FRNL ARABLE MONITOR FARMS

FINAL REPORT 2019

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Forages for Reduced Nitrate Leaching is a DairyNZ-led collaborative research programme across the primary sector delivering science for better farming and environmental outcomes. The aim is to reduce nitrate leaching through research into diverse pasture species and crops for dairy, arable and sheep and beef farms. The main funder is the Ministry of Business, Innovation and Employment, with co-funding from research partners DairyNZ, AgResearch, Plant & Food Research, Lincoln University, Foundation for Arable Research and Manaaki Whenua-Landcare Research.

FRNL arable monitor farms – End of project report

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SUMMARY

- This study used the **S**imple **C**rop **R**esource **U**ptake **M**odel operating within the **A**gricultural **P**roduction **S**ystems s**IM**ulator (SCRUM-APSIM) to quantify nitrate nitrogen (N) leaching over five to six years from three nominated arable farms in Canterbury.
- Leaching was mainly influenced by rainfall and soil type, but management practices determined the amount of soil nitrogen at risk of loss.
- Model estimates of crop N balance of the first one to two seasons of the study showed that soil N at risk of leaching was associated with excessive nitrogen fertiliser application, mineralisation of N-rich crop residues, extended fallow periods, and stony/sandy soil types.
- A re-simulation of the first one to two seasons to include growing oats as a catch crop in paddocks that remained fallow over autumn-winter, and a closer match of applied N fertiliser with crop N supply, resulted in reduced N leaching and increased gross margins.
- Results of further evaluation of model-estimated versus farmer-estimated N fertiliser rates on demonstration paddocks of each farm indicated potential to reduce fertiliser N without forfeiting yield.
- This programme has increased the understanding of N leaching risk factors and resulted in changes in management to optimise crop yield and minimise N losses.
- Model estimates indicate average whole-farm N leaching was less 20 kg N/ha in the last four seasons of the study.

1. BACKGROUND

The Forages for Reduced Nitrate Leaching (FRNL) programme has been undertaking research with the aim of improving the sustainability of New Zealand farming systems. The focus of the programme has been the development of management options to mitigate nitrogen (N) leaching based on detailed field experimentation and farm systems modelling. Participation of owners of nominated farms in the generation of the research questions, setting the direction of research and trialling the resulting N leaching mitigation options, has been a major component of the FRNL programme. This report focuses on simulation and demonstration study findings from three nominated arable farms.

2. METHODOLOGY

2.1. Simulation tool

The **S**imple **C**rop **R**esource **U**ptake **M**odel operating within the **A**gricultural **P**roduction **S**ystems s**IM**ulator (SCRUM-APSIM) was the tool selected for simulating arable farm systems participating in the FRNL programme. The crop model SCRUM (http://www.apsim.info/scrum) was developed using the mechanisms and coefficients of the OVERSEER crop model (Cichota et al. 2013) and so the two models have similar functionality with regard to crop processes. However, unlike OVERSEER, SCRUM includes dynamic water and N functions to allow production to decrease in the presence of water or N stress (Khaembah et al. 2015). Within APSIM, the nutrient and soil water modules function on a daily time-scale, allowing continuous simulation of changes in the N and water status in response to weather, management and crop uptake (Holzworth et al. 2014).

The generic and simple nature of SCRUM means new crops can be added easily. The crops grown on monitor farms that were added included chicory, fescue, Italian ryegrass, linseed, plantain, radish, fodder beet and turnips. Growth patterns were estimated from similar crops, and so were crop N concentrations unless published/unpublished research data were available. Also, research data from the Foundation for Arable Research (FAR) were used to modify crop N concentrations of wheat, barley and perennial ryegrass in SCRUM. This was important because crop N influences N uptake from the soil, which ultimately impacts the N balance of the system. Also, improvements were made to the water movement through the Templeton silt loam and Wakanui silt loam soils (see Section 2.2) using data collated by Plant & Food Research.

In addition to modification of crop parameters, regrowth of crops was introduced in SCRUM-APSIM to enable simulation of grazing and cutting managements of crops on the monitor farms.

2.2. Monitor farms

The farms modelled in this study are located at Wakanui, Mayfield and St Andrews. The Wakanui farm (481ha) is characterised by Wakanui silt loam, Wakanui clay loam and Templeton silt loam soil types. The Mayfield farm (522ha) has four soil types - Templeton silt loam, Wakanui silt loam, Lismore stony silt loam and Eyre stony sandy loam soils. The St Andrews farm (137ha) is part of a mixed arable-livestock block. The arable block is dominated by Claremont soil.

2.3. Arable farm initialisation in SCRUM-APSIM and assumptions

The Wakanui and Mayfield farms were modelled for six seasons (2013-2019), while the St Andrews farm was modelled for five seasons (2014-2019). A New Zealand season was defined as the 12 months from 1 April to 31 March. At Wakanui, soil mineral N contents determined from samples taken to a depth of 60cm from four representative paddocks were used to estimate initial soil N levels across the farm. Soil mineral N measurements were not available for the other monitor farms and therefore, initial soil N was estimated from paddock history. In view of these estimations, the first season was considered a ‘spin up’ period to allow the soil conditions to stabilise in the model. Therefore, results are reported from the second season onwards.

Farmers used both quick- and slow-release N fertilisers. The slow-release function is not yet implemented in the model, and so quick release is assumed at all times.

2.4. Baseline and alternative simulations

The climate data used in simulations were obtained from the National Institute of Water and Atmospheric Research stations (NIWA 2019) closest to the farm. Mean monthly temperature and monthly total rainfall over the seasons are shown in Fig. 1 (Wakanui and Mayfield) and Fig. 2 (St Andrews). Soil descriptions for each farm were obtained from the S-map soil data (SMAP 2017). Crop management data were obtained on the online management systems ProductionWise (https://www.productionwise.co.nz) or Agworld (https://agworld.co.nz) used by monitor farmers. At Mayfield and St Andrews where crop residues and catch crops were grazed, N returned in urine and dung was estimated in the model. The amounts of manure and urine returned were estimated using the procedure described by Pleasants et al. (2007) and Shorten and Pleasants (2007). There was no grazing at Wakanui. Drainage and N leaching model outputs were estimated at the depth of 150cm of the soil profile. At St Andrews, drainage and N leaching were also generated at the top 60cm to allow comparison with the dairy part of the farm modelled by the OVERSEER model (Wheeler et al. 2006). Evaluated outputs were drainage, N leaching and residual soil N at harvest.

For Wakanui and Mayfield, alternative simulations aimed at mitigating N leaching were developed for the 2014/15 and 2015/16 seasons. The mitigation options tested were (i) sowing a catch crop (oats) during the fallow period and (ii) reducing fertiliser N rates without penalising production. Increases in gross margins from lowering the fertiliser N input and sale of oats were estimated. An establishment cost of New Zealand dollar ($) 190/ha and sale price of $0.22/kg dry matter (DM) for oats was assumed.

2.5. Demonstration paddocks

As part of the monitor farm study, one or two paddocks on each farm were selected and divided into two sections to demonstrate crop performance using farmer- and model-estimated fertiliser N application rates in the 2017/18 season. Evaluated crops were barley (Wakanui and Mayfield) and Oats (St Andrews). SCRUM-APSIM fertiliser N rate calculations were based on estimated crop yield (provided by the farmer), long-term average climate data (NIWA 2019), and soil mineral N (0-90cm) and mineralisable N (0-15cm) measured prior to sowing. The final grain yield was estimated from plant samples harvested from 0.25-m^2 quadrats. Demonstration paddocks were simulated again using actual yield, crop management (fertiliser N input, irrigation) and climate data, to estimate N leaching and residual N.

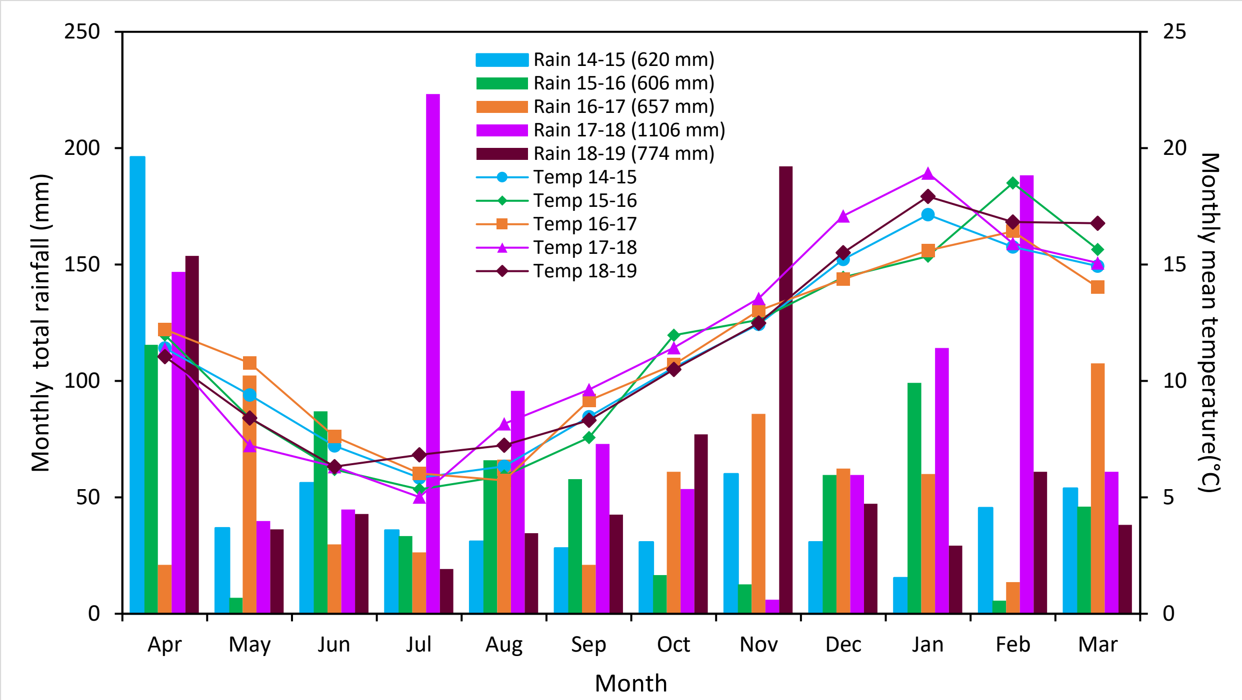

Figure 1: Monthly total rainfall and mean temperature obtained from the Lincoln Broadfield weather station (National Institute of Atmospheric Research – NIWA, 2019). Data from this weather station were used in the Wakanui and Mayfield simulations.

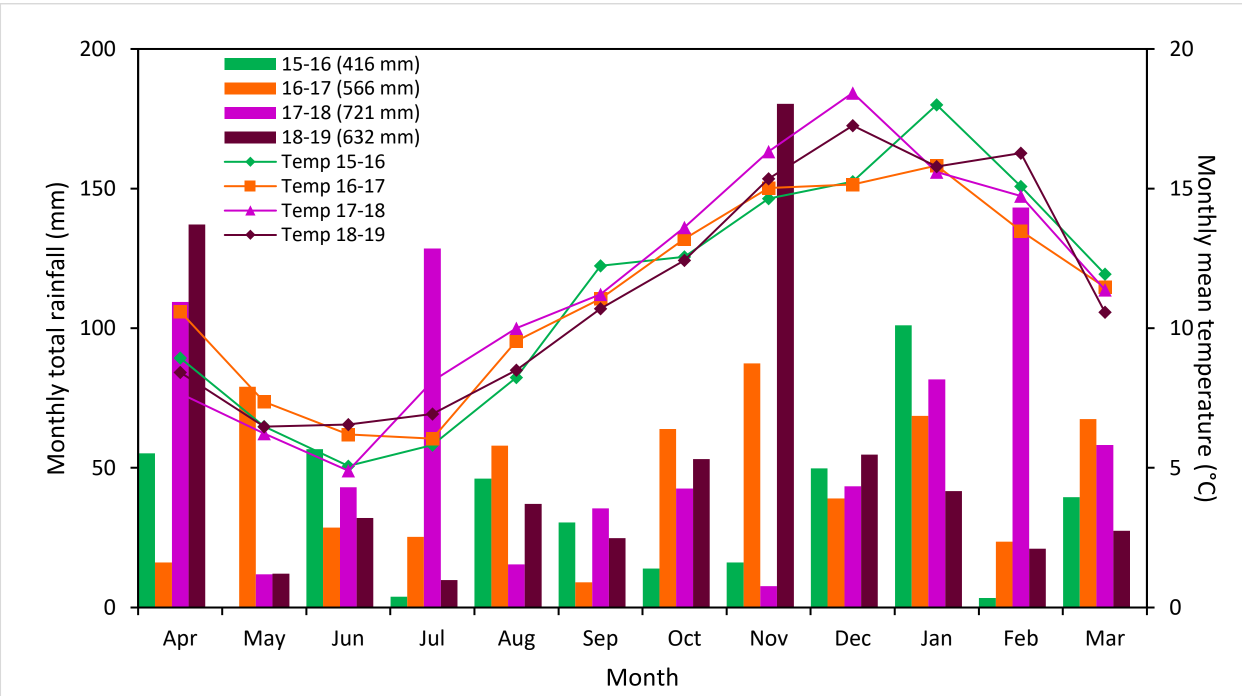

Figure 2: Monthly total rainfall and mean temperature for the virtual climate station nearest to St Andrews, obtained from the National Institute of Atmospheric Research – NIWA (2019). These data were used in the St Andrews simulations.

3. RESULTS & DISCUSSION

Model estimates of N balance and farm management from the 2014-15 to 2017-18 seasons were discussed in annual progress reports. Some findings were documented in a conference paper (Khaembah & Horrocks 2018). This end-of-project report includes results of the final season (2018-19) of the programme, and builds on the discussions of previous seasons. Overall, results have shown that leaching is mainly influenced by rainfall through its impact on drainage, but farm management practices determine the amount of soil N at risk of leaching. Results are summarised below.

Modelling outcomes of the first two seasons of the study identified a number of factors that increased the amount of leachable soil N. These were (i) application of N fertiliser in excess of crop N requirements, (ii) mineralisation of N-rich crop residues, (iii) paddocks remaining fallow during the high N leaching risk period (autumn-winter) and (iv) “leaky” soils e.g. the free-draining Eyre and Lismore soils. Leaching was greater when at least two of these factors were in play. For example, excessive N application to spring-sown crops resulted in high residual soil N at risk of leaching if no crops were sown after the summer harvest to take up the N. Similarly, mineralised N from residues retained in paddocks was available for leaching if there was no vegetation to take up water/N and reduce drainage/leaching. A re-run of benchmark simulations with adjusted (reduced) fertiliser N application to match crop N demand without affecting yield and/or growing of catch crops (as detailed in Section 2.4) resulted in a reduction in N leaching. These findings encouraged farmers to modify management in subsequent seasons. Demonstration paddock results supported model indications of lower N fertiliser inputs and greater N use efficiency that translated into greater farm profitability and reduced N footprint.

Figs. 1 & 2 show that, on average, annual rainfall increased over the evaluated seasons with the 2017-18 being the wettest season. Rainfall distribution varied among seasons, but significant amounts were recorded in autumn-winter. The heavy rainfall in 2017-18 resulted in high drainage events at Wakanui and Mayfield, but whole-farm average N leaching was less than 20kg N/ha (Tables 1a & 2a). These low leaching values resulted from reduced fertiliser N applications (Tables 1b & 2b) and reduced farm area and period in fallow over the two previous seasons (Figs. 3 & 4). Based on the 2014-15 data, the model estimated leaching reduction of 11–72% over subsequent seasons (Tables 1a & 2a).

At St Andrews, the average N leaching values generated at 150cm depth were marginal, ranging from 0 to 7.4 kg N/ha (Table 3a). These low figure reflect the low estimated drainage values because the farm is dominated by the poorly drained Claremont soils (SMAP 2017). Also, farm records show that most paddocks were sown in crops soon after completion of grazing and harvesting events (Fig. 5), allowing the utilisation of residual soil N and N returned in manure and urine. Like Wakanui and Mayfield, St Andrews farm records showed a reduction in average N applied over the studied seasons.

The association of slow water percolation with heavy clay soils like the Claremont soils present on the farm prompted assessment of denitrification and run-off as additional pathways of N loss. Results indicated whole-farm average denitrification losses of 0.6, 1.2, 5.5 and 9.5 Kg N/ha in 2015-16, 2016-17, 2017-18 and 2018-19, respectively. Estimated run-off over these seasons was, respectively, 1.7, 0.8, 46 and 33mm. These model estimates indicate an association of wet heavy clay soils with increases in denitrification and run-off. The patterns observed here are supported by literature (e.g. van der Salm et al. 2007). However, denitrification and run-off have not been validated in SCRUM-APSIM and so the results should be considered indicative only.

Nitrogen leaching and drainage estimates generated at a soil depth of 60cm were greater than those estimated at 150cm depth, but there was similarity in patterns across seasons (Tables 3a & b). Greater values of N leaching and drainage at 60cm are expected because most crops grown on the farm have deep roots that allow water and N extraction in layers that are deeper than 60cm.

4. CONCLUSION

This modelling study quantified drainage and N leaching from a sample of arable farms in order to establish a good understanding of factors affecting N loss by leaching, and some management options to mitigate these losses. The results support earlier conclusions that rainfall is the leading factor affecting N leaching, but that farm practices determine the quantity of N at risk of loss. This study tested and demonstrated two management strategies that can reduce the amount of soil N available for leaching: calculating fertiliser N requirements with a recommendation system that accounts for soil mineralisation, and sowing catch crops immediately after the summer harvest to mop up residual soil N or N mineralised from soil organic matter and crop residues. The demonstration paddock study results indicated that there is potential for reduction of fertiliser N input without yield penalties.

Table 1a: SCRUM-APSIM estimates of nitrogen (N) leaching and drainage at Wakanui over the 2014-19 cropping seasons. A season is described as the 12 month period from 01 April to 31 March. Drainage and leaching were generated at a soil depth of 150cm.

Paddock ID	Leaching (Kg N/ha)					Drainage (mm)				
	2014-15	2015-16	2016-17	2017-18	2018-19	2014-15	2015-16	2016-17	2017-18	2018-19
RH1	39.6	23.0	5.8	18.0	5.2	207	213	62	248	171
RH2	18.2	4.3	0.2	9.2	37.4	237	338	10	337	279
RH2A	10.7	23.0	0.1	31.1	3.0	386	212	1	513	112
RH3	7.6	20.7	26.2	30.8	7.2	208	135	73	485	239
RH4	74.2	48.9	0.3	27.7	4.0	255	223	2	460	205
RH5	7.2	15.2	1.6	18.2	21.5	400	209	24	218	196
RH6	51.6	5.4	4.7	21.8	5.0	333	60	39	349	61
RH7	18.6	7.9	4.4	20.0	6.9	178	75	33	263	141
RH8_12	79.2	9.8	9.2	41.5	51.0	402	186	167	429	187
RH9A	13.7	4.9	2.5	31.5	15.9	256	86	70	333	191
RH9B	14.3	8.4	7.7	24.8	13.5	293	111	21	491	183
RH10	53.3	10.2	3.6	7.9	20.5	416	262	47	312	289
RH11A	8.9	7.8	45.9	31.1	14.8	160	137	132	398	151
RH11B	8.9	21.8	54.5	43.6	21.2	160	149	133	323	146
RH13	34.9	19.1	71.3	39.6	7.2	263	141	151	316	139
RH14	7.7	30.3	4.3	12.4	6.8	172	300	202	374	128
RH15	60.5	26.8	10.3	15.6	26.8	288	283	45	337	201
RH16	9.0	0.8	0.0	8.1	22.9	146	11	0	310	126
RH17	24.7	51.5	1.6	4.0	14.8	227	303	14	381	121
RH18	6.3	2.7	0.6	13.4	14.7	189	59	11	431	124
RH19	24.6	1.1	4.0	8.5	14.4	149	85	69	423	238
RH20	56.0	7.4	0.5	7.6	7.1	528	137	50	474	134
RH21	28.1	52.6	5.9	11.5	4.8	129	251	125	236	109
Whole-farm average	**33.7**	**16.2**	**9.5**	**19.5**	**16.9**	**284**	**178**	**71**	**384**	**173**

Table 1b: Fertiliser nitrogen (N) leaching and SCRUM-APSIM estimates of N uptake by crops in rotation at Wakanui over the 2014-19 cropping seasons. A season is defined as the 12 month period starting from 01 April and ending on 31 March.

Paddock ID	Applied fertiliser (Kg N/ha)					Nitrogen Uptake (Kg N/ha)				
	2014-15	2015-16	2016-17	2017-18	2018-19	2014-15	2015-16	2016-17	2017-18	2018-19
RH1	287	95	0	–	0	342	101	125	–	80
RH2	268	189	253	209	57	358	117	357	180	176
RH2A	340	182	112	94	203	258	254	199	220	251
RH3	266	373	111	179	141	229	357	149	275	193
RH4	19	94	65	114	90	73	215	157	108	148
RH5	321	79	304	151	96	234	80	343	230	171
RH6	290	15	304	108	191	156	222	403	230	234
RH7	377	57	130	172	57	345	265	173	203	140
RH8_12	216	150	146	283	268	151	150	130	347	341
RH9A	63	341	124	280	81	73	352	210	333	134
RH9B	134	341	0	280	117	132	353	134	317	125
RH10	182	169	396	–	96	141	109	225	–	122
RH11A	165	341	111	15	224	223	349	191	44	317
RH11B	186	341	111	122	57	165	349	181	120	265
RH13	219	341	111	72	257	264	358	236	161	328
RH14	272	205	131	128	192	331	165	140	267	315
RH15	157	150	258	98	100	98	116	404	138	142
RH16	327	249	184	118	212	335	326	258	125	314
RH17	230	182	253	158	110	355	80	348	102	310
RH18	331	58	181	118	212	343	218	219	100	323
RH19	202	92	230	200	40	234	64	238	212	139
RH20	368	239	0	168	23	265	257	60	233	68
RH21	203	0	230	188	185	266	200	273	254	267
Whole-farm average	**248**	**183**	**167**	**161**	**129**	**238**	**205**	**217**	**198**	**210**

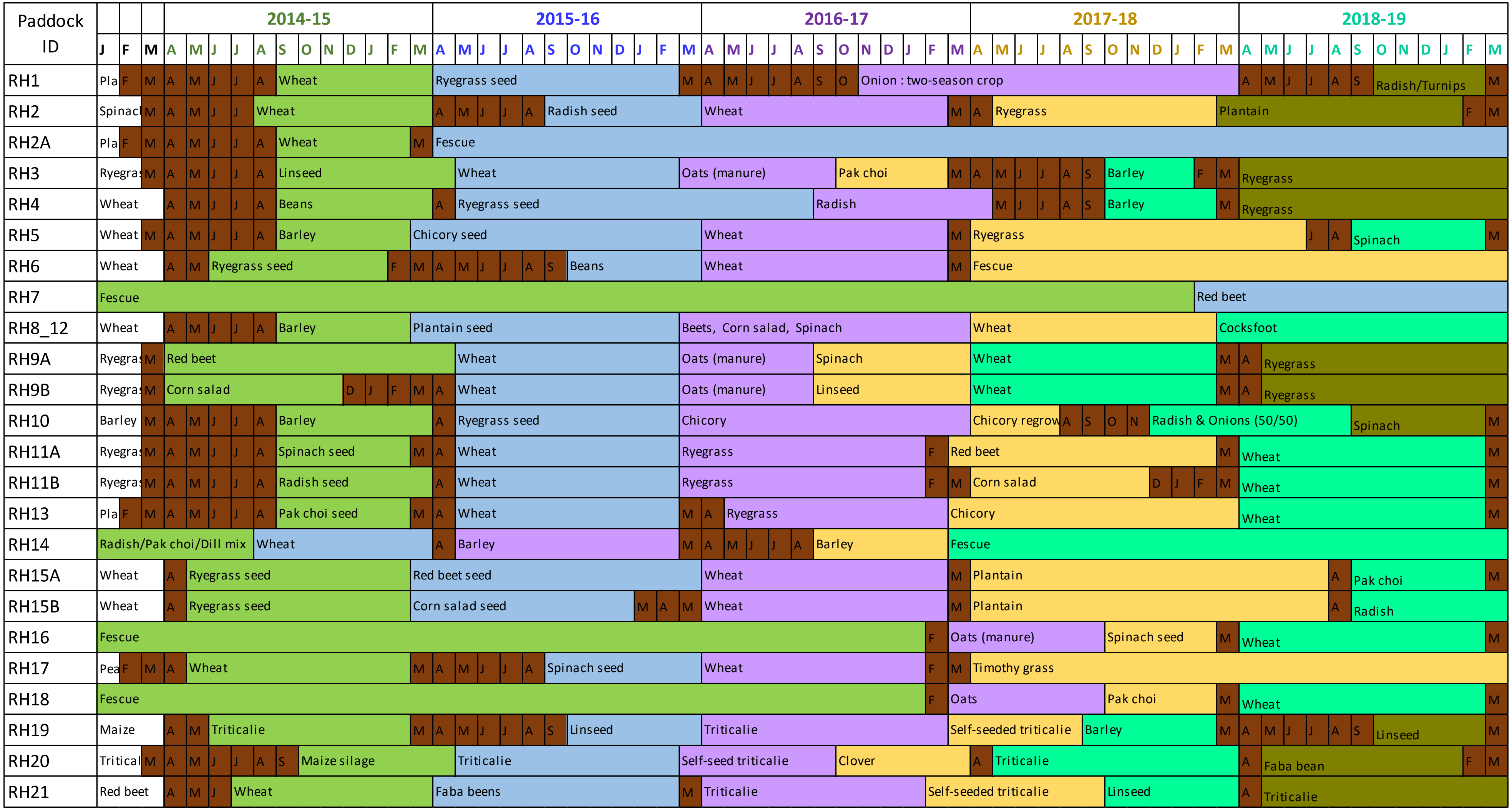

Figure 3: Wakanui crops in rotation over the 2014-19 cropping seasons. A season is the 12 month period starting on 01 April and ending on 31 March. Fallow periods are indicated by brown cells.

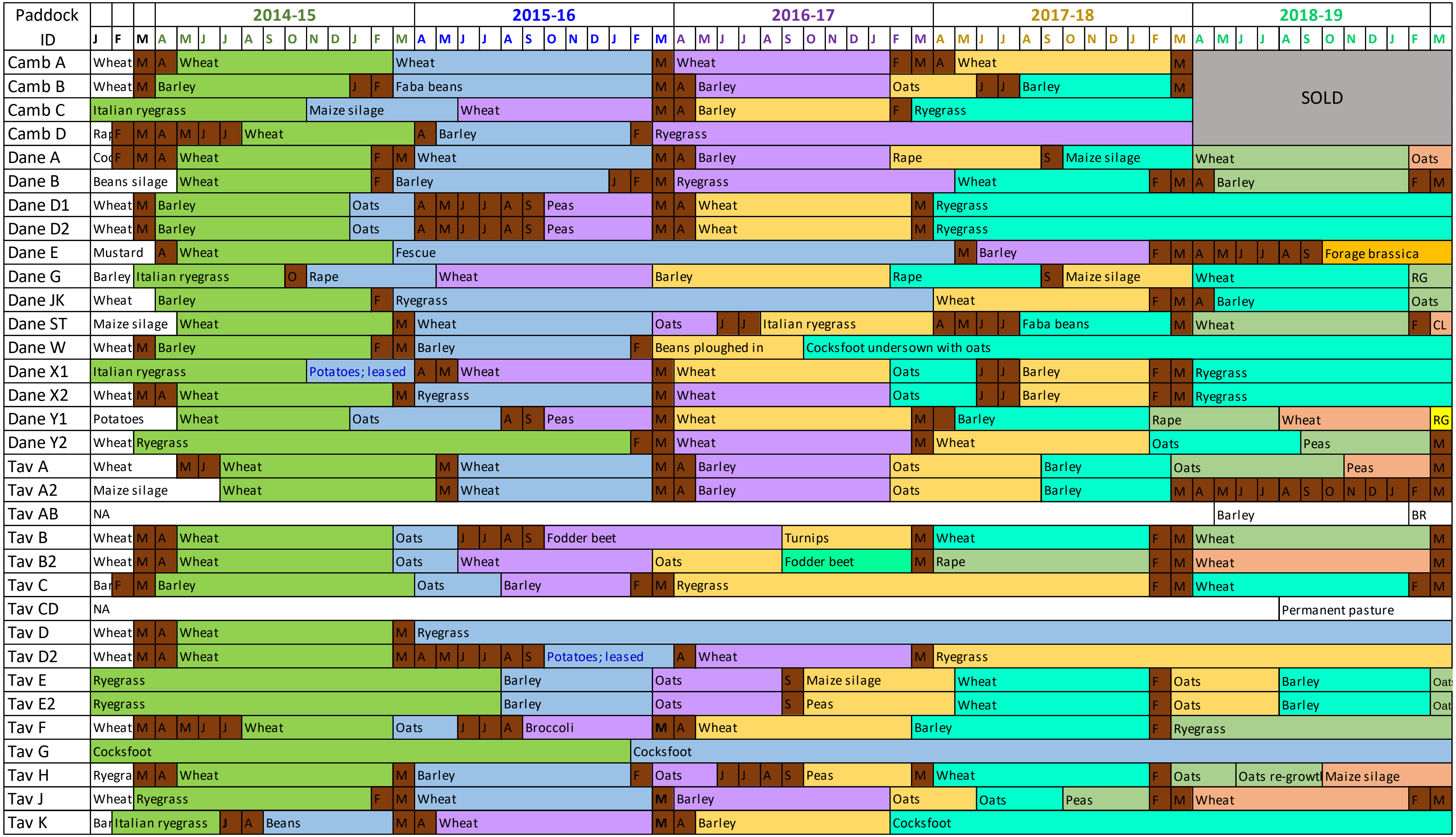

Figure 4: Mayfield crops in rotation over the 2014-19 cropping seasons. A season is a 12 month period starting on 01 April and ending on 31 March. Fallow periods are indicated by brown cells.

Table 2a: SCRUM-APSIM estimates of nitrogen (N) leaching and drainage at Mayfield over the 2014-19 cropping seasons. A season is described as the 12 month period from 01 April to 31 March. Drainage and leaching were generated at a soil depth of 150cm.

Paddock ID	Leaching (kg N/ha)					Drainage (mm)				
	2014-15	2015-16	2016-17	2017-18	2018-19	2014-15	2015-16	2016-17	2017-18	2018-19
Camb A	45.8	22.1	8.6	13.5	-	271	167	144	351	-
Camb B	10.5	3.9	17.7	22.3	-	240	60	125	425	-
Camb C	53.5	9.2	22.7	32.2	-	316	97	260	442	-
Camb D	18.5	13.5	3.4	16.1	-	222	160	50	266	-
Dane A	16.3	14.3	0.4	20.9	9.4	177	156	21	317	160
Dane B	17.6	17.3	6.2	31.5	15.3	155	129	48	333	227
Dane D1	6.8	1.9	2.9	22.4	16.7	305	90	56	292	148
Dane D2	7.4	1.9	3.0	28.3	11.4	305	77	52	335	124
Dane E	23.6	7.0	0.2	27.9	5.9	197	44	2	264	273
Dane G	19.1	4.4	3.0	24.1	13.7	270	99	45	357	307
Dane JK	13.5	3.4	0.0	16.5	24.0	255	70	0	328	224
Dane ST	19.4	13.2	6.3	10.8	9.2	221	135	48	328	151
Dane W	38.2	19.1	24.9	29.6	4.5	226	91	110	355	127
Dane X1	57.2	1.8	0.7	5.6	10.8	565	66	22	296	313
Dane X2	14.6	2.5	0.6	4.9	14.2	324	78	17	410	306
Dane Y1	19.6	3.9	1.5	4.4	7.7	256	80	31	409	246
Dane Y2	22.2	8.2	0.8	13.2	15.4	216	74	7	282	219
Tav A	38.5	7.9	15.0	11.6	8.6	326	139	160	393	322
Tav A2	7.7	3.0	13.5	11.4	10.0	196	125	165	405	435
Tav AB	-	-	-	-	10.1	-	-	-	-	265
Tav B	6.4	1.7	0.0	24.3	15.1	246	133	0	292	235
Tav B2	5.4	6.3	13.8	9.1	5.9	371	348	234	259	135
Tav C	19.2	1.3	0.1	5.8	3.6	246	45	8	242	126
Tav CD	-	-	-	-	4.3	-	-	-	-	134
Tav D	6.1	1.2	2.0	14.0	13.9	232	71	236	327	123
Tav D2	6.1	2.7	1.1	32.3	16.3	232	146	30	293	162
Tav E	4.2	2.7	7.7	12.5	11.6	129	89	289	385	206
Tav E2	4.2	2.7	7.0	19.3	13.1	129	89	306	305	225
Tav F	6.6	1.2	3.1	13.4	11.3	336	85	76	438	254
Tav G	20.5	5.0	8.4	19.3	8.4	212	53	94	369	159
Tav H	25.3	19.3	33.9	17.3	19.7	205	70	223	404	284
Tav J	29.1	29.9	14.2	29.1	8.8	188	121	146	418	147
Tav K	15.0	10.7	14.9	13.3	10.7	176	107	124	318	156
Whole-farm average	**20.2**	**8.5**	**8.0**	**17.9**	**11.3**	**247**	**105**	**101**	**347**	**209**

Table 2b: Fertiliser nitrogen (N) leaching and SCRUM-APSIM estimates of N uptake by crops in rotation at Mayfield over the 2014-19 cropping seasons. A season is defined as the 12 month period starting from 01 April and ending on 31 March.

Paddock	Applied fertiliser (Kg N/ha)					Nitrogen uptake (kg N/ha)				
	2014-15	2015-16	2016-17	2017-18	2018-19	2014-15	2015-16	2016-17	2017-18	2018-19
Camb A	183	183	95	236	-	249	265	145	232	-
Camb B	229	30	83	182	-	176	122	262	161	-
Camb C	146	194	166	231	-	218	296	205	289	-
Camb D	183	204	89	70	-	266	190	131	81	-
Dane A	196	183	164	246	274	247	194	140	347	241
Dane B	181.	204	124	276	230	224	191	211	262	218
Dane D1	229	201	150	230	105	231	270	227	178	223
Dane D2	229	201	143	115	151	225	280	250	113	202
Dane E	229	133	176	68	83	242	206	225	132	137
Dane G	104	201	210	303	388	96	280	230	427	258
Dane JK	229	183	92	253	184	204	258	231	258	199
Dane ST	181	194	30	21	162	191	210	119	75	291
Dane W	229	201	114	159	158	232	252	178	254	232
Dane X1	100	114	184	184	227	114	193	184	232	268
Dane X2	196	198	135	184	227	178	116	289	192	284
Dane Y1	247	23	120	197	205	276	70	255	174	201
Dane Y2	247	275	99	230	23	101	314	340	239	119
Tav A	167	240	152	184	0	192	252	181	165	36
Tav A2	167	240	152	147	-	195	259	196	234	-
Tav AB	-	-	-	-	243	-	-	-	-	219
Tav B	167	215	47	170	231	153	265	68	269	199
Tav B2	167	229	92	101	231	148	315	131	218	215
Tav C	137	158	89	23	297	110	185	171	125	302
Tav CD	-	-	-	-	92	-	-	-	-	198
Tav D	167	206	229	66	21	175	140	352	235	152
Tav D2	167	200	184	205	44	186	255	251	231	259
Tav E	220	161	184	235	205	283	164	278	241	232
Tav E2	220	161	92	0	205	318	171	209	275	232
Tav F	181	193	30	138	231	160	174	265	145	274
Tav G	90	182	257	218	134	150	190	302	315	245
Tav H	196	137	0	293	251	198	197	36	304	255
Tav J	134	194	143	0	205	128	325	157	106	289
Tav K	0.0	201	152	134	257	34	321	163	194	380
Whole-farm average	**178**	**165**	**124**	**166**	**185**	**181**	**206**	**193**	**196**	**227**

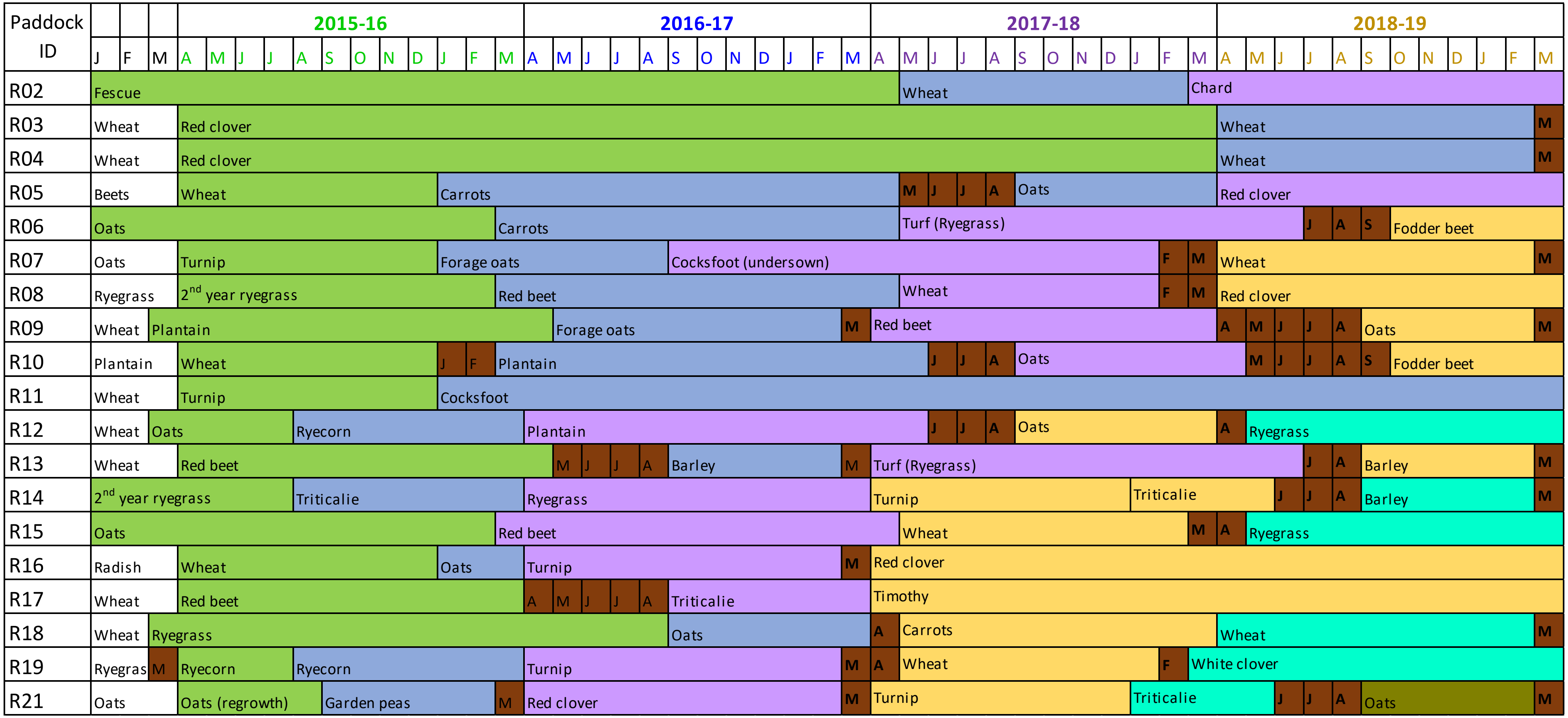

Figure 5: St. Andrews crops in rotation over the 2015-19 cropping seasons. A season is defined as the 12 month period starting on 01 April and ending on 31 March. Fallow periods are indicated by brown cells.

Table 3a: SCRUM-APSIM estimates of nitrogen (N) leaching and drainage from St Andrews paddocks over the 2015-19 cropping seasons. A season is defined as the 12 month period starting from 01 April and ending on 31 March. Drainage and leaching were generated at a soil depth of 150cm.

Paddock ID	Leaching (kg N/ha)				Drainage (mm)			
	2015-16	2016-17	2017-18	2018-19	2015-16	2016-17	2017-18	2018-19
R02	0.0	0.0	7.1	9.5	0.0	0.0	105	124
R03	0.0	0.0	0.9	1.2	0.0	0.0	51	51
R04	0.0	0.0	0.9	1.2	0.0	0.0	51	47
R05	0.0	0.0	1.1	20.8	0.0	0.0	23	276
R06	0.0	0.0	5.0	6.6	0.0	0.0	99	107
R07	0.0	0.0	1.6	3.1	0.0	0.0	66	68
R08	0.0	0.0	3.0	4.5	0.0	0.0	93	190
R09	0.0	0.0	2.9	8.3	0.0	0.0	58	113
R10	0.0	0.0	0.3	5.1	0.0	0.4	14	141
R11	0.0	0.0	0.9	4.1	0.0	0.0	32	90
R12	0.0	0.0	0.8	8.0	0.0	0.0	32	173
R13	0.0	0.0	5.7	6.7	0.0	0.0	96	151
R14	0.0	0.0	6.6	12.3	0.0	0.0	113	93
R15	0.0	0.0	2.4	6.1	0.0	0.0	64	74
R16	0.0	0.0	1.3	5.5	0.0	0.0	41	93
R17	0.0	0.0	4.1	5.7	0.0	0.0	78	76
R18	0.0	0.0	3.0	3.8	0.0	0.0	125	76
R19	0.0	0.0	1.9	9.6	0.0	0.0	48	174
R21	0.0	0.1	4.7	24.3	0.0	3.0	81	265
Whole-farm average	**0.0**	**0.0**	**3.1**	**7.4**	**0.0**	**0.1**	**70**	**117**

Table 3b: SCRUM-APSIM estimates of nitrogen (N) leaching and drainage from St Andrews paddocks over the 2015-19 cropping seasons. A season is defined as the 12 month period starting from 01 April and ending on 31 March. Drainage and leaching were generated at a soil depth of 60cm.

Paddock ID	Leaching (kg N/ha)				Drainage (mm)			
	2015-16	2016-17	2017-18	2018-19	2015-16	2016-17	2017-18	2018-19
R02	1.3	10.6	24.9	7.5	0	8	152	138
R03	0.0	0.5	3.7	19.0	0	17	79	90
R04	0.0	1.1	3.7	18.7	0	17	79	87
R05	0.2	11.6	26.2	4.7	0	24	64	280
R06	0.0	8.7	28.4	9.4	0	29	172	144
R07	2.8	1.3	16.8	37.3	0	27	96	95
R08	0.0	1.6	12.9	2.4	0	14	168	191
R09	0.0	1.5	38.8	33.4	0	24	76	138
R10	0.0	2.3	7.5	12.1	0	24	63	153
R11	0.1	1.7	30.7	36.2	1.5	17	87	147
R12	0.0	3.9	15.3	9.9	0	11	64	177
R13	0.0	2.5	16.6	39.2	0	15	127	179
R14	1.4	11.5	33.4	51.0	0	19	150	130
R15	1.4	3.9	19.4	7.6	2.9	25	85	103
R16	0.0	1.6	13.1	9.1	0	16	76	123
R17	0.0	3.0	31.7	10.2	0	14	112	91
R18	0.1	0.7	4.3	25.7	0.3	18	158	102
R19	0.0	12.3	14.0	3.6	0	21	94	178
R21	1.9	18.5	38.2	30.0	11.6	29	109	287
Whole-farm average	**0.5**	**6.3**	**20.0**	**21.8**	**0.7**	**19**	**109**	**143**

Table 3c: Fertiliser nitrogen (N) leaching and SCRUM-APSIM estimates of N uptake by crops in rotation at St Andrews over the 2015-19 cropping seasons. A season is defined as the 12 month period starting from 01 April and ending on 31 March.

Paddock ID	Applied fertiliser (kg N/ha)				Nitrogen uptake (kg N/ha)			
	2015-16	2016-17	2017-18	2018-19	2015-16	2016-17	2017-18	2018-19
R02	269	249	198	158	295	341	226	216
R03	54	42	0	221	288	149	114	276
R04	54	44	0	221	97	147	112	276
R05	198	0	39	35	217	124	119	31
R06	27	0	189	83	141	78	242	159
R07	240	152	192	263	229	160	255	276
R08	238	89	184	35	314	156	230	81
R09	54	163	177	166	70	153	169	232
R10	191	46	52	86	182	117	96	158
R11	159	240	231	204	154	248	297	310
R12	104	46	58	136	112	107	100	137
R13	201	95	182	212	195	159	231	227
R14	209	256	240	221	225	344	286	296
R15	17	81	205	243	140	187	287	281
R16	228	185	0	35	217	181	142	214
R17	253	143	187	152	244	139	328	288
R18	195	155	37	221	116	287	78	276
R19	100	197	189	43	94	207	257	72
R21	118	46	228	102	78	226	228	169
Whole-farm average	**166**	**130**	**139**	**161**	**186**	**195**	**205**	**223**

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Foundation for Arable Chertsey catch crop trial and monitor farm demonstration trial result summary

Chertsey catch crop trial – 2018

In 2018, FAR carried out a catch crop trial at the Chertsey arable research site, looking at single and mixed species. The aim of the trial was to provide information on:

1) The winter activity of a range of catch crops
2) The amount of N that catch crops take up compared to early sown main crops
3) Differences in weed suppression between the catch crop treatments

Table 1 shows the catch crop treatments and dry matter production (at green chop and whole crop silage maturity stages). Except for treatments 9 and 10, the sowing date was 29 June 2018. Soil mineral N sampling to 60cm depth was carried out at the beginning of the trial and at the green chop stage. Given the trial replicated a post grazing situation and the baseline mineral N in the top 30cm was 25kg N/ha, urea was applied at the rate of 109kg/ha (approx. 50 kg N/ha).

Table 1. Catch crop trial treatments and biomass production harvested around green chop (beginning of November) and around whole crop silage stage (end of December 2018).

Tmt	Catch crop/s (& cultivar)	Green chop (t DM/ha)	Whole crop (t DM/ha)
1	Faba (Ben)	5.44	18.3
2	Ryecorn (Rahu)	7.41	16.5
3	Triticale (Wintermax)*	8.09	14.7
4	Oats (Intimidator)*	8.05	17.8
5	Oats & plantain (Intimidator & Oracle)*	9.61	15.7
6	Oats, faba & plantain	8	17.3
7	Oats, triticale, ryecorn, faba & plantain	8.29	15.0
8	Weedy Fallow	3.35	3.3
9	Fallow then August sowing of triticale	6.32	12.4
10	Fallow then August sowing of barley (Sanette)	4.55	9.1

*Triricale (Wintermax), oats (Intimidator) and plantain (Oracle) were kindly provided by Plant Research (NZ) Ltd, Luisetti Seeds and Cropmark Seeds respectively.

All of the June sown catch crops established well. There were no significant differences in how much total N was taken up between the June sown catch crops, but they all took up significantly more N then an August sown main crop of barley (Figure 1a). On average, the June sown catch crops took up 160kg N/ha. The greatest risk of N loss came from the fallow treatment.

All the June sown catch crops and the August sown triticale significantly reduced N leaching risk compared to the fallow and the August sown barley. Faba beans accumulated the most N (Figure 1b). A positive net N supply is indicative of an accumulation of soil N at the end of the trial (once crop uptake is accounted for) above what can be explained by soil N levels at the beginning of the trial and fertiliser N inputs. Mineralisation and legume N fixation can explain a positive net N supply. A negative net N supply is indicative of N lost from the system (via leaching and volatilisation). Figure 1b shows that there were significant differences in the net N supply between the treatments with greatest loses coming from the fallow treatment ($P<0.001$). All treatments supressed weeds compared to the weedy fallow treatment. It is important to note that if there had been a chemical fallow instead of a weedy fallow, an additional 80kg

N/ha would have been exposed to leaching over the winter in the fallow treatment. The faba catch crop treatment was also significantly weedier than any of the other treatments (Figure 1c). Ryecorn, followed by the triticale catch crops, had the least weed pressure. Although mixed species treatments did not take up any additional N compared to single species, there was a trend for there to be less weeds; however, this was not statistically significant and targeted work would need to be carried out to determine if this trend has any merit (Figure 1 d).

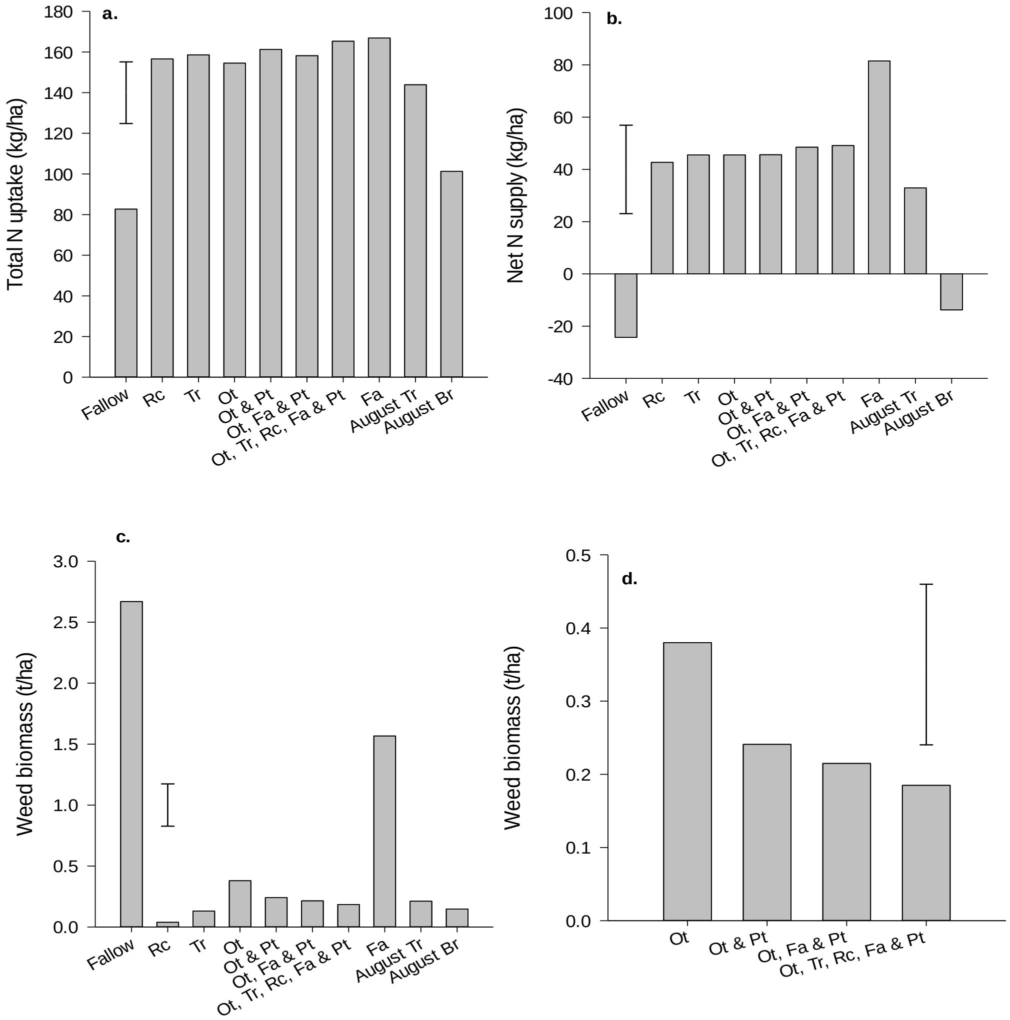

Figure 1 a-c. Total N uptake (kg/ha), Net N supply (kg/ha), weed biomass (t/ha) for each of the catch crop treatments and weedy fallow at the green chop stage. 1d. Weed biomass (t/ha) for a single species catch crop (oats) compared to mixed species catch crop treatments.

Key observations

- Establishing catch crops post grazing can help mitigate N leaching.
- Catch crops can increase annual dry matter production by reducing fallow periods.
- Catch crops sown in June 2018 removed soil N that would have been vulnerable to leaching over winter and spring (on average the June sown catch crops took up 160 kg N/ha).
- Ryecorn then triticale catch crops offered the most weed suppression.
- Catch crops reduced the risk of N loss, compared to fallow soil and compared to where there was a fallow period followed by an early sown main crop of barley.

Catch crop demonstration trials; Austin Farming (2017 and 2018).

2017 demonstration trial

TAV B and TAV J were autumn grazed paddocks chosen for the demonstration catch crop trial. Oats had been grazed in TAV J and fodder beet had been grazed in TAV B (Table 2). Catch crops were sown in autumn (26 May 17). In TAV B, 12m columns were sown in catch crops (oats and faba beans) for comparison with a 12m fallow column. In TAV J a 12m column was sown in oats for comparison with a 12m fallow column. Regrowth oats came up in the TAV J fallow and ended out yielding slightly higher than the sown oats. The cover crops were in the ground for three months (dry matter cuts were taken 7 Sept 17 prior to spring barley being sown) but the low June establishment temperatures and wet winter which meant yields were low (Figures 4 & 5, Table 2).

Figure 2. Faba bean catch crop at Austin Farm, 7 September 2017.

Figure 3. Pugging in fallow plot at Austin Farm, 7 September 2017.

Table 2. Catch crop yields (t/ha); sow date 26/5/17 and harvest date 7/9/17, baseline and harvest profile soil mineral N (kg/ha); soil sampling dates 30/5/17 and 7/9/17 respectively and catch crop N uptake (kg/ha) at the two catch crop demonstration paddocks at Austin Farm.

Monitor farm	Paddock	Pervious crop	Catch Crop sown	Baseline profile soil mineral N (kg/ha)	Harvest profile soil mineral N (kg/ha)	Catch crop yield (t/ha)	Catch crop N uptake (kg/ha)
Austin Farming	TAV B	Grazed fodder beet	Faba beans	66.2	51.3	0.34	17.12
Austin Farming	TAV B	Grazed fodder beet	Oats	60.9	42.2	0.06	4.83
Austin Farming	TAV B	Grazed fodder beet	Fallow	39.7	63.1	-	-
Austin Farming	TAV J	Grazed oats	Catch crop oats	40.1	47.6	0.06	3.19
Austin Farming	TAV J	Grazed oats	Regrowth oats*	32.8	48.5	0.28	5.44

*This was supposed to be fallow but the prior crop of oats regrew and ended out yielding higher than the catch crop oats.

Given that the paddocks were treated the same prior to the catch crops being sown, the baseline soil profile mineral N differences (sampled 30/5/2017) must reflect variability across the paddock and suggest that, given there is no replication in this demonstration, caution is required when interpreting results.

In TAV B the profile soil mineral N increased in the fallow over the two sampling dates suggestive of N mineralisation (about 25 kg/ha). Assuming that this mineralisation rate took place across the whole paddock, the catch crop N uptake (Table 2) does not account for the decrease in soil mineral N over winter compared to the fallow (Figure 4). Actively growing plants do have an impact on soil and N accessibility and it is possible that because of root exudates more immobilisation took place with catch crops.

Changes in mineral N for the two catch crop treatments are a net result of N mineralisation (increasing min N), crop N uptake, and immobilisation of N during the decomposition of the residual fodder beet. These numbers suggest that there was greater immobilisation in the presence of catch crops, despite low yields.

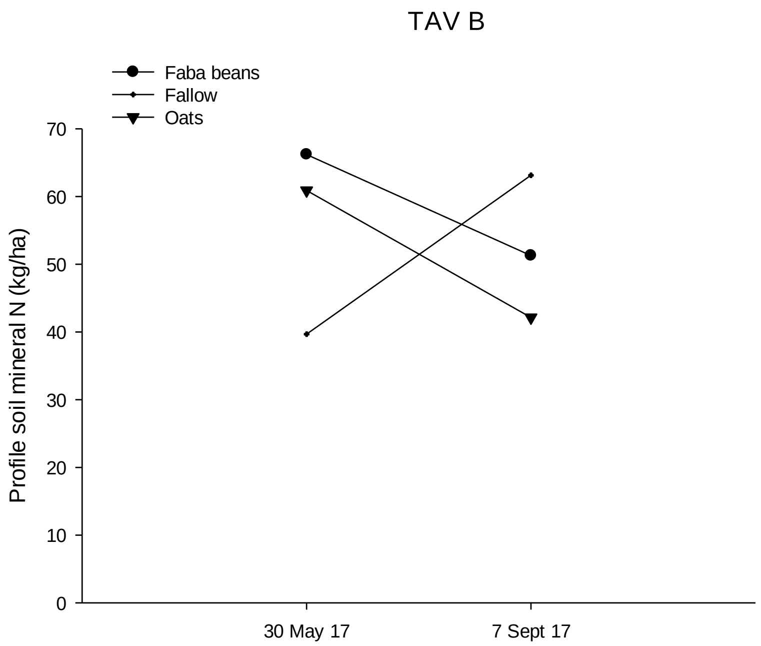

Figure 4. Baseline (30 May 17) and harvest (7 Sept 17) profile (0-60cm) soil mineral N (kg/ha) from faba bean and oat catch crops and a fallow.

In contrast, profile soil mineral N increased over the sampling period for both the catch crop and regrowth oats in TAV J (Figure 5). As there was not a fallow due to regrowth of the previous crop, there is not the opportunity to see if the two paddocks had similar trends relative to the control.

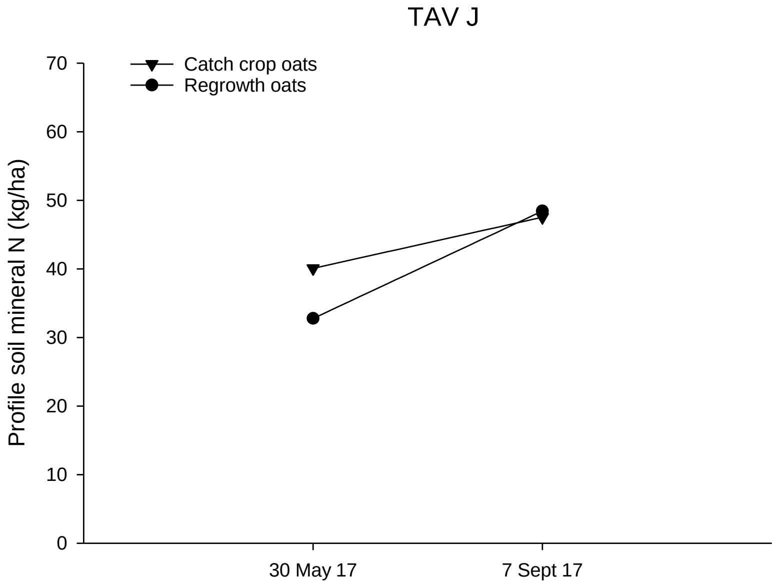

Figure 5. Baseline (30 May 17) and harvest (7 Sept 17) profile (0-60cm) soil mineral N (kg/ha) from the catch crop and regrowth oats.

2018 demonstration trial

The simple aim of this demonstration trial was to compare the autumn sown barley to an area in the paddock left fallow (which would hypothetically be going into a spring barley) to see how much N the early sown barley takes compared to the fallow over the winter period prior to fertiliser being applied.

Catch crop type and proposed management: Winter sown barley (Tavern) sown 10 May 2018 following wheat harvested 18 February 2018.

Treatments to be compared: Fallow (followed by a hypothetical spring sown barley) vs autumn sown barley.

Soil and plant assessments: Baseline soil mineral N from the fallow and barley areas (0-30cm and 30-60cm soil). Plant (biomass and N uptake) and soil sampling (0-30cm and 30-60cm soil) to be carried out in July and again in September (before fertiliser is applied to the paddock).

Trial issues to be considered when interpreting results: Inherent spatial soil N variability within paddocks is common. This needs to be taken into consideration in this demonstration trial as baseline soil mineral N samples were taken from near the final fallow plot, but not from in it (due to the fallow area changing location within the paddock after baseline soil sampling). A second issue to consider is that N fertiliser was applied to the whole paddock on 14 August and again at the beginning of September, prior to the final sampling event being carried out (due to a miscommunication with the farmer). As a result, degree days were used to determine how much N the crop would have taken up between the July sampling event and prior to the first N fertiliser application on 14 August 2018. An additional soil and biomass sample was taken in November to see how the barley crop had utilised the available and applied N.

Spring sown barley is usually sown between mid-August and mid-September in Canterbury. Brent Austin's experience of sowing it earlier (instead of having a winter fallow) is that this can be risky as there are no true winter barleys and if it does not get established well (due to unfavourable establishment conditions) the spring sown crops will yield better. Sowing the crop in autumn, however, has the upside of taking up N over the high risk leaching period over winter, and is also likely to decrease spring N leaching as the crop will be well established compared to an August or September sown crop.

Table 3. Monthly rainfall (mm)

Monthly rainfall	**mm**
May	26.8
June	55.2
July	25.8
August	24.2
September	46.2
October	114.8
November	172.8

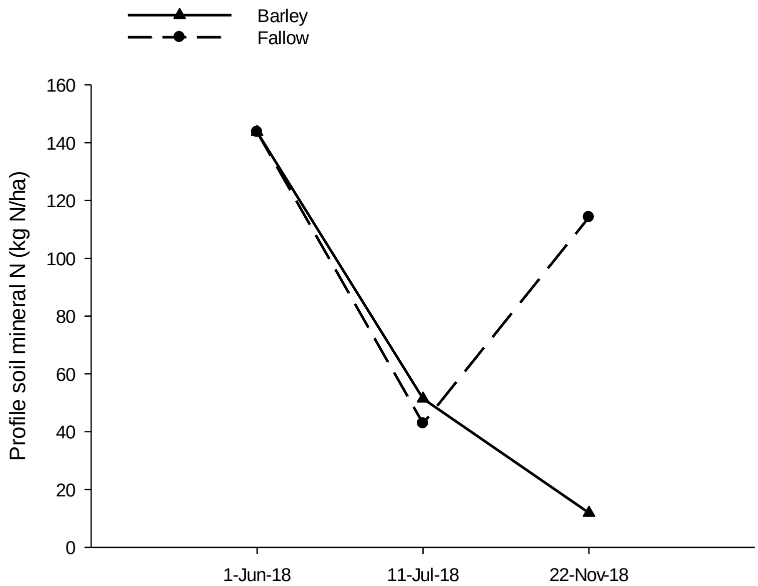

Figure 6. Baseline (1 June 18), 11 July and 22 November soil mineral N (kg/ha) from the fallow and autumn sown barley (0-60cm).

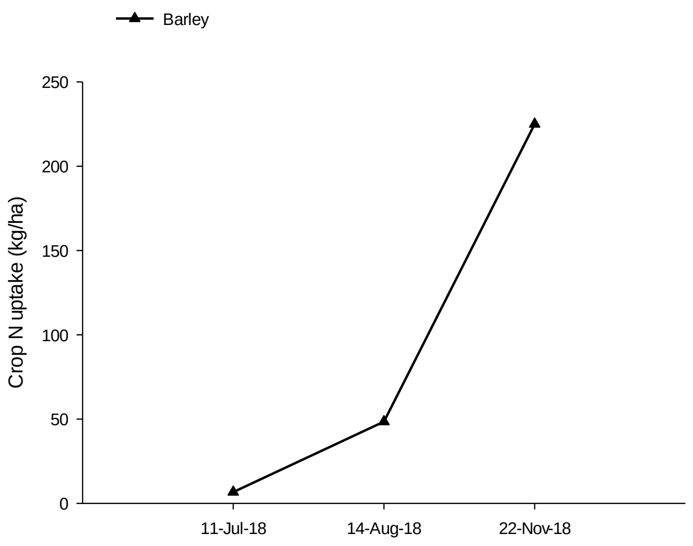

Figure 7. N uptake (kg/ha) 11 July 2018 - two months after the crop was sown (10 May 2018) and at 22 November. 14 August 2018 crop uptake has been calculated using degree day modelling.

Key observations

- N leaching between 1 June and 11 July 2018 was high for both fallow and barley with soil mineral N results indicating 101kg N/ha and 92kg N/ha being lost respectively (Figure 6). The difference can be accounted for by crop uptake with the barley at 11 July 2018 having taken up 7kg N/ha (Figure 7).
- An additional 42kg N/ha was taken up between 11 July and mid-August by barley from N available in the soil, and represents N that would otherwise have been available for leaching. In total, for the period 1 June - 14 August, the autumn sown barley utilised 51kg N/ha that would have otherwise been vulnerable to leaching.
- It is likely that the autumn sown barley would provide further mitigations to leaching losses between August and November, especially in light of the very wet spring in 2018 (Table 3). Even though, hypothetically, a spring barley could have been sown as early as mid-August, it would not have been taking up as much N as the further developed autumn sown crop over this period.
- 168kg N/ha fertiliser were applied to the paddock between mid-August and end of September 2018, which equates to around 130 units of N once volatilisation has been accounted for (note that this was applied to the fallow as well and accounts for the difference in soil mineral N between fallow and barley at 22 November soil sampling, Figure 6). At 11 July, the barley crop had only taken up 7kg N/ha, the remaining 228kg N/ha (additional N taken up by the crop and what was left in the soil at 22 November 2018) can be accounted for by the 51kg N/ha available in the soil, the 130 units N supplied by fertiliser N and the additional 47kg N/ha is likely to have been provided by mineralisation.
- N content of the barley crop decreased from 5.63% 11 July 2018 to 2.39% by 22 November 2018 (whilst C% remained the same at 44%).

Estimating fertiliser N rates

The industry agreed good management practice for nutrient management is to match the nutrient supply from the soil and fertiliser to the demand from the crop to reach its yield. To do this with confidence, farmers require reliable information and methods for working out how much fertiliser to apply to their crops.

Comparisons were carried out in crops sown in spring 2017 comparing farmers' current N application rates with APSIM forecasts based on deep mineral N sampling. Models like APSIM use a mass balance approach to determine how much nitrogen fertiliser should be applied to the crop to achieve its potential yield. A simple N mass balance may be expressed as:

$N_{fertiliser} = N_{crop\ demand} - N_{mineral} - N_{mineralisable}$

Table 4. Selected paddock demonstrations comparing farmer fertiliser N rates to APSIM predicted fertiliser N rates for the 2017−18 growing season at the FRNL arable monitor farms.

Monitor farm	Paddock	Crop	Soil sampling date	Pre-sowing soil mineral N (kg/ha)	APSIM estimated fertiliser N (kg/ha)	Farmer fertiliser N (kg/ha)
Rangitata Holdings	3	Barley	23 Aug 17	82.5	140	205
Rangitata Holdings	4	Barley	23 Aug 17	47.3	170	197
Austin Farming	TAV A	Barley	7 Sept 17	46.1	100	184
Austin Farming	TAV B	Forage Rape	7 Sept 17	52.2	130	122
St. Andrews Dairies	R12	Oats	10 Aug 17	17.1	120	140
St. Andrews Dairies	R14	Turnip	10 Aug 17	46.1	124	174*

*By mistake 174kg N/ha went on the whole paddock- will pick up a 2018 autumn wheat to repeat comparison.

The basic reason for doing a soil N test is to improve fertiliser N predictions. Without information about how much available N is in the soil profile, too much or too little may be applied. Although there is scope for soil N testing to better inform the rates of N fertiliser that are applied, the measurement of soil N supply can be costly and time consuming. The mineral N test provides a measure of N currently available for plant uptake and is the most common in New Zealand. The most widely used test to determine N that will become available over the growing season is anaerobically mineralisable N (AMN), which measures ammonium-N release from a sample incubated at 40 degrees C for seven days.

While both tests are well established, the time taken to get results and the cost can be off-putting. For soil mineral N, one method which may overcome some of the time and analyses cost factors is the nitrate 'quick test'. This in-field approach utilises a test strip and simple colorimetric scale which can be used to quantify soil solution nitrate-N concentrations. The test strips are readily available, cost effective, and currently being validated as part of the SFF project '404944 Nitrogen-Measure it and manage it'. An additional forecasting demonstration treatment using the quick test approach was included in the two paddocks at Rangitata Holdings (Table 5).

Table 5. Additional APSIM N fertiliser prediction treatments at Rangitata Holdings using the N quick test method 2017–08.

Monitor farm	Paddock	Crop	Mineral N estimated fertiliser N (kg/ha)	Quick test estimated fertiliser N (kg/ha)	Farmer fertiliser N (kg/ha)
Rangitata Holdings	3	Barley	140	160	205
Rangitata Holdings	4	Barley	170	170	197

Predicting the quantity of N a soil can supply via mineralization also remains a serious obstacle to the improvement of N management. Fundamental to the success of the mass balance approach is the ability to estimate the N supplied during the growing season through mineralization of soil organic matter. There has been substantial research effort to identify tests that would enable N mineralisation potential to be estimated rapidly and with an acceptable level of confidence. Recent research by Plant & Food Research is finding that hot water extractable N is an easily-measured organic N fraction that can be used to predict N supply potential across a wide range of soil types and land uses. Soil samples taken 4 August 2017 from Paddocks 3 & 4 at Rangitata farm were analysed for both hot water extractable nitrogen (HWEN, 0-15 and 15-30cm) and AMN (0-15cm). Results show that the amount of mineralisable N predicted from the HWEN method was lower than that predicted by the AMN method (Table 6). The HWEN method is thought to be a better indicator, however, the method is just at the preliminary stages and further work is required to calibrate laboratory potential with field conditions.

Table 6. Hot water extractable N, Anaerobically mineralisable N and potentially mineralisable N (kg/ha) in paddocks 3 & 4 at Rangitata Holdings. Soil samples taken 4 August 2017.

Monitor farm	Depth (cm)	Paddock	Crop	Anaerobically mineralisable N (kg/ha)	Potentially mineralisable N (kg/ha)	Hot water extractable N (kg/ha)
Rangitata Holdings	0-15	3	Barley	94	74	51
Rangitata Holdings	0-15	4	Barley	111	80	58
Rangitata Holdings	15-30	3	Barley	62	-	-
Rangitata Holdings	15-30	4	Barley	72	-	-

Table 7. Applied nitrogen (N) fertiliser, crop yield, N use efficiency (NUE) and model-predicted N leaching residual soil N at harvest for four demonstration paddocks evaluated across three FRNL arable monitor farms.

Farm - Paddock ID	Crop	N rate estimated by	*Applied N (kg N/ha)	*Yield (t DM/ha)	#NUE	†Leaching (kg N/ha)	†Residual N (kg N/ha)
Rangitata Holdings - RH 3	Barley	Farmer	205	8.99	0.88	26	74
		Model	140	10.39	1.34	17.2	39
Rangitata Holdings - RH 4	Barley	Farmer	197	9.97	0.96	33	29
		Model	170	13.51	1.67	29.3	19
Austinfarming - Tav A	Barley	Farmer	184	10.12	0.83	1.7	96
		Model	100	8.54	1.28	1.7	41
St. Andrews - R 12	Oats	Farmer	140	9.92	1.35	-	14.6
		Model	120	10.30	1.63	-	14.6

#NUE = grain DM produced per kg of N applied.