facility in New Jersey and opened another in Utah in the spring of 2020. Oatly plans to expand to China next[142]. There are more coffee shops in Shanghai than there are in New York City.

Oatly's proprietary process involves combining whole oat groats with water and a natural enzyme blend. The enzyme breaks the oats down into liquid parts and Oatly then strains out insoluble fibre, leaving in the ß-glucans. Other companies use a mechanical breakdown process that involves blending and straining[143].

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141 https://www.oatly.com/uploads/attachments/ck16jh9jt04k9bggixfg6ssrn-report-the-climate-footprint-of-enriched-oat-drink-ambient-carboncloud-20190917.pdf

142 https://thebeet.com/oatly-announces-plans-for-the-worlds-largest-oat-milk-factory/

143 Which Plant-Based Milk Is Best for the Environment? (ediblebrooklyn.com)

A lot of Oatly's success is owed to their unique, honest, and clever marketing strategies – led by John Schoolcraft and Toni Petersson. They aim to run a more "humane" almost self-deprecating campaign and made sure every side of the milk carton has something to read with the hopes that consumers will pick it up and take it home with them.

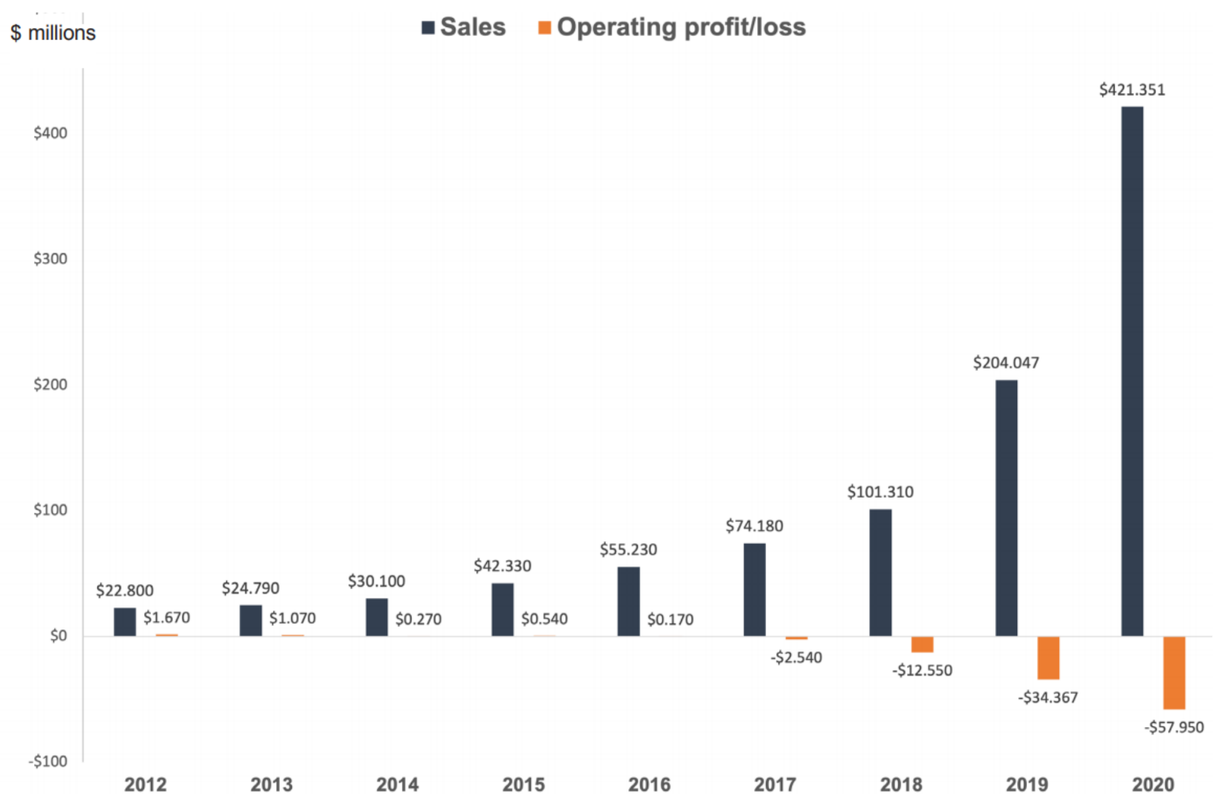
Oatly's growth comes at a cost

Oatly's immense growth has come at a cost. Their turnover is US$400M with a 30% gross margin, yet they are not profitable[144] and the last four years have seen losses grow (Figure 11). Their recent IPO has made their poor profitability more public. The different funding model highlights the gap between private equity and venture capital investors, who are willing to put money into growing, non-profitable companies - versus listed company investors.

There are also concerns regarding Oatly's pricing strategy and the fact that competition is intensifying and barriers to entry are low (Figure 12).

There are other challenges for Oatly as well. Their recent lawsuit against "PureOaty," a brother-sister start-up company, regards naming and branding (Oatly's brand shown in Figure 13), was unsuccessful and has raised considerable ire amongst the community. Prior to the lawsuit, negative online comments about Oatly were only 13%, whereas now, positive comments are only at 13%[145].

Figure 11. Oatly's financial performance sales[146] (US dollars).



[144] Mellentin, J. (May, 2021). Oatly: sales up, losses up, New Nutrition Business Volume 26, number 8.

[145] https://www.thedrum.com/news/2021/08/10/why-oatly-s-lawsuit-loss-goliath-wake-up-call

[146] Mellentin, J. (May, 2021). Oatly: sales up, losses up, New Nutrition Business Volume 26, number 8.

Figure 12. Competition in British supermarket milk sector (UK pound)

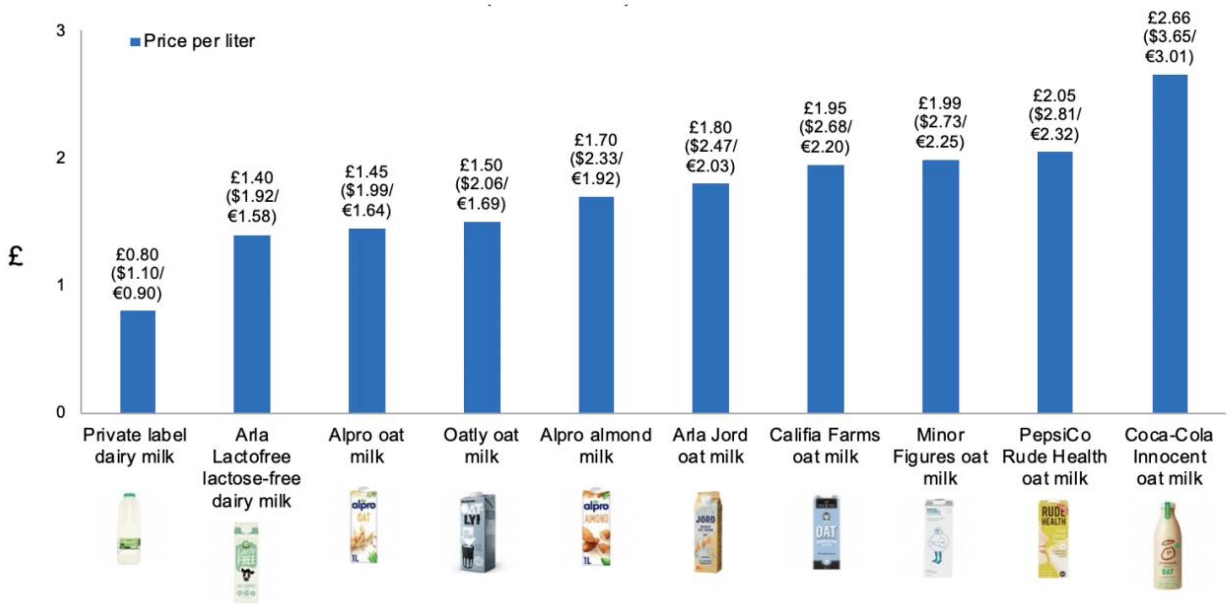


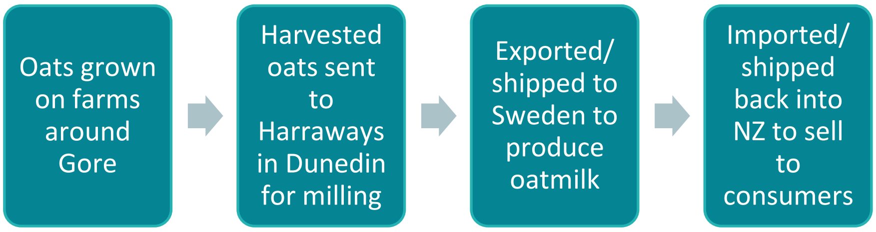
Figure 13. Marketing materials from Oatly

Otis Oat Milk[147]

[Otis Oat M!lk (otisoatmilk.co.nz)](otisoatmilk.co.nz)

The supply chain of New Zealand grown oat milk is complex, with raw product being moved from Southland to Otago for de-husking, then shipped to Sweden for enzymatic treatment and then back to New Zealand for sales and marketing (Figure 14).

Figure 14. Current supply chain of Otis oat milk



Otis timeline

- Launched in 2019, by founder Tim Ryan (Figure 15);
- Initially supplied milk to a few cafes in Dunedin – now sold in over 150 cafes throughout New Zealand;
- An Otis and New Zealand Trade and Enterprise (NZTE) study estimated it would cost $73.5 million to build a brand-new factory – outside investment is required;
- A "plant-plant" would be capable initially of producing 25 million litres of plant-based milk for export with options to include plant-based ice creams, creams, flavoured milks, and yogurts too (an alternative option would be for New Zealand to transition some of the large dairy factory infrastructure to dairy free);
- Updated detail on Southland's plans for the factory: https://whatsoninvers.nz/oat-milk-processing-will-soon-join-dairy-in-the-south/
- Pro-farmer brand and company – hence decision to build in the South Island;
- All of their oats are proudly kiwi grown in Southland and Otago, there are around 60-70 oat growers that produce the L5 variety, all these oats are processed at Harraways Mill in Dunedin, NZ (for other oat uses as well);
- Demand has exceeded expectations which has led to the desire to expand production capacity and distribution.
- New Zealand oats already have a great reputation all over the world;
- The prevalence of lactose intolerance in Asia is high, so there are export opportunities in line with our export markets for other agricultural products;
- Otis intends to build on the New Zealand branding to provide the provenance of clean and green, and work with NZ Trade to do this;
- A technical challenge in making the oat milk is to maintain good ß-glucan levels in the end-products.

[147] https://www.foodnavigator-asia.com/Article/2020/04/14/Turning-New-Zealand-plant-based-Otis-Oat-M!lk-wants-to-reduce-country-s-dependence-on-dairy

Figure 15. Tim Ryan, Founder of Otis Oat Milk[148]

Innovative Opportunities

We wanted to capture some of the innovative opportunities we found while reviewing the literature that are a little more leftfield but are worth mentioning.

1. Pea milk is the latest plant milk and is likely to be highly competitive health and production wise[149],[150].
2. Plant-milk mixes – in general, the plant milks do not stack up with cows' milk for nutritional quality. A plant milk mix might move closer to gaining a full amino acid profile[151], with the inclusion of other bioactives such as ß-glucan.
3. A company which owns an oat milk processing plant will likely assess multiple product options and functional foods and beverages. There are also options for including additional product lines to the supply chain related to waste. For example, we found a Bulgarian post-graduate thesis which examined oat milk processing and insect farming using the oat waste product (Figure 16)[152]; there are also examples of companies making milk from organisms such as fungi[153,154].

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148 https://www.viva.co.nz/article/food-drink/otis-oat-milk-kiwi-start-up-locally-grown-oat-milk-to-the-world/

149 https://thebeet.com/why-protein-packed-pea-milk-is-the-next-non-dairy-alternative-you-need-to-try/

150 https://www.washingtonpost.com/news/food/wp/2017/09/21/get-ready-for-pea-milk-it-doesnt-taste-like-peas-and-its-not-even-green/

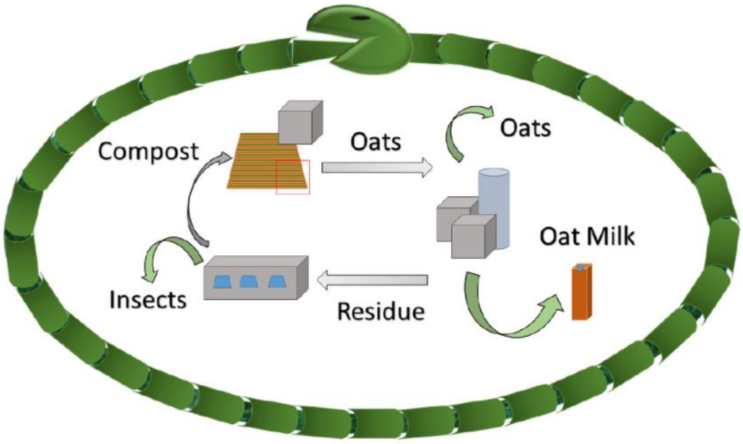
151 Amino acid composition of novel plant drinks from oat, lentil and pea (2000), Foods, 429.

152 https://www.researchgate.net/publication/339750094_Profitability_Analysis_of_Combined_Oat_Milk_and_Insect_Protein_A_case_study_on_a_Bulgarian_arable_farm

153 https://www.digitaltrends.com/cool-tech/perfect-day-vegan-flora-based-dairy/#:~:text=Artificial%20casein%20and%20whey%20genes,a%20new%20kind%20of%20dairy.

154 https://perfectdayfoods.com/

Figure 16. Integrating oat milk production with black soldier fly production[155]



Gaps in the literature

There is a reasonable amount of on-farm and production literature around oats, but very little pertaining to organic or regenerative production in the Southland area. We have mostly had to discuss material from other crops for that section.

Similarly, carbon and environmental data specifically for oats in Southland are quite limited and we have made quite broad comparisons because of this, which are indicative, but by no means exact.

We have included some market analysis for oat milk and comparison with other plant milks. Commercial data regards processing costs and methodologies were limited, and better information is probably available from those who have visited commercial plants, so we have chosen not to include oat milking processing information in this literature review, but we will address it in our main project report.

155 https://www.researchgate.net/publication/339750094_Profitability_Analysis_of_Combined_Oat_Milk_and_Insect_Protein_A_case_study_on_a_Bulgarian_arable_farm