Winchmore long-term fertiliser trial: 2020-2021 annual update

Col Gray and Ray Moss

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Contents

1. Executive Summary

The Winchmore long-term fertiliser trial was set up in 1952 to measure the response of pasture production to increasing rates of phosphorus (P) fertiliser. Fertiliser treatments included no P (control), 188, 250 and 376 kg of single superphosphate (SSP) ha^{-1} yr^{-1} and 175 ha^{-1} yr^{-1} Sechura reactive rock phosphate (RPR)/elemental Sulphur (S). This report summarises the results of soil and pasture monitoring from the trial undertaken for the 2020 – 2021 season.

Pasture production was measured nine times over the season, using the rate of growth technique with movable pasture cages. Dry matter (DM) production on the four fertiliser treatments averaged 12,000 kg DM ha^{-1}, consistent with the long-term annual average. This was despite a period of unusually low pasture growth in early summer, linked to low soil moisture monitored at the site. Dry matter production for the no P treatment was significantly less at 5,400 t DM ha^{-1}. Pasture was dominated by grass species, with lesser amounts of clover and weeds. There was however a notable increase in the amount of clover present (up to 30%) in early spring/summer.

Compared to the no P treatment, the application of P fertiliser had no significant ($P < 0.05$) effect on magnesium (Mg), potassium (K), and sodium (Na) concentrations or soil pH. There has been a slow decline in soil pH since the last application of lime at the site in 1975 until the early 1990's, although pH has remained reasonably consistent (between 5.7 and 5.9) over the last 30 years. Calcium (Ca) was significantly higher in the fertilised treatments compared to the no P treatment. Probably a result of the input of Ca that along with P is contained in both the SSP and RPR fertiliser. The application of fertiliser resulted in higher sulphate-S concentrations in the three SSP fertiliser treatments than the no P treatment, but there was no increase in the RPR/elemental S treatment. Olsen P concentrations in the fertiliser treatments were significantly higher ($P < 0.05$) than the no P treatment. Olsen P concentrations have increased over the last 20 years, particularly in the 375 SSP treatment which has increased from about 50 to 80 µg mL^{-1}.

The relationship between soil Olsen P and relative pasture yield for the last three seasons under spray irrigation was lower than that previously measured under border-dyke irrigation, indicating the possibility of a different relationship between the two types of irrigation systems. More data collected over the next few years is still required to confirm this hypothesis.

2. Background

The Winchmore long-term fertiliser trial commenced in 1952. The initial aim of the trial was to establish the response of pasture ryegrass (*Lolium spp*) and white clover (*Trifolium repens*) production (kg $ha^{-1}yr^{-1}$) and productivity (production per unit of phosphorus (P) input) to increasing rates of P fertiliser applied as single superphosphate (SSP) or reactive phosphate rock (RPR). However, the trial has been used extensively by many researchers over the last 40 years for a wide variety of studies including soil carbon (C), nitrogen (N), P, potassium (K) and sulphur (S) chemistry, nutrient cycling, effects of P fertiliser on earthworm numbers, as well as on DDT, cadmium (Cd) and fluorine (F) residue research.

Research on the trial has resulted in several hundred scientific publications and has been used in the development and validation of several models including OVERSEER®, Farmax and CadBal. The Winchmore trial was highlighted in a special edition of the New Zealand Journal of Agricultural Research in 2012 (Smith et al. 2012) and more recently in a data descriptor paper in Nature Scientific Reports (McDowell et al. 2021).

This report summarises the results from the annual soil and pasture monitoring programme undertaken at the trial over the 2020 – 2021 growing season.

3. Materials and Methods

1.1 Trial setup and management

The trial has 20 plots (0.09 ha), divided into five treatments each with four replicates arranged in a randomised block design. The treatments applied annually since 1952 include 0 (no P), 188 and 375 kg ha^{-1} of single superphosphate (SSP). Since 1980, there has also been a 250 kg ha^{-1} yr^{-1} SSP treatment, and a Sechura RPR/S treatment applied annually at 22 kg P ha^{-1} (equivalent to 250 kg SSP ha^{-1}).

All treatments received their fertiliser on 17th July 2020. As in previous years, SSP fertiliser was applied using a farm drill with the down tubes removed. To avoid the risk of applying too much fertiliser, the drill was calibrated to apply less fertiliser than required and the deficit applied by hand. The RPR/S application was applied by hand with the S sieved through a 2 mm screen prior to being applied. The RPR was supplied by Ravensdown and contained 13% total P, 5.2% citric acid soluble P, 8.0% formic acid soluble P, 30% calcium and a maximum of 280 mg Cd kg^{-1} P. Subsamples of the SSP, RPR and S fertiliser applied to the trial have been retained.

The plots were grazed by separate mobs of sheep that rotated between replicates within treatments from September to May. Stocking rates were adjusted during the year with the aim of achieving a post-grazing residual herbage mass height of approximately 30 mm.

Between 1952 to 2018, the trial received on average 4.3 irrigation events (100 mm per event) per annum using border-dyke irrigation. In 2019, the trial was converted from border-dyke to overhead spray irrigation. Irrigation water is applied via a variable rate-controlled centre pivot irrigator. Irrigation is managed in cooperation with the farm owner. The aim of the irrigation is to apply water when the soil moisture level reaches 50% of field capacity. Sufficient water will then be applied to return the soil moisture level to 90% of field capacity. A NIWA operated "irrigation insight" climate station has been installed at a mid-point on plot five, recording at 2-hourly intervals, soil moisture, soil temperature, and the amount of rainfall and irrigation water applied to the trial. This data is used to calculate potential evapo-transpiration enabling the calculation of soil moisture deficits.

1.2 Sampling and analysis

Pasture production was measured using the rate of growth technique using two movable pasture exclusion cages (3.25 m long × 1.02 m wide) per plot (Radcliffe 1974; Lynch 1960). Areas within each cage were trimmed to 25 mm above ground level and left for a standard grazing interval for that time of year. Following each grazing interval, a lawnmower was used to harvest a 0.52 m wide strip in the middle of each enclosure to 25 mm above ground level. The wet weight was determined, and a sub-sample taken to determine dry matter percentage. A separate sample was manually dissected into grass, clover and weeds to the determine botanical composition of the pasture four times over the growing season in September, November, January and May using the method described in Lynch (1966). Subsamples of grass and clover have been retained.

A composite soil sample of 14 cores (2.5 cm diameter and 7.5 cm deep) was collected from each plot four times, in July, prior to fertiliser application, and in November, February, and April. Cores were taken at random following a diagonal route from end to end of each plot. The surface pasture/thatch was removed from samples before the soils were air-dried, sieved to 2 mm and analysed at a commercial laboratory for soil pH, exchangeable cations Ca, Mg, K, Na, Olsen P and sulphate-S. After laboratory analysis a subsample of soil has been retained.

4. Results and Discussion

4.1 Irrigation scheduling

In total 620 mm of rainfall was recorded at the trial site for 2020 – 2021, 17% lower than the long-term annual average of 745 mm. There was 380 mm of irrigation applied between early September 2020 through to late April 2021. This compares with the approximately 350 to 400 mm of irrigation typically applied under the flood irrigation system previously used at the trial site. Irrigation was applied on 31 occasions at rates between 2 to 23 mm (Figure 1).

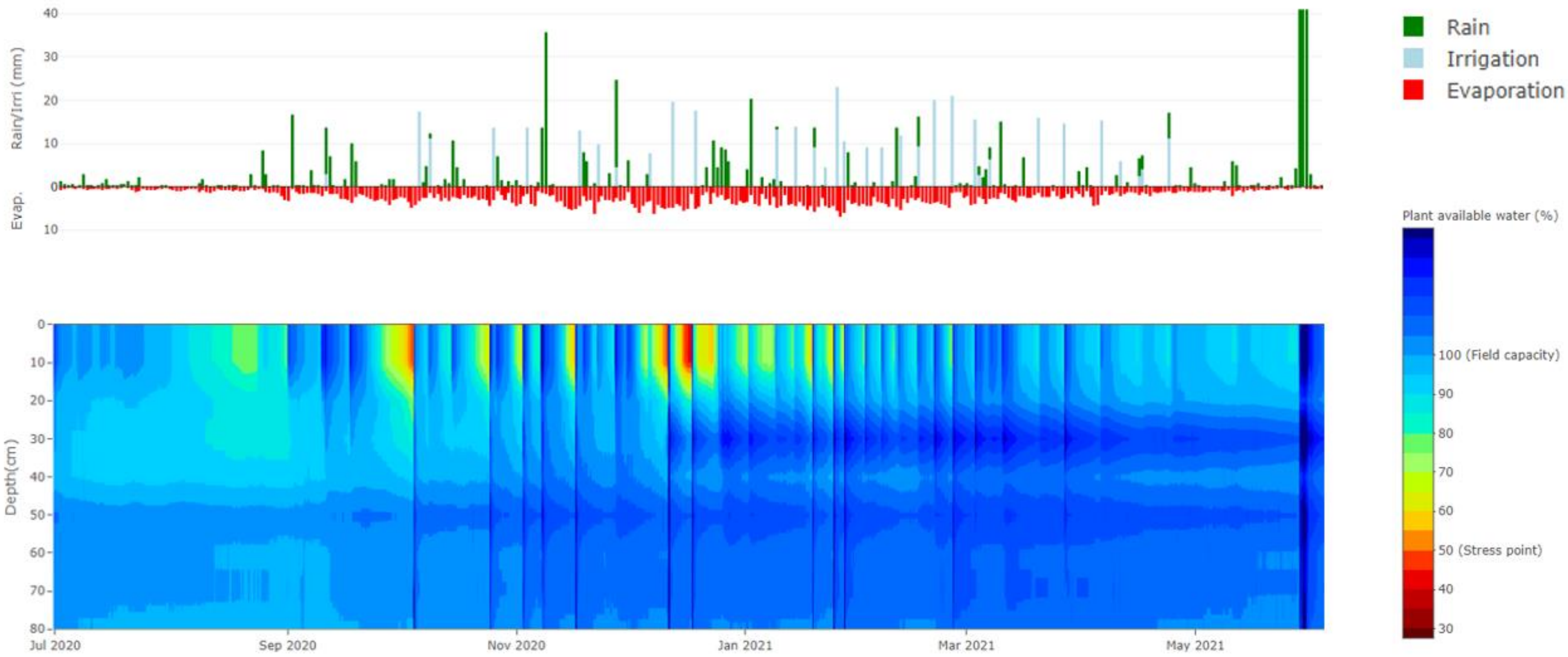

Figure 1. Daily rainfall (mm), irrigation (mm), evaporation (mm) (top panel) and soil moisture (%) (lower panel) at the Winchmore long term fertiliser trial over the 2020-2021 season.

As noted, the protocol for irrigation management states that irrigation water will be applied when the topsoil moisture drops to 50% of field capacity, at which time sufficient water will be applied to return the soil moisture level to 90% of field capacity. Figure 1 shows that soil moisture was maintained around this target for much of the year, with the exception of brief periods after heavy rainfall where it exceeded this target. Soil moisture levels also dropped below the target in late October, and two occasions in December.

4.2 Pasture production

Pasture was harvested on nine occasions between early September 2020 and mid May 2021. Dry matter (DM) yields were significantly greater from the fertiliser treatments than the control (Table 1; Figure 2). Despite different rates of P fertiliser, there was no significant difference in DM yield between the four fertiliser treatments (Table 1), which averaged c. 12,000 kg ha^{-1}, similar to the long-term average for the trial (Figure 2).

Table 1: Seasonal and annual pasture production from the irrigated Winchmore long-term fertiliser trial for 2020-2021 (kg DM ha^{-1}). The least significant difference (LSD0.05) at the P<0.05 level is given along with the F-statistic for comparison of treatment means (bold if significant). Note the Ex. No P comparison covers the applied fertiliser treatments only.

Treatment	Spring	Summer	Autumn	Total
No P	2476	1103	1576	5155
188 kg SSP ha^{-1}	4441	2776	4052	11269
250 kg SSP ha^{-1}	4579	2999	3823	11401
175 kg RPR ha^{-1}	4901	2950	4171	12021
375 kg SSP ha^{-1}	4650	2893	4901	12444
All $LSD_{0.05}$	920	645	1086	2000
All F-Statistic	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Ex. No P $LSD_{0.05}$	645	491	1159	1443
Ex. No P F-Statistic	0.472	0.763	0.245	0.285

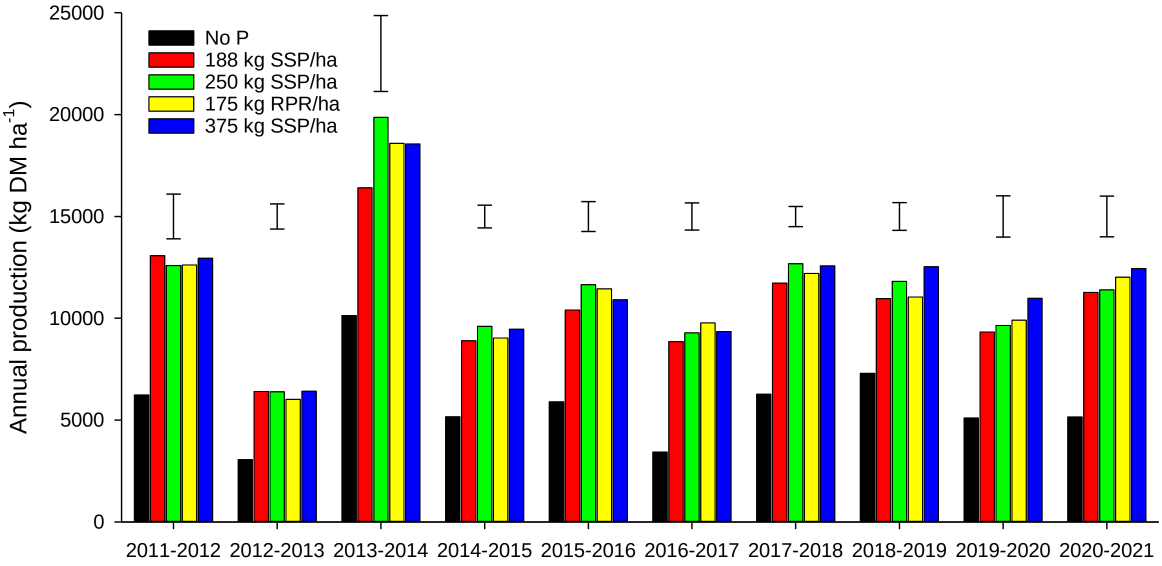

Figure 2. Annual pasture production over 10 years for the long-term irrigated fertiliser trial at Winchmore (kg DM ha^{-1}). Bars indicate LSD (P<0.05).

As expected, daily pasture growth rates increased in spring but surprisingly stabilised over early summer before then peaking in mid-summer (Figure 3). Except for September, daily pasture growth rates were significantly greater in the fertiliser treatment than the control. A likely reason for the low growth in early summer was as reported earlier due to low soil moisture that had developed during the early summer period (Figure 1).

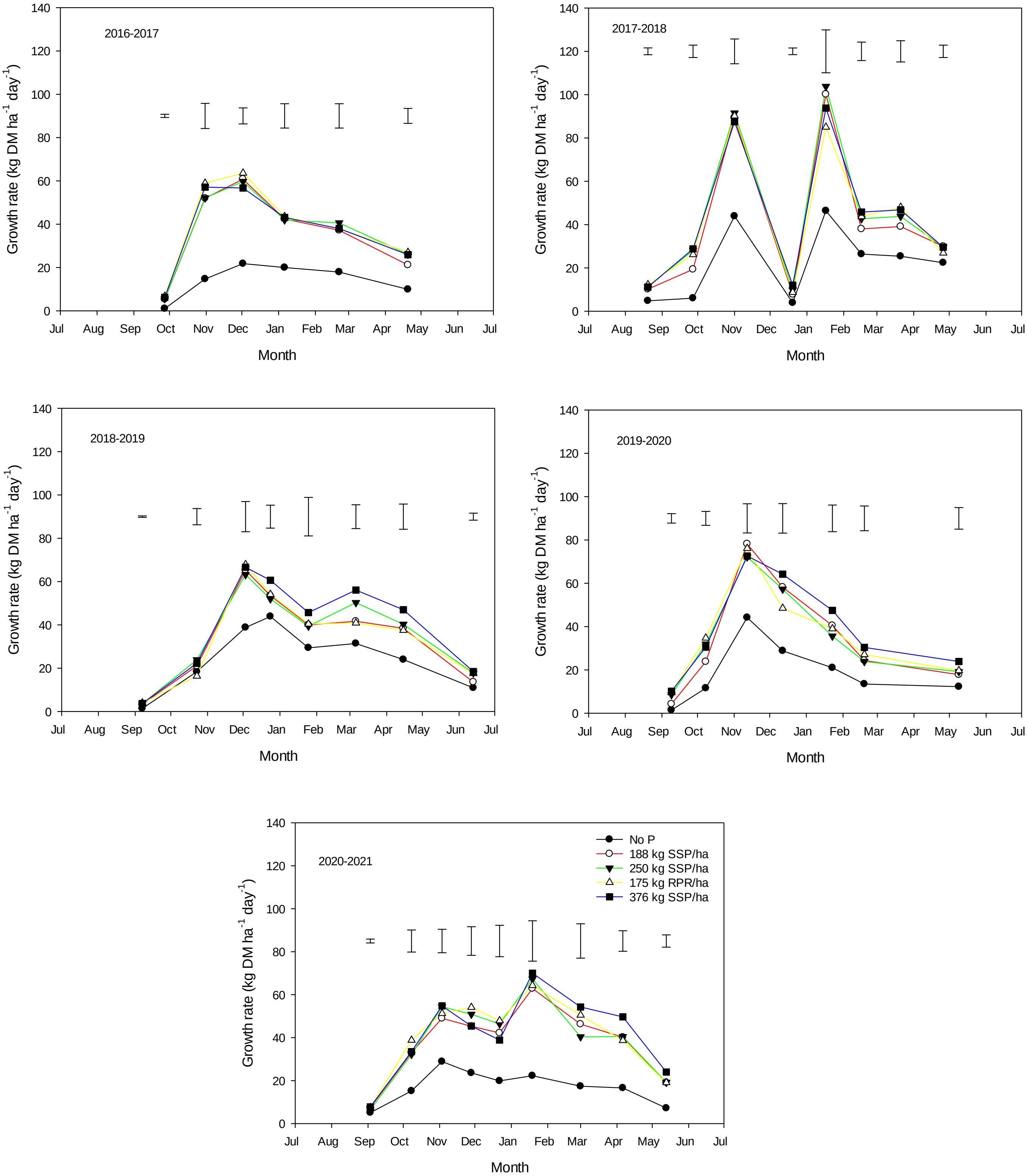

Figure 3. Daily pasture growth over five years for the long-term irrigated fertiliser trial at Winchmore (kg DM ha^{-1} day^{-1}). Bars indicate LSD ($P<0.05$). NB the growth rate shown is the daily growth rate from the previous measurement to the date shown in the graphs.

It was also observed this year that there was considerable variation in pasture DM yields both within an individual plot and also between plots for a given treatment. An example is given for the January 19th pasture harvest (Table 2).

Table 2: Pasture dry matter (DM) yields (kg DM ha^{-1}) for January 19th 2021.

Treatment	Replicate 1	Replicate 2	Replicate 3	Replicate 4	Mean	Standard Deviation
No P	980	398	510	963	713	302
188 kg SSP ha^{-1}	2022	2460	1903	1205	1897	520
250 kg SSP ha^{-1}	1842	1361	1586	1832	1655	229
175 kg RPR ha^{-1}	2009	1938	2367	1974	2072	199
375 kg SSP ha^{-1}	2122	3031	1616	2131	2225	589

Although it is expected there will be some inherent variability in DM yields between treatments, it is thought this variability may be being exacerbated by sheep selectively grazing the more palatable species (patch grazing) in some parts of the plots resulting in areas being grazed below mower trimming height, thus resulting in an under estimation of regrowth. In comparison, less palatable species such as cocksfoot are relatively ungrazed, forming clumps which when trimmed are denuded of virtually all vegetative material, resulting in a slow rate of recovery. A means of overcoming the effect of these two issues on regrowth would be to use the double-trim mowing technique which ensures regrowth measurement cuts occur following a uniform herbage trimming height. A description of the double-trim mowing technique is given in (Lynch 1960).

4.3 Species composition

In line with previous years, pasture was dominated by grass species throughout the year, with lesser amounts of clover and weeds (Table 3). Over the summer months however there was a notable increase in the proportion of clover across all treatments. This is in contrast to the previous two years where clover was largely absent (Figure 4). Interestingly, there have been several incidences over the last 30 years where clover has declined to low levels and then recovered the following year in the summer months (Figure 4).

Table 3: Seasonal and treatment effects on pasture species fractions from the Winchmore long-term irrigated fertiliser trial for 2020-2021 (% species present on a dry matter basis). The least significant difference (LSD0.05) at the P<0.05 level is given along with the F-statistic for comparison of treatment means (bold if significant).

Treatment	3/9/20			4/11/20			25/1/21			13/5/21		
	Grass	Clover	Weeds	Grass	Clover	Weeds	Grass	Clover	Weeds	Grass	Clover	Weeds
No P	92	1	7	91	8	1	80	17	3	96	3	1
188 kg SSP ha^{-1}	96	1	3	87	12	1	62	37	1	98	2	0
250 kg SSP ha^{-1}	96	1	4	77	22	1	68	29	3	94	4	2
175 kg RPR ha^{-1}	96	1	2	81	18	1	68	30	2	97	2	1
375 kg SSP ha^{-1}	97	1	2	86	13	1	71	26	3	95	4	0
All LSD 0.05	1.9	1.3	1.6	11.9	11.6	1.7	15.4	15.2	2.3	3.0	2.1	1.4
All F-Statistic	**0.003**	0.777	**<0.001**	0.170	0.147	0.921	0.200	0.141	0.526	0.057	**0.048**	**0.034**

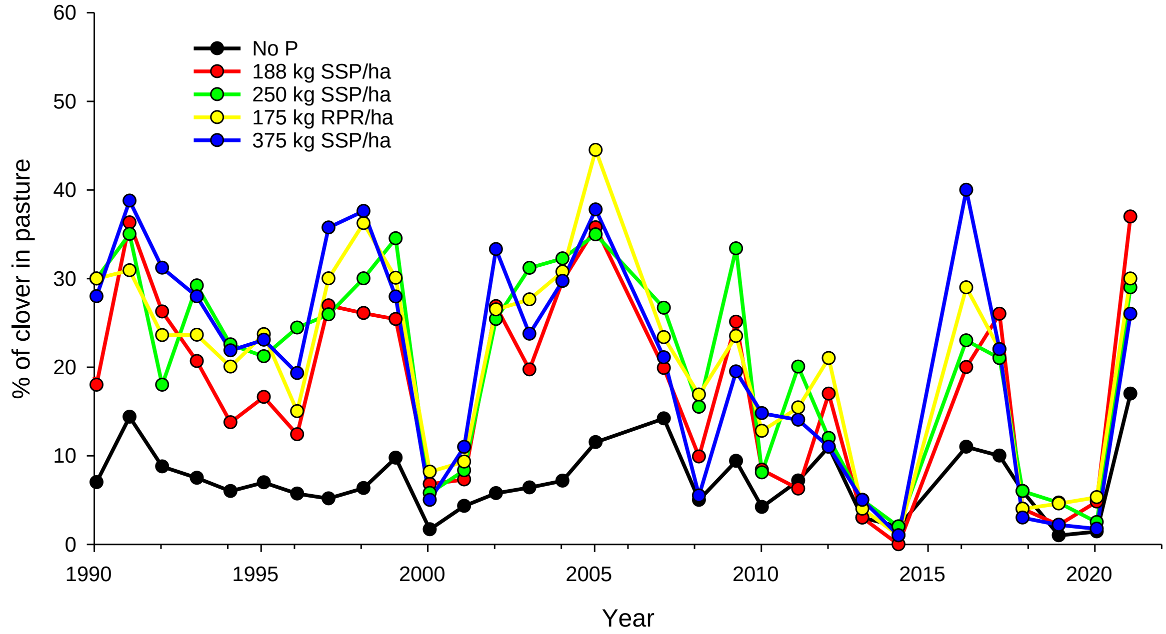

Figure 4. Long term effect of P fertiliser application on clover content over the summer months (December – January).

4.4 Soil analysis

Soil samples were analysed four times over the 2020 – 2021 season, in July prior to the application of P fertiliser and again in November, February and April. The application of P fertiliser had no significant effect on soil pH, Mg, K, or Na concentrations (Table 4).

Table 4: Soil test results from the Winchmore long-term irrigated fertiliser trial for the 2020-2021 season. The least significant difference (LSD 0.05) at the P<0.05 level is given along with the F-statistic for comparison of treatment means (bold if significant).

Treatment	pH	Ca (QT)	Mg (QT)	K (QT)	Na (QT)	Olsen P ($\mu g\ mL^{-1}$)	SO_4-S ($\mu g\ mL^{-1}$)
July 2020							
No P	5.8	7	20	10	4	6	5
188 kg SSP ha^{-1}	5.8	9	19	8	5	22	6
250 kg SSP ha^{-1}	5.8	10	21	9	5	34	5
175 kg RPR ha^{-1}	5.8	9	20	11	6	29	7
375 kg SSP ha^{-1}	5.8	10	19	12	6	79	26
LSD 0.05	0.1	1	2	5	1	9	28
F-Statistic	0.823	<0.001	0.436	0.567	0.056	<0.001	0.455
November 2020							
No P						7	6
188 kg SSP ha^{-1}						28	17
250 kg SSP ha^{-1}						39	38
175 kg RPR ha^{-1}						30	9
375 kg SSP ha^{-1}						81	58
LSD 0.05						7	26
F-Statistic						<0.001	0.004
February 2021							
No P						6	4
188 kg SSP ha^{-1}						22	10
250 kg SSP ha^{-1}						31	8
175 kg RPR ha^{-1}						27	8
375 kg SSP ha^{-1}						71	13
LSD 0.05						7	4
F-Statistic						<0.001	0.011
April 2021							
No P						2	8
188 kg SSP ha^{-1}						20	11
250 kg SSP ha^{-1}						30	9
175 kg RPR ha^{-1}						28	12
375 kg SSP ha^{-1}						79	15
LSD 0.05						<0.001	0.043
F-Statistic						2	8

Potassium concentrations were slightly higher than the recommended range (5 – 8) for pasture sites grazed by sheep in New Zealand (Morton and Roberts 2018). Magnesium was about double the recommended concentration range (8 – 10) for pasture growth, although below the recommend concentration for ewes in spring of 25 to 30 (Morton and Roberts 2018).

Soil pH was at the lower end of the recommended range (5.8 – 6.0). There has been a slow decline in soil pH since the last application of lime at the site in 1975 until the early 1990's (Figure 5). Although with the exception of 2007, 2010 and 2016, soil pH has been remained reasonably consistent between 5.7 and 5.9.

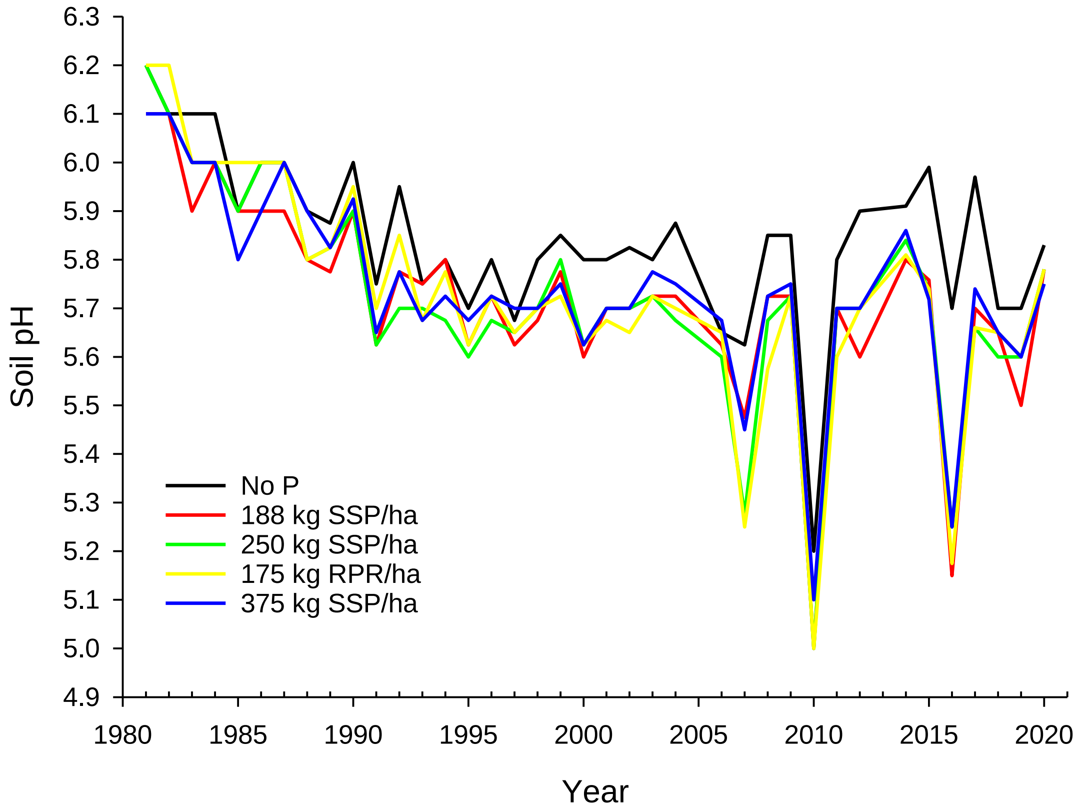

Figure 5: Soil pH values (0 – 75 mm depth) measured in winter each year from the long-term irrigated fertiliser trial at Winchmore.

Calcium was significantly higher in the fertilised treatments compared to the no P treatment. This is probably a result of the input of Ca that along with P is contained in both the SSP and RPR fertiliser.

The application of fertiliser resulted in higher sulphate-S concentrations in the three SSP fertiliser treatments than the no P treatment. In comparison, there didn't appear to be any increase in sulphate-S in the RPR treatment. Sulphate-S concentrations were highest in soils sampled after the application of fertiliser but had decreased to below the recommended range (10 – 12) (Morton and Roberts 2018) before the next sampling three months later in all but the 376 SSP treatment.

Olsen P concentrations in the fertiliser treatments were significantly higher than the no P treatment for all four sample dates. Olsen P concentrations were largely within the recommended range (20 – 30) (Morton and Roberts 2018) for the 188 SSP, 250 SSP and 175 RPR treatments. In comparison, Olsen P concentrations were about 2.5-fold higher than the recommended range in the 375 SSP treatment.

There has been a steady increase in Olsen P concentrations over the last 20 years, particularly in the 375 kg SSP treatment which has increased from about 50 to 80 µg mL^{-1} (Figure 6).

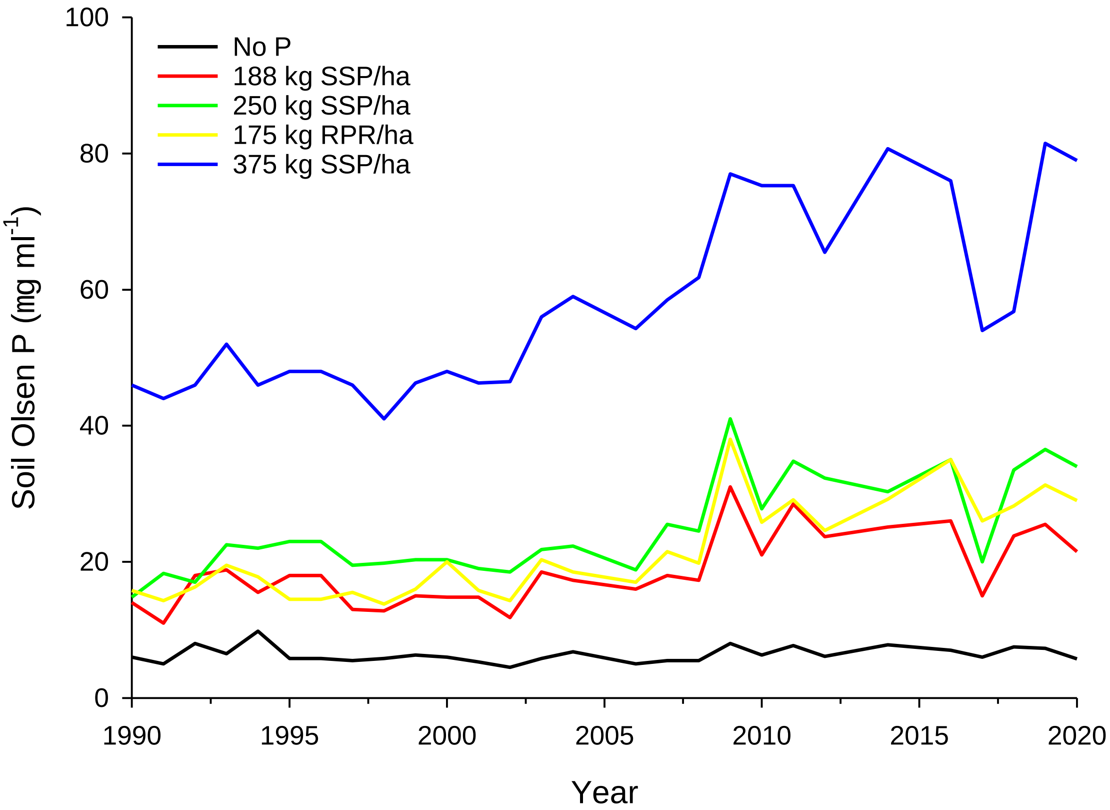

Figure 6: Soil Olsen P (0 – 75 mm depth) measured in winter each year from the long-term irrigated fertiliser trial at Winchmore.

5. Response curve

Using the methodology of Sinclair et al. (1997), it was possible to use data from 24 of the 37 years over the 1981 to 2018 period to derive a long-term response curve between Olsen P and relative pasture yields under border-dyke irrigation. The relative yields from this year's production are below the long-term response curve for all of the fertilised treatments (Figure 7), although are closer than for those measured in the 2019 – 2020 season. This may indicate a different response curve to Olsen P under spray irrigation to that previously measured under border-dyke irrigation. However, several years' more pasture yield data is still required to confirm this hypothesis.

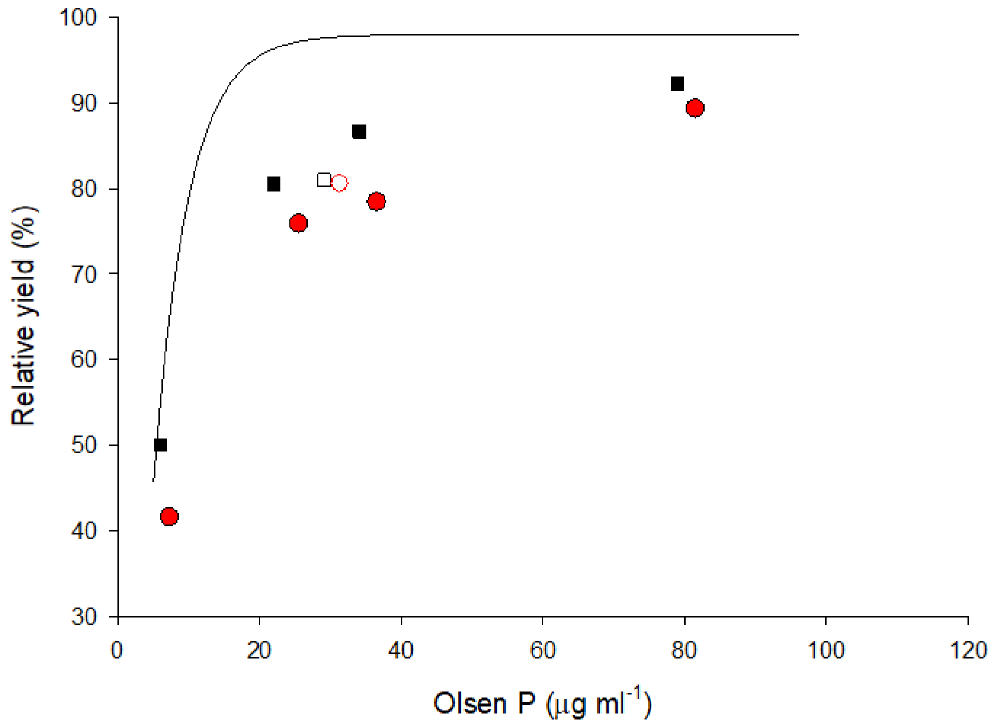

Figure 7. Relative pasture yields for the No P and SSP ● and RPR treatments ○ for the 2019-2020 season and No P and SSP ■ and RPR treatments □ for the 2020-2021 season. The solid line is the long term (1981-2018) pasture response curve.

6. Acknowledgements

We would like to acknowledge Chris Olley the farm owner for irrigation management and access to the site, the Lincoln farm team for stock management and the Fertiliser Association of New Zealand for their continued funding of this trial.

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