Winchmore long-term fertiliser trial: 2022-2023 annual update

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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 375 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 2022 – 2023 season.

Pasture production was measured eleven times over the season, using the rate of growth technique with movable pasture cages. Dry matter (DM) production on the four fertiliser treatments averaged 13,700 kg DM ha^{-1}, slightly higher than the long-term annual average (c.12,000 kg DM ha^{-1}). Dry matter production for the no P treatment was significantly less at 7,200 kg DM ha^{-1}, which is slightly higher than long-term average of 5,400 kg 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 (about 15%) in summer.

Compared to the no P treatment, the application of P fertiliser had no significant effect on magnesium (Mg), potassium (K), and sodium (Na) concentrations or soil pH. There was 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 an increase in sulphate-S concentrations in the fertiliser treatments, that remained within or slightly above the recommended range across the rest of the year in all the fertiliser treatments. Olsen P concentrations in the fertiliser treatments were significantly higher 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 100 µg mL^{-1}.

The relationship between soil Olsen P and relative pasture yield 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 dichloro-diphenyl-trichloroethane (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 2022 – 2023.

3. Materials and Methods

1.1 Trial setup and management

The trial has 20 plots (0.09 ha each), 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}).

The SSP treatments received their fertiliser on 29th August 2022. However, due to the inability to obtain supply of RPR only S was applied to this treatment, (in the form of S90), during the 2022/23 year. 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. Subsamples of the SSP applied to the trial have been retained.

The plots were grazed by separate mobs of sheep that rotated between replicates within treatments from 8th September until 12th May 2023, shifting at approximately 4 day intervals. 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 sufficient water to ensure the soil moisture level is maintained above 50% of field capacity up to a maximum of 90% of field capacity. A NIWA operated “irrigation insight” climate station has been installed at a mid-point on plot five (188 SSP), recording at 2-hourly intervals, soil moisture, soil temperature and irrigation water applied to the trial. Rainfall was measured at a NIWA climate station located on the adjacent farm, 300m from the trial site. 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, with all plots harvested simultaneously. 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, February and May l using the method described in Lynch (1966). Dried subsamples of grass and clover have been retained for future analysis.

A composite soil sample of 12 cores (2.5 cm diameter and 7.5 cm deep) was collected from each plot four times, in August , prior to fertiliser application, and in November, February , and May l. Cores were taken at random following a diagonal route from end to end of each plot. The surface pasture/thatch was removed from samples which were air-dried and sieved to 2 mm. All were analysed at a commercial laboratory, the July samples for soil pH, exchangeable cations Ca, Mg, K, Na, Olsen P and sulphate-S, and on all other occasions for Olsen P and sulphate-S. After analysis a subsample of soil was retained.

4. Results and Discussion

4.1 Irrigation scheduling

In total 895 mm of rainfall was recorded at the trial site for 2022 – 2023, 20% higher than the long-term annual average of 745 mm (Table 1). The winter rainfall total was much higher than the long-term average (Table 1). Rainfall totals in spring, summer and autumn were similar to the long-term average.

There was 254 mm of irrigation spread over the 21 applications that occurred between early September 2022 through to late April 2023. This compares with the approximately 350 to 400 mm of irrigation that was typically applied under the flood irrigation system previously. (Figure 1).

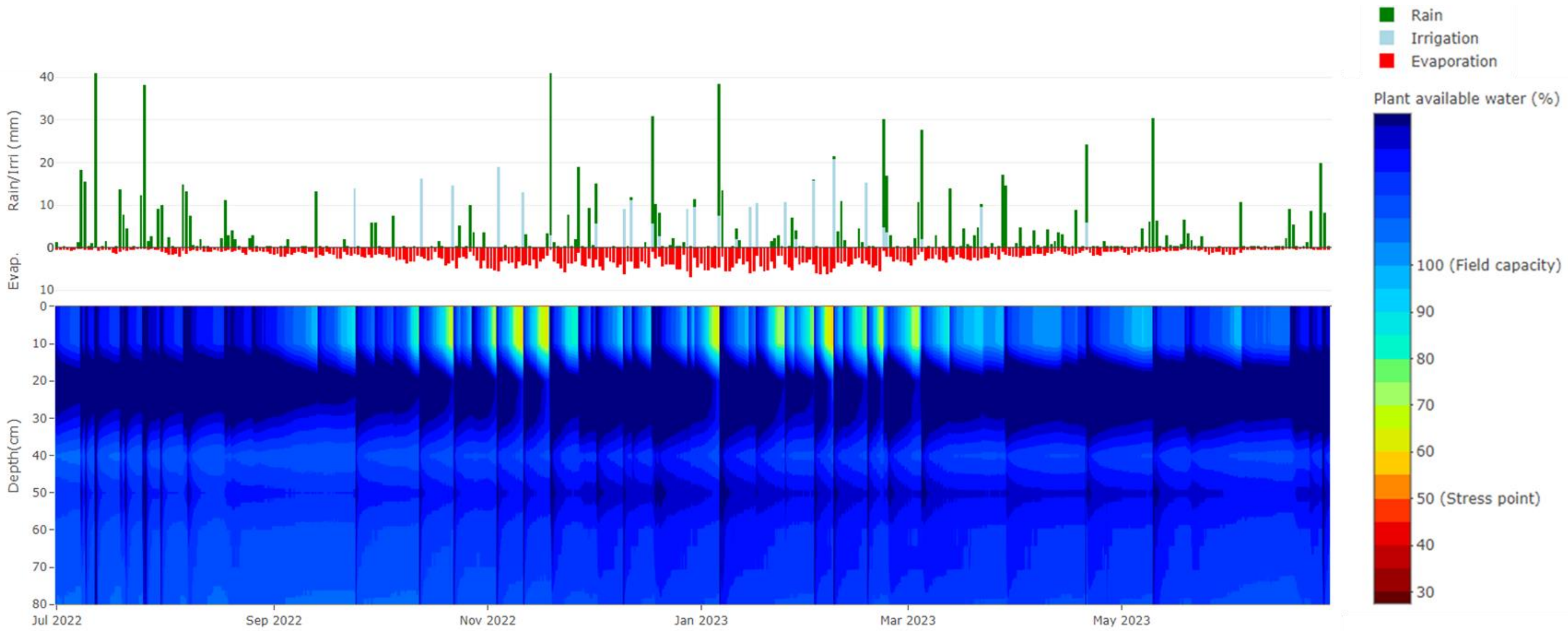

Figure 1. Daily rainfall (mm), irrigation (mm), evaporation (mm) (top panel) and soil moisture (%) (lower panel) at the Winchmore long term fertiliser trial over the 2022-2023 season.

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 about 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.

***Table 1**: Seasonal and annual rainfall, potential evapotranspiration and irrigation applications on the irrigated Winchmore long-term fertiliser trial for 2022-2023. Values in parentheses are long-term average rainfall.*

	Rainfall (mm)		PET * (mm)		Irrigation (mm)		
	maximum / day	total	maximum / day	total	Number of applications	maximum / application (mm)	Total (mm)
Winter	56	329(181)	4.3	65	0	0	0
Spring	41	147(168)	6.4	245	5	19	80
Summer	23	192(190)	5.0	357	14	21	156
Autumn	30	227(206)	2.2	145	2	10	18
Annual total		895		812	21		254

*PET potential evapotranspiration

4.2 Pasture production

Pasture was harvested on eleven occasions between late May 2022 and early June 2023. Dry matter (DM) yields were significantly greater from the fertiliser treatments than the control (Table 2; Figure 3). Despite different rates of P fertiliser, there was no significant difference in DM yield between the four fertiliser treatments (Table 2), which averaged c. 13,700 kg ha^{-1}, slightly higher than the long-term average for the trial of c. 12, 000 kg ha^{-1} (Figure 2). As expected, daily pasture growth rates increased in spring before peaking in mid-summer (Figure 3).

Table 2: *Seasonal and annual pasture production from the irrigated Winchmore long-term fertiliser trial for 2022-2023 (kg DM ha^{-1}). Differences are assumed to be significant with $P<0.05$. Note the Ex. No P comparison covers the applied fertiliser treatments only.*

Treatment	Winter	Spring	Summer	Autumn	Total
No P	72	2295	3014	1816	7197
188 kg SSP ha^{-1}	726	4768	5216	2540	13250
250 kg SSP ha^{-1}	658	4958	5669	2696	13981
175 kg RPR ha^{-1}	477	4888	5336	2745	13446
375 kg SSP ha^{-1}	661	4947	5677	2939	14224
P-value	<0.001	<0.001	<0.001	<0.001	<0.001
Ex. No P-value	>0.1	>0.1	>0.1	>0.1	>0.1

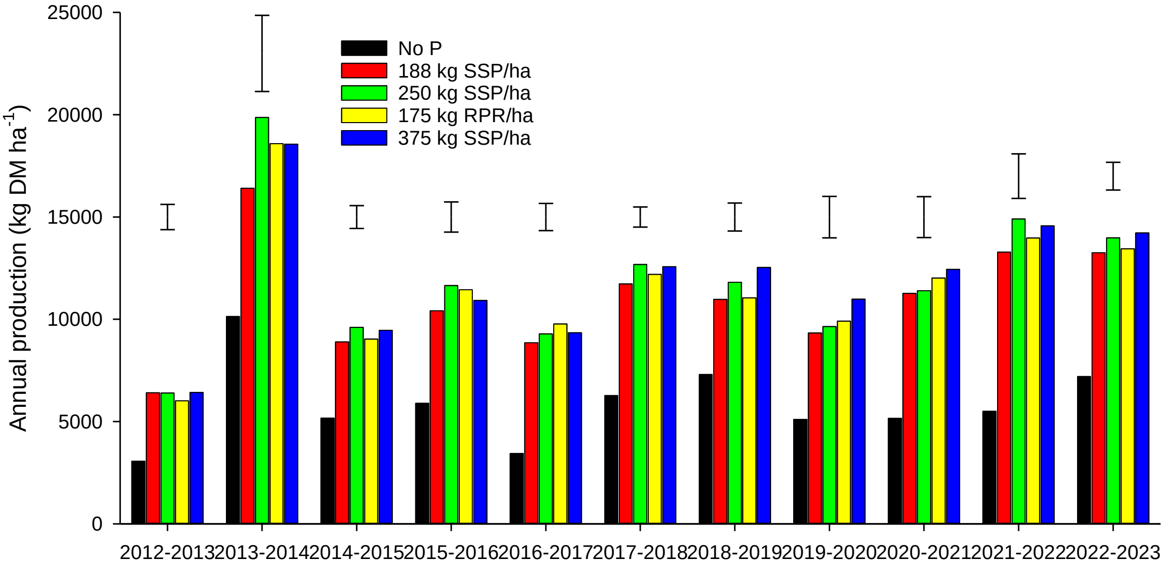

Figure 2. Annual pasture production over 10 years for the long-term irrigated fertiliser trial at Winchmore (kg DM ha^{-1}). Bars indicate LSD ($P<0.05$).

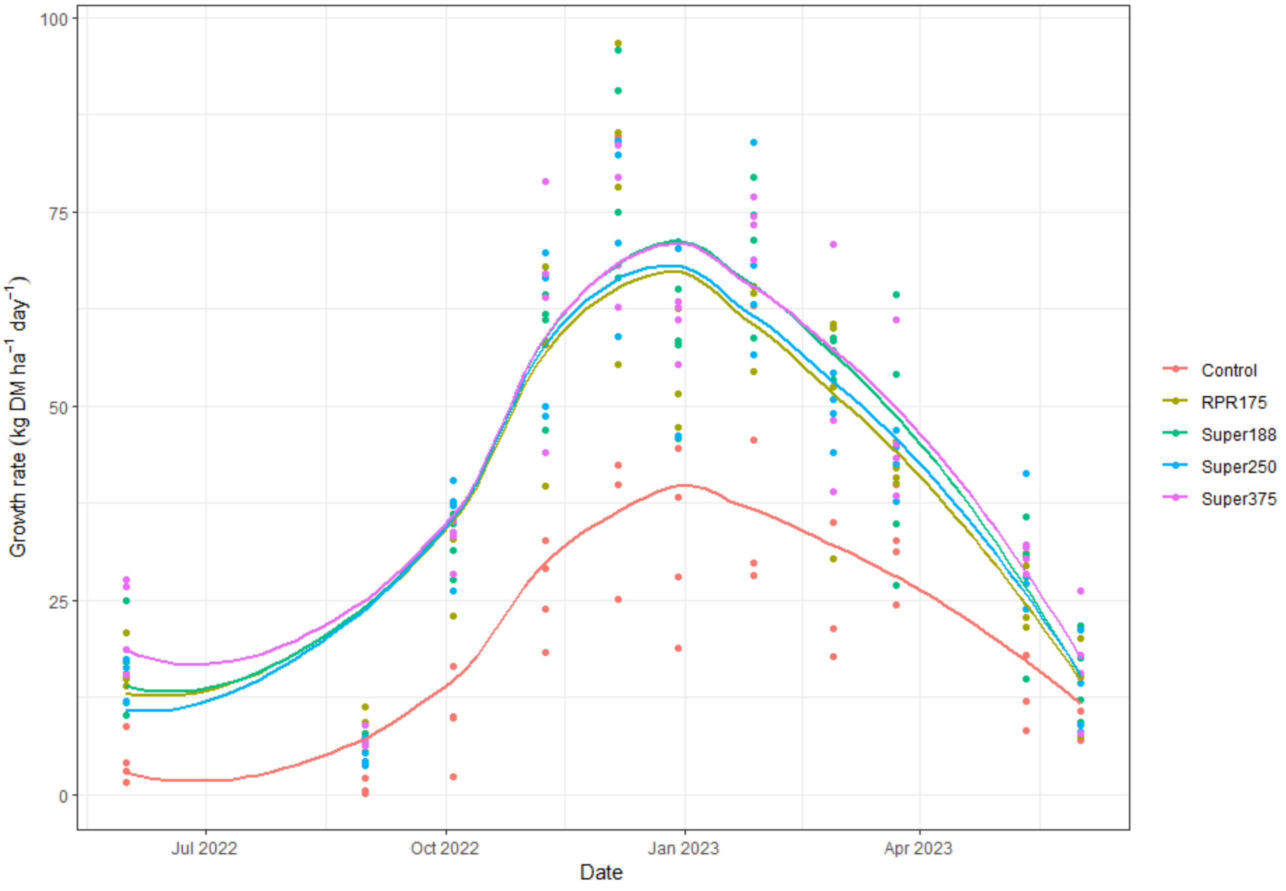

Figure 3. Replicate daily pasture growth for the 2022/2023 year for the long-term irrigated fertiliser trial at Winchmore (kg DM ha^{-1} day^{-1}). Smooth curves for each treatment have been fitted to the data.

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 warmer months however there was a notable increase in the proportion of clover across all treatments. 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 2022-2023 (% species present on a dry matter basis). Differences are assumed to be significant with $P < 0.05$.*

Treatment	**31-8-22**			**8-11-22**			**27-2-23**			**12-5-23**		
	Grass	Clover	Weeds	Grass	Clover	Weeds	Grass	Clover	Weeds	Grass	Clover	Weeds
No P	98.7	0.9	0.4	93.8	6.2	0.0	81.9	12.3	5.7	81.9	3.1	0.3
188 kg SSP ha^{-1}	99.2	0.5	0.2	97.4	2.6	0.0	87.7	9.5	2.8	87.7	2.0	0.0
250 kg SSP ha^{-1}	99.4	0.5	0.2	94.1	5.3	0.6	89.3	10.6	0.1	89.3	1.3	0.2
175 kg RPR ha^{-1}	98.5	1.5	0.0	94.4	5.6	0.0	77.2	19.1	3.8	77.2	0.0	0.0
375 kg SSP ha^{-1}	99.3	0.6	0.2	96.3	3.7	0.0	83.7	14.8	1.5	83.7	2.2	0.7
P-value	0.609	0.443	0.538	0.680	0.670	0.352	0.259	0.432	0.289	0.259	0.755	0.596

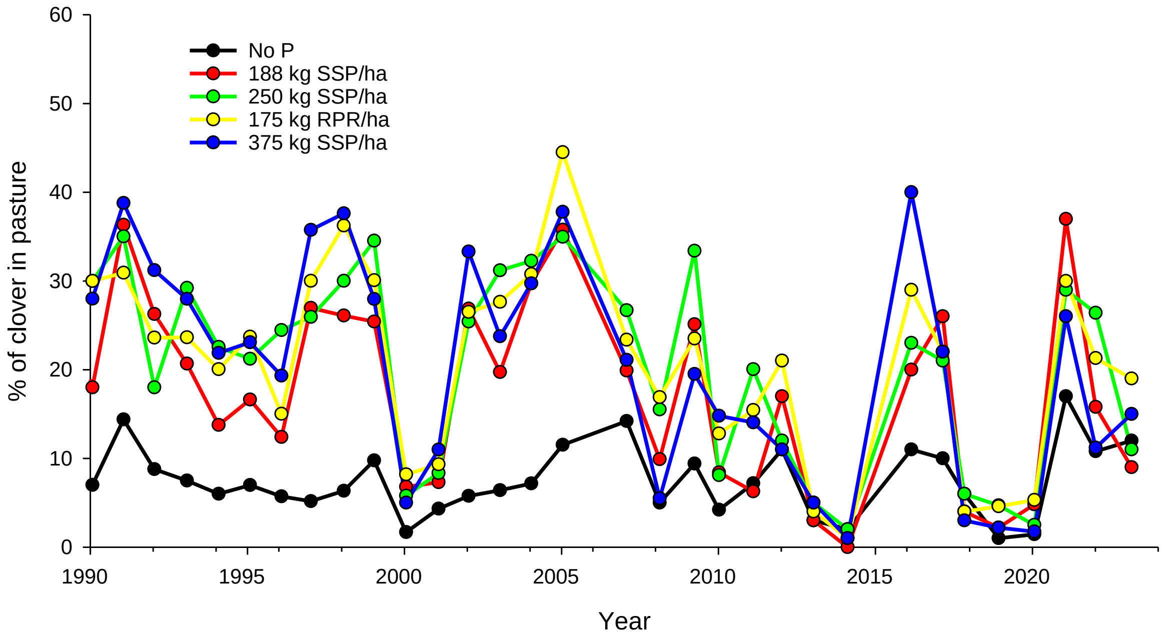

Figure 4. Long term effect of phosphate fertiliser application on clover content (%) over the summer from the Winchmore long-term irrigated fertiliser trial.

4.4 Soil analysis

Soil samples were analysed four times over the 2022 – 2023 season, in August prior to the application of P fertiliser and again in November, February and May. 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 2022-2023 season. Differences are assumed to be significant with $P < 0.05$.).*

Treatment	pH	Ca	Mg	K	Na	Olsen P	SO$_4$-S
		(QT)	(QT)	(QT)	(QT)	(µg mL^{-1})	(µg mL^{-1})
August 2022							
No P	5.7	10	31	15	5	11	9
188 kg SSP ha^{-1}	5.4	12	30	19	7	32	14
250 kg SSP ha^{-1}	5.4	12	29	17	6	46	13
175 kg RPR ha^{-1}	5.5	12	32	18	7	39	17
375 kg SSP ha^{-1}	5.5	13	28	13	6	102	13
P-value	>0.05	<0.05	>0.05	>0.05	>0.05	<0.05	>0.05
November 2022							
No P						8	5
188 kg SSP ha^{-1}						33	15
250 kg SSP ha^{-1}						44	24
175 kg RPR ha^{-1}						40	9
375 kg SSP ha^{-1}						98	19
P-value						<0.05	>0.05
February 2023							
No P						7	7
188 kg SSP ha^{-1}						33	12
250 kg SSP ha^{-1}						36	16
175 kg RPR ha^{-1}						32	17
375 kg SSP ha^{-1}						92	23
P-value						<0.05	>0.05
May 2023							
No P						6	9
188 kg SSP ha^{-1}						34	12
250 kg SSP ha^{-1}						49	12
175 kg RPR ha^{-1}						45	20
375 kg SSP ha^{-1}						92	13
P-value						<0.05	>0.05

In line with the results found in previous years, K 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 triple the recommended concentration range (8 – 10) for pasture growth, although similar to the recommend concentration for ewes in spring of 25 to 30 (Morton and Roberts 2018).

Soil pH was at the lower end or slightly below 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 5.4 and 5.9.

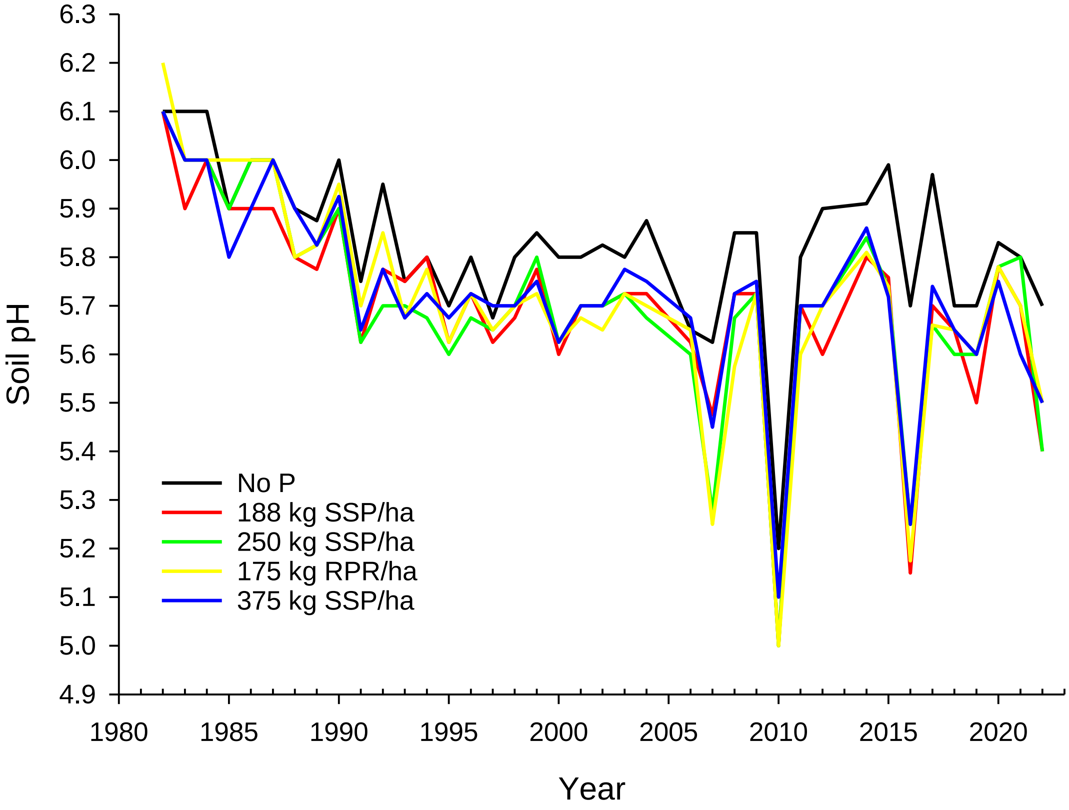

Figure 5: Soil pH values (0 – 75 mm depth) measured in winter each year from the long-term irrigated fertiliser trial at Winchmore.

Calcium was significantly higher in the fertilised treatments compared to the no P treatment (Table 4). 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 an increase in sulphate-S concentrations in the fertiliser treatments (Table 4). Sulphate-S concentrations remained within or slightly above the recommended range (10 – 12 µg mL^{-1}) (Morton and Roberts 2018) across the rest of the year in all the fertiliser treatments.

Olsen P concentrations in the fertiliser treatments were significantly higher than the no P treatment at all four sample dates. Olsen P concentrations were largely well above the recommended range (20 – 30 µg mL^{-1}) (Morton and Roberts 2018) for all the four fertiliser treatments across the year (Table 4).

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 102 µg mL^{-1} (Figure 6).

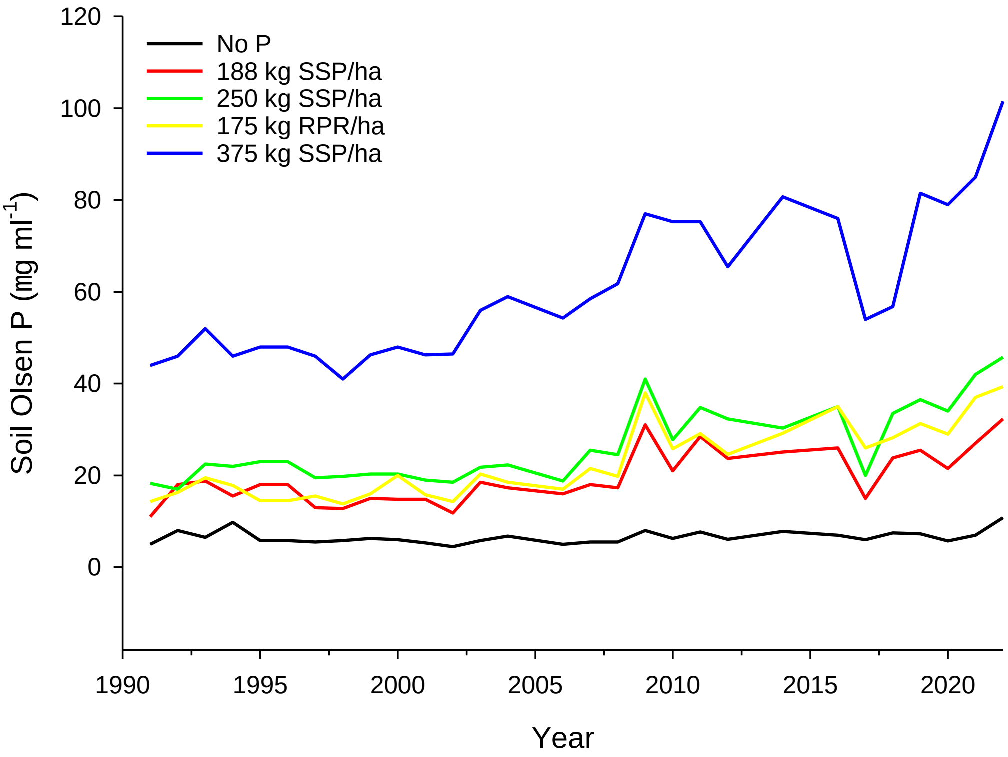

Figure 6: Soil Olsen P concentrations (0 – 75 mm depth) measured in winter each year from the long-term irrigated fertiliser trial at Winchmore.

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). 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.

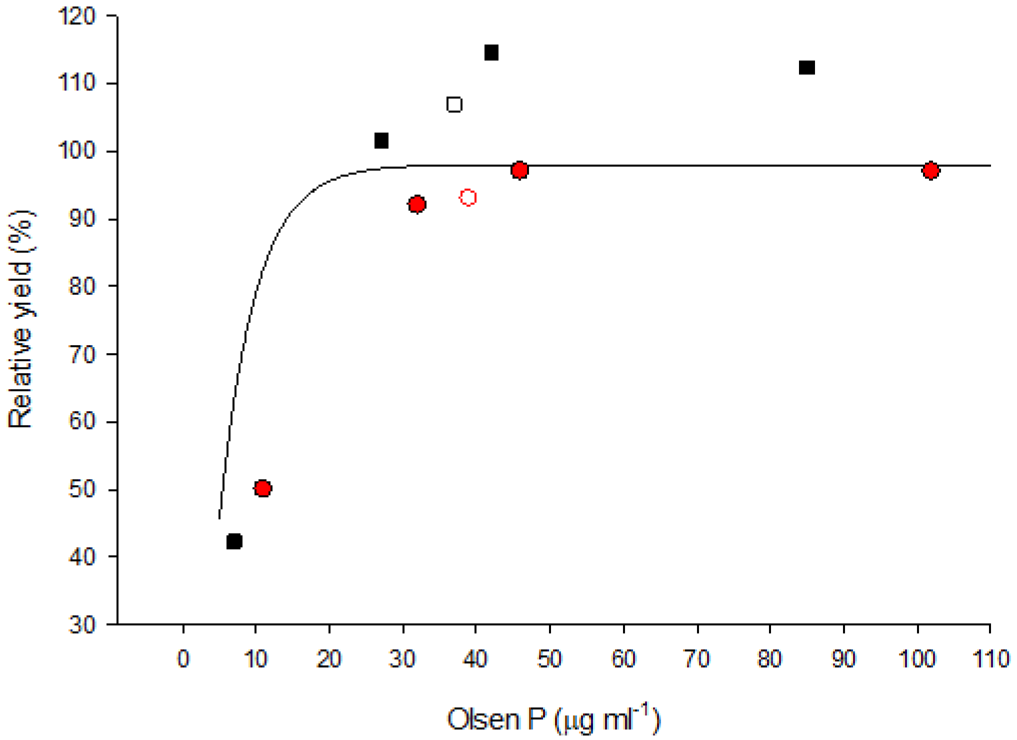

Figure 7. Relative pasture yields for the No P and SSP ● *and RPR treatments* ○ *for the 2022-2023 season and No P and SSP* ■ *and RPR treatments* □ *for the 2021-2022 season. The solid line is the long term (1981-2018) pasture response curve.*

6. Acknowledgements

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

7. References

Lynch PB 1960. Conduct of field experiments. New Zealand Department of Agriculture Bulletin 399. 72pp.

McDowell RW, Moss R, Gray CW, Smith LC, Sneath G 2021. Seventy years of data from the world’s longest grazed and irrigated pasture trials. Scientific Reports 8:53 https://doi.org/10.1038/s41597-021-00841-x.

Morton JD, Roberts AHC 2009. Fertiliser use on New Zealand sheep and beef farms. Auckland, New Zealand, New Zealand Fertiliser Manufacturer’s Research Association. 40p.

Radcliffe JE 1974. Seasonal distribution of pasture production in New Zealand I. Methods of measurement. New Zealand Journal of Experimental Agriculture 2: 337–340.

Rickard DS, 1978. Meteorological data, 1950-1976. Winchmore Irrigation Research Station Technical Report 11. 34p

Rickard DS, Moss RA 2012. Winchmore and the long-term trials: the early history. New Zealand Journal of Agricultural Research 55: 93–104.

Sinclair AG, Johnstone PD, Smith LC, Roberts AHC, O'Connor MB, Morton JD 1997. Relationship between pasture dry matter yield and soil Olsen P from a series of long-term field trials. New Zealand Journal of Agricultural Research 40: 559–567.

Smith LC, Moss RA, Morton JD, Metherell A, Fraser T 2012. Pasture production from a long-term fertiliser trial under irrigation. New Zealand Journal of Agricultural Research 55: 105–118.