Winchmore long-term fertiliser trial: 2023-2024 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. Treatments included no P (control), 188, 250 and 376 kg of single superphosphate (SSP) ha^{-1} yr^{-1} and a Sechura reactive rock phosphate (RPR) + elemental Sulphur (S) treatment applied at a phosphorus (P) and sulphur (S) rate equivalent to 250 kg SSP ha^{-1} yr^{-1}. Fertiliser is applied annually in late winter or early spring. This report summarises the results of soil and pasture monitoring from the trial undertaken for the 2023 – 2024 season.

Pasture production was measured seven times over the season, using a single trim technique with movable pasture cages to determine the rate of growth. Dry matter (DM) production from the four fertilised treatments was not significantly different, averaging 9,428 kg DM ha^{-1}. The past year's production from the no P treatment was significantly less than the fertiliser treatments at 5,507 kg DM ha^{-1}. The difference between the fertilised and no P treatments has been observed previously. However, the pasture production measured in 2023-2024 was lower than the long-term annual average (c.12,000 kg DM ha^{-1}) for the fertilised treatments, with the no P treatment consistent with the long-term average of 5,400 kg DM ha^{-1}. The relatively low level of production from the fertilised treatments occurred in the summer and early autumn when rainfall was low, evapotranspiration high and irrigation inputs apparently insufficient to meet plant water requirements. Pasture was dominated by grass species, with lesser amounts of clover and weeds which when averaged over all treatments and dates averaged 4.6 and 0.4% respectively. There was an annual summer increase in the amount of clover in the fertilised treatments, averaging 13.4 % compared to 5.9% from the no P at the summer sampling.

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 consistently between 5.6 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 a significant increase in sulphate-S concentrations in the fertiliser treatments, that remained within or slightly above the recommended range across the rest year in all the fertiliser treatments. Olsen P concentrations in the fertilised 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}. Despite the continuing increase in soil Olsen P the level of pasture production has continued to decline relative to the Olsen P accumulation and SSP application rate. The use of the spray irrigation system, which was introduced during 2019, has potential for more frequent water application to achieve increased pasture production than under the previously used border-dyke technique which applied significantly more water per application but considerably less frequently. An increase in irrigation inputs and scheduling may be required if the production potential of these pastures is to be achieved.

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 and other soil and pasture invertebrates, 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 conference proceedings 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 2023–2024 year.

3. Materials and Methods

3.1 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. Treatments applied annually since 1952 include 0 (no P), 188 and 376 kg ha^{-1} of single superphosphate (SSP). Since 1980, there has also been a 250 kg ha^{-1} yr^{-1} SSP treatment, and a 175 ha^{-1} yr^{-1} Sechura RPR/S treatment applied annually at 22 kg P ha^{-1} (equivalent to 250 kg SSP ha^{-1}).

The SSP treatments received fertiliser on 8th August 2023. However, due the inability to obtain supply, no RPR was applied during the 2022/23 year. This deficit was rectified on 8th August 2023 when a double rate was applied. 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 fertiliser applied to the trial have been retained.

The plots were grazed by separate mobs of either weaned lambs or hoggets that rotated between replicates within treatments from 14th September until 8th May 2024, shifting at 4- or 5-day intervals. Stocking rates were adjusted during the year with the aim of achieving a post-grazing residual herbage mass height of approximately 30mm.

Between 1952 to autumn 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 kg SSP), recording at 2-hourly intervals, soil moisture, soil temperature and irrigation water applied to the trial. Rainfall is measured at a NIWA climate station located on the adjacent farm, 200 metres from the trial. This data is used to calculate potential evapotranspiration (PET) enabling the calculation of soil moisture balance.

3.2 Sampling and analysis

Pasture production was measured using the rate of growth technique with two movable grazing exclusion cages (3.15 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 central strip 0.52 m wide and 3.25 m long in the middle of each enclosure to 25 mm above ground level. The wet weight was recorded, and a sub-sample taken to determine dry matter percentage. A separate sample was manually dissected into grass, clover and weeds to determine the botanical composition of the pasture, four times over the growing season, in September, November, February and March using the method described in Lynch (1966). Dried seasonal samples of grass and clover have been retained, for future analysis.

A composite soil sample of 12 cores (25 mm diameter and 75 mm deep) was collected from each plot four times: in July 2023, prior to fertiliser application, and in November, February and May 2024. Cores were taken at random following a diagonal route from end to end of each plot. All were analysed at a commercial laboratory following air drying and sieving to 2 mm, 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 625 mm of rainfall was recorded at the trial site during 2023/24, 10 % lower than the long-term annual average of 745 mm (Table 1), of which 66% occurred during winter and spring, as shown in Table 1. Summer and autumn rainfall was below the annual average with 94 and 116mm respectively. Evapotranspiration totalled 256, 373 and 135mm during spring, summer and autumn respectively, reaching a daily maximum of 8.1 mm during summer.

There was 305 mm of irrigation spread over 29 applications (average 10.5mm/application), that occurred between early September 2023 through to late April 2024. This compares with the approximately 430 mm of irrigation that was typically applied under the flood irrigation system previously, albeit, at less frequent intervals with the previous system. (Figure 1).

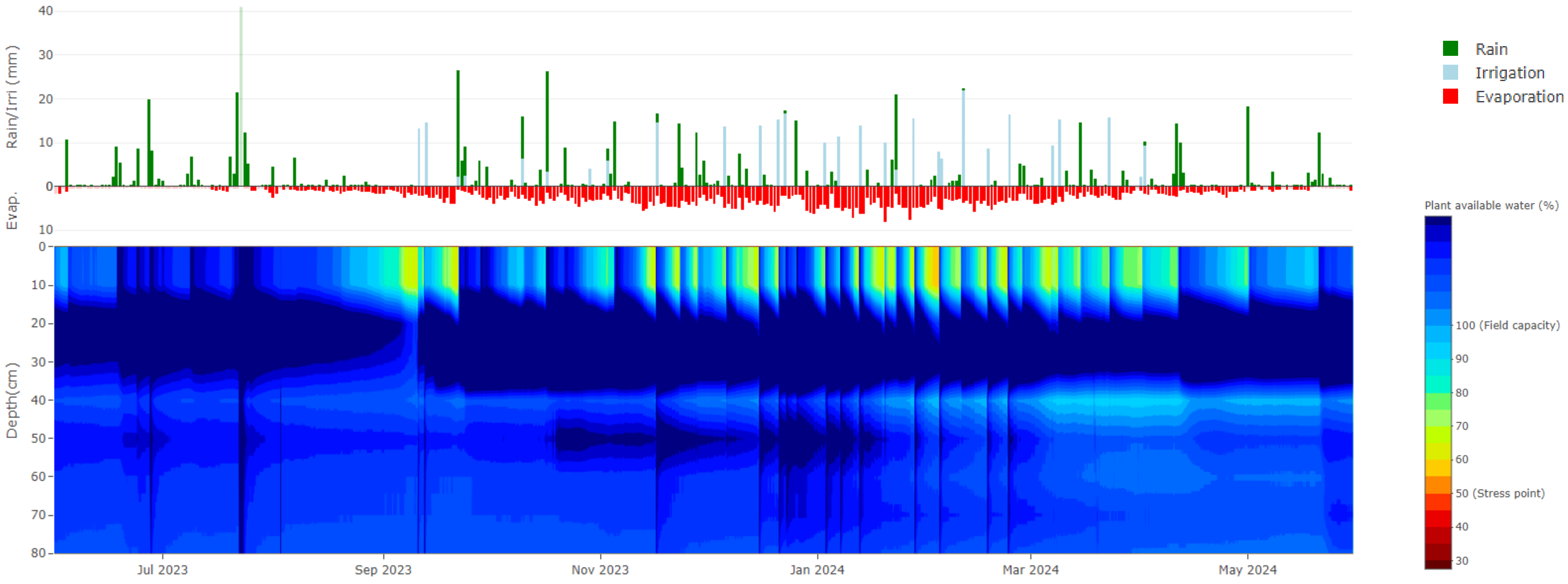

Figure 1. Daily rainfall (mm), irrigation (mm), evaporation (mm) (top panel) and soil moisture (%) (lower panel) at the Winchmore long term fertiliser trial over the 2023-2024 season.

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. As Figure 1 shows soil moisture was maintained within this target for much of the year, however, when compared overall during late spring and summer there was a soil moisture deficit (Table 1). An example of such occurrences being from 6th January, when 11.4 mm of irrigation was applied, over the next seven days (at the end of which the next irrigation occurred), PET equated to 39 mm by which time a 27.6 mm soil moisture deficit existed with the potential to detrimentally impact pasture growth.

Table 1: Seasonal and annual rainfall, potential evapotranspiration, and irrigation applications on the irrigated Winchmore long-term fertiliser trial from June 2023.

	Rain	Irrigation	PET*	Soil moisture balance #	N irrigation applications	Irrigation frequency	Irrigation / event
	mm	mm	mm	mm		days	mm
June	68	0	13	55	0	0	0
July	160	0	16	144	0	0	0
Aug	20	0	33	-13	0	0	0
Sep	45	32	57	20	1	31	14
Oct	50	14	84	-20	2	15	11
Nov	59	21	102	-22	4	8	15
Dec	40	60	110	-10	5	6	13
Jan	33	65	144	-46	4	7	15
Feb	22	61	101	-18	3	10	13
Mar	33	40	75	-2	1	30	12
Apr	35	12	42	5	0	0	0
May	48	0	18	30	0	0	0

*PET potential evapotranspiration

Soil moisture balance calculated as rain + irrigation – PET.

4.2 Pasture production.

Pasture was harvested on seven occasions between early April 2023 and late May 2024. Dry matter (DM) yields were higher from the fertilised treatments than the No P throughout the year and in total, but differences were not significant during autumn (Table 2; Figure 2). Despite different rates of P fertiliser application and associated soil Olsen P levels (Table 4), there were no significant differences in DM yield between the four fertilised treatments (Table 2) which averaged c. 9,428 kg ha^{-1}. This was lower than the long-term average for the trial of c. 12, 000 kg ha^{-1} (Figure 3). Daily pasture growth rates increased in spring, as is the historical trend, before declining in summer (Figure 2).

Table 2: Seasonal and annual pasture production from the irrigated Winchmore long-term fertiliser trial for 2023-2024 (kg DM ha^{-1}). Data with letters in common, within treatments and dates, are not significantly different. (P < 0.05.).

Treatment	Winter	Spring	Summer	Autumn	Total
No P	508 a	3248 a	1225 a	353 a	5333 a
188 kg SSP ha^{-1}	1146 b	5854 b	1774 b	420 a	9193 b
250 kg SSP ha^{-1}	1465 b	5527 b	1917 b	584 a	9494 b
175 kg RPR ha^{-1}	1131 b	5570 b	1861 b	669 a	9231 b
375 kg SSP ha^{-1}	1222 b	5739 b	2118 b	715 a	9795 b

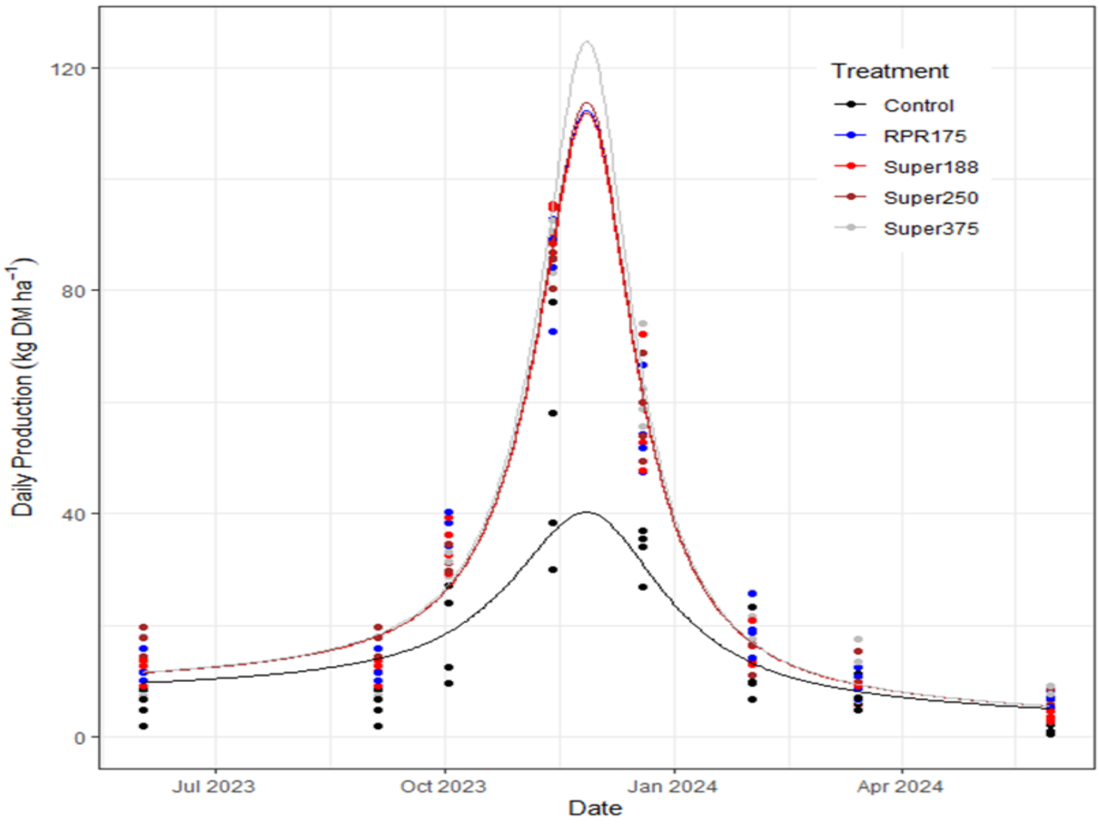

Figure 2. Daily pasture growth over for the 2023/24 year for the long-term irrigated fertiliser trial at Winchmore (kg DM ha^{-1} day^{-1}). Smoothed curves have been fitted to the data.

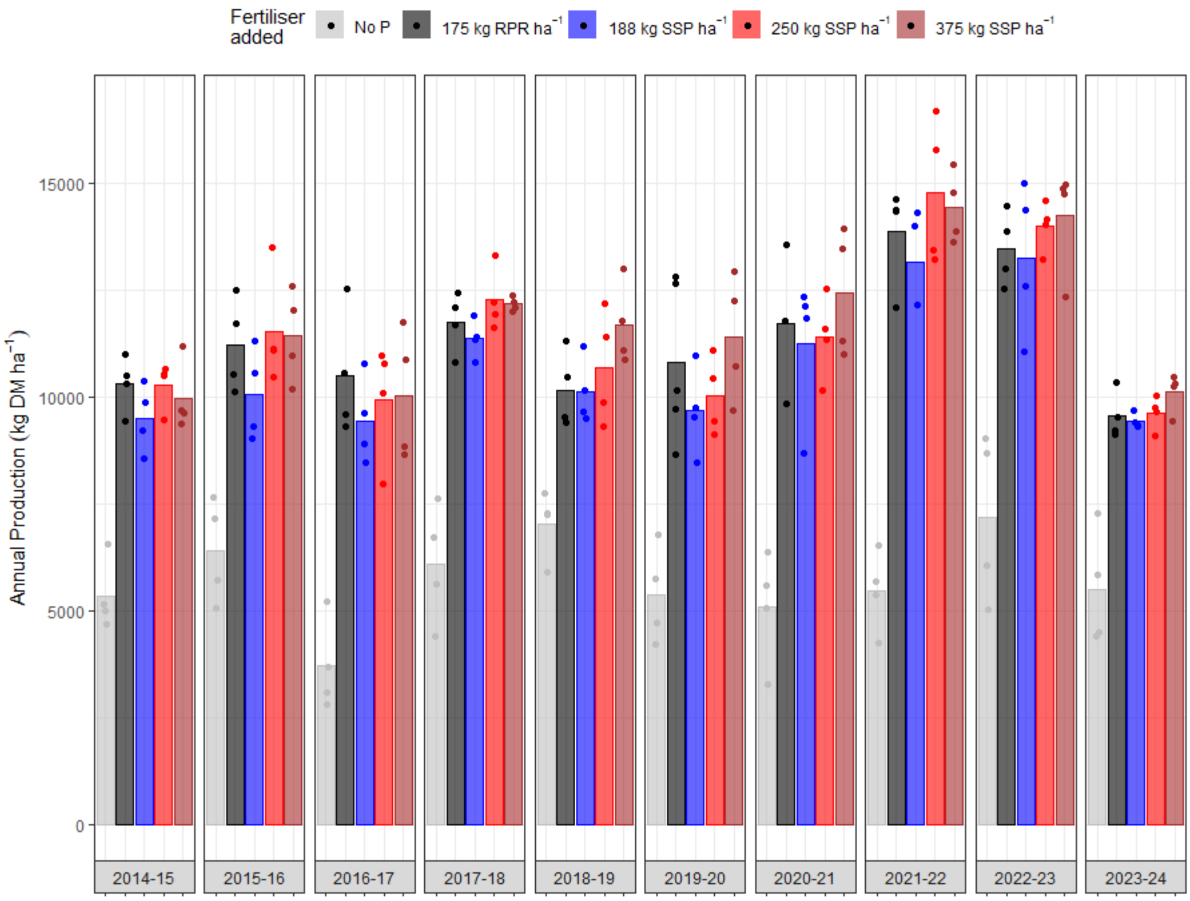

Figure 3. Annual pasture production over the past 10 years for the long-term irrigated fertiliser trial at Winchmore (kg DM ha[1]).

4.3 Species composition

In common 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 the proportion of clover typically increased averaging 13.4% from the fertilised treatments compared with 5.9% from No P treatment during summer. However, variation within treatments were such that differences were not significant. 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). Although the population of clover root weevil was not measured, it is reasonable to assume that their fluctuating population will have had some influence on the overall performance of clover.

Californian thistles have been an issue of increasing concern during the past three years, following the agreed position to avoid herbicide use, the recommended control method of twice-yearly mowing was implemented, however this was not effective and, their numbers continued to increase. Consequentially, the decision was made to apply the herbicide "Versatill" (ai clopyralid) which was sequentially applied, following grazing, via "rotowiper" during late December and early January, with apparently effective control. The competition for soil moisture and nutrients exerted by the significant population of Californian thistles prior to their herbicide treatment, may have contributed to the lower level of pasture production discussed above.

Table 3: Seasonal and treatment effects on pasture species compositions from the Winchmore long-term irrigated fertiliser trial for 2023-2024 (% species present on a dry matter basis). Differences are assumed to be significant with P < 0.05, at which level no significant differences between treatments and within species occurred.

Treatment	**4-9-23**			**13-11-23**			**1-2-24**			**14-3-24**		
	Grass	Clover	Weeds	Grass	Clover	Weeds	Grass	Clover	Weeds	Grass	Clover	Weeds
No P	99.4	0.6	0.0	96.2	3.1	0.7	92.1	5.9	2.0	98.2	1.8	0.0
188 kg SSP ha^{-1}	99.4	0.5	0.1	96.8	2.5	0.7	90.7	8.5	0.8	95.4	4.0	0.6
250 kg SSP ha^{-1}	99.6	0.4	0.0	97.4	2.3	0.3	86.9	13.5	0.5	97.0	2.9	0.1
175 kg RPR ha^{-1}	99.8	0.2	0.0	98.1	1.8	0.1	81.9	17.4	0.7	94.8	5.1	0.1
375 kg SSP ha^{-1}	99.8	0.1	0.1	96.9	2.7	0.4	85.6	14.0	0.4	92.1	7.9	0.0
P-value	0.767	0.570	0.711	0.963	0.852	0.984	0.639	0.483	0.524	0.385	0.115	0.385

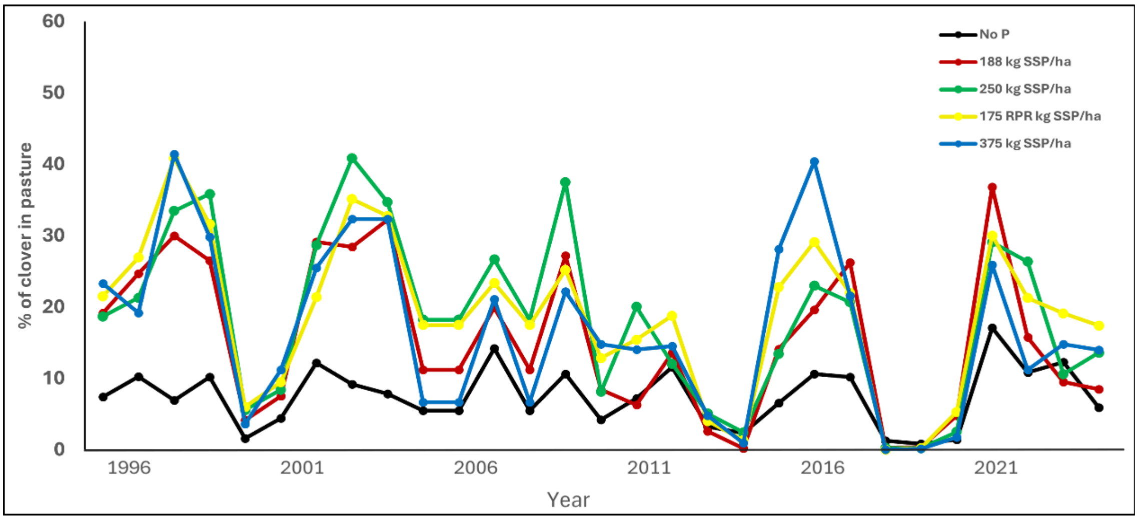

Figure 4. Long term effect of phosphate fertiliser application on clover content (%) over the summer from the Winchmore long-term irrigated fertiliser trial.

Soil analysis

The application of P fertiliser had no significant effect on soil pH, Mg, K, or Na concentrations (Table 4). In line with the results found in previous years, K concentrations were slightly higher than the recommended range (5 – 8 QT) for pasture sites grazed by sheep in New Zealand (Morton and Roberts 2018). Magnesium was about triple the recommended concentration range (8 – 10 QT) for pasture growth, although similar to the recommended concentration for ewes in spring of 25 to 30 (Morton and Roberts 2018). This reflects soil type rather than fertiliser inputs.

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, apart from 2004, 2010 and 2016, soil pH has been remained reasonably consistently between 5.4 and 5.9.

Calcium was significantly higher in the fertilised treatments compared to the no P treatment (Table 4), consistent with previous years. 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). Other than in July, sulphate-S concentrations were above the recommended range (10 – 12 µg mL^{-1}) (Morton and Roberts 2018) in all the fertiliser treatments. Olsen P concentrations in the fertilised treatments were significantly higher than the No P treatment at all four sampling 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 (Tables 4 and 6).

Table 4: Soil test results from the Winchmore long-term irrigated fertiliser trial for the 2023-2024 season. Data with letters in common, within treatments and dates, are not significantly different. ($P < 0.05$.).

Treatment	pH	Ca (QT)	Mg (QT)	K (QT)	Na (QT)	Olsen P ($\mu g\ mL^{-1}$)	SO_4-S ($\mu g\ mL^{-1}$)
July 2023							
No P	5.7 a	10 a	30 a	17 a	4.7 a	7 a	8 a
188 kg SSP ha^{-1}	5.5 a	12 b	31 a	17 a	5.8 a	32 b	11 ac
250 kg SSP ha^{-1}	5.5 a	12 b	30 a	14 a	5.8 a	49 c	11 ac
175 kg RPR ha^{-1}	5.5 a	12 b	32 a	17 a	5.3 a	42 bc	17 b
375 kg SSP ha^{-1}	5.5 a	14 c	30 a	13 a	5.8 a	104 d	12 c
November 2023							
No P						8 a	6 a
188 kg SSP ha^{-1}						33 b	15 b
250 kg SSP ha^{-1}						41 b	18 b
175 kg RPR ha^{-1}						35 b	21 c
375 kg SSP ha^{-1}						89 c	28 c
February 2024							
No P						8 a	7 a
188 kg SSP ha^{-1}						29 b	17 ab
250 kg SSP ha^{-1}						48 c	28 b
175 kg RPR ha^{-1}						33 b	26 b
375 kg SSP ha^{-1}						101 d	45 c
May 2024							
No P						8 a	6 a
188 kg SSP ha^{-1}						29 b	13 ab
250 kg SSP ha^{-1}						49 c	23 ab
175 kg RPR ha^{-1}						35 b	27 b
375 kg SSP ha^{-1}						88 d	30 b

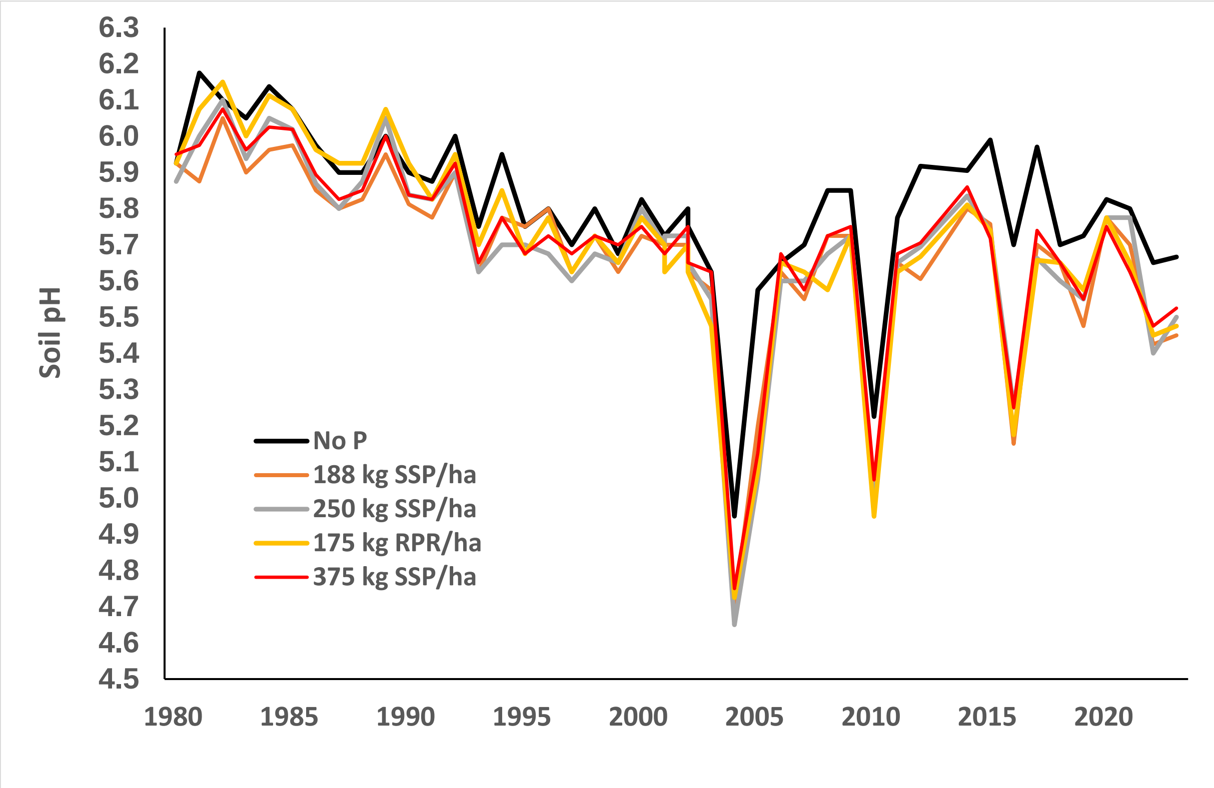

Figure 5: Soil pH values (0 – 75 mm depth) measured in winter each year from the long-term irrigated fertiliser trial at Winchmore.

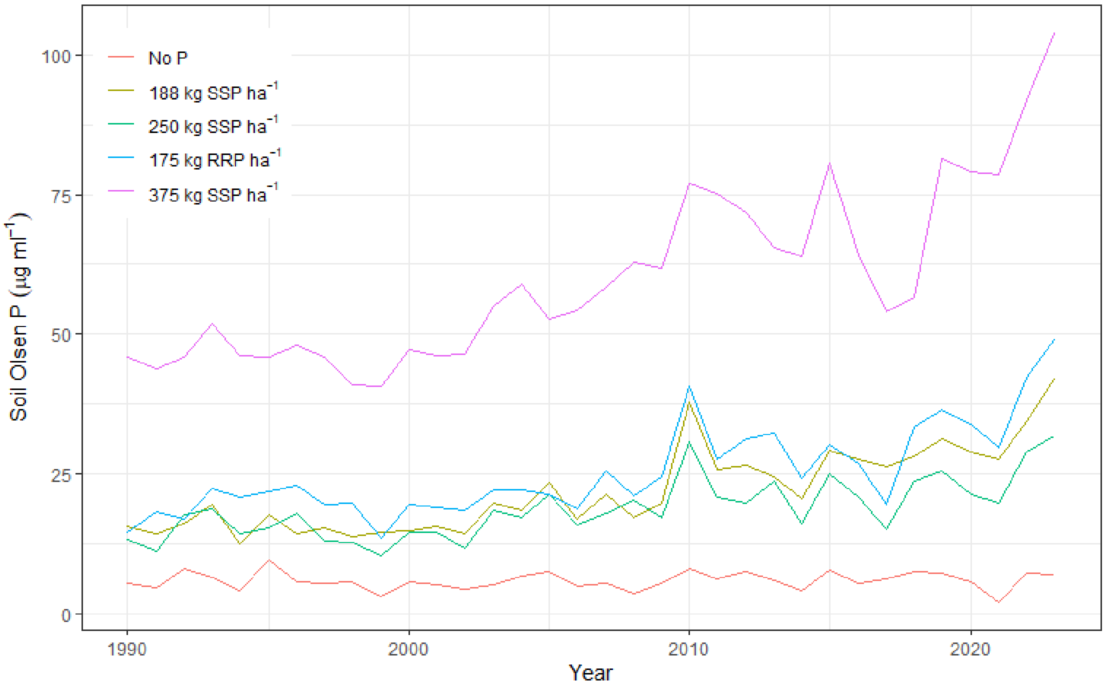

Figure 6: Soil Olsen P concentrations (0 – 75 mm depth) measured in winter prior to the annual application of fertiliser, from the immediate past 33 years, from the long-term irrigated fertiliser trial at Winchmore.

5 Response curve

There has been a steady increase in Olsen P concentrations associated with the fertilised treatments over the last 25 years, especially in the 375 kg SSP treatment which has increased from about 50 to 104 µg mL^{-1} (Figure 6). However, there has not been a concomitant increase in pasture production associated with the increase in accumulated Olsen P (Figure 7). Furthermore, the relative yields from this year's production are consistently below the long-term response curve for the majority of treatments.

While Californian thistles may have had some impact on total pasture production, as discussed above, they did not infest the entire area of any plots whereas the soil moisture balance, displayed in Table 1, indicated there was a soil moisture deficit on every month from October through to March which will have had a major negative impact on pasture performance.

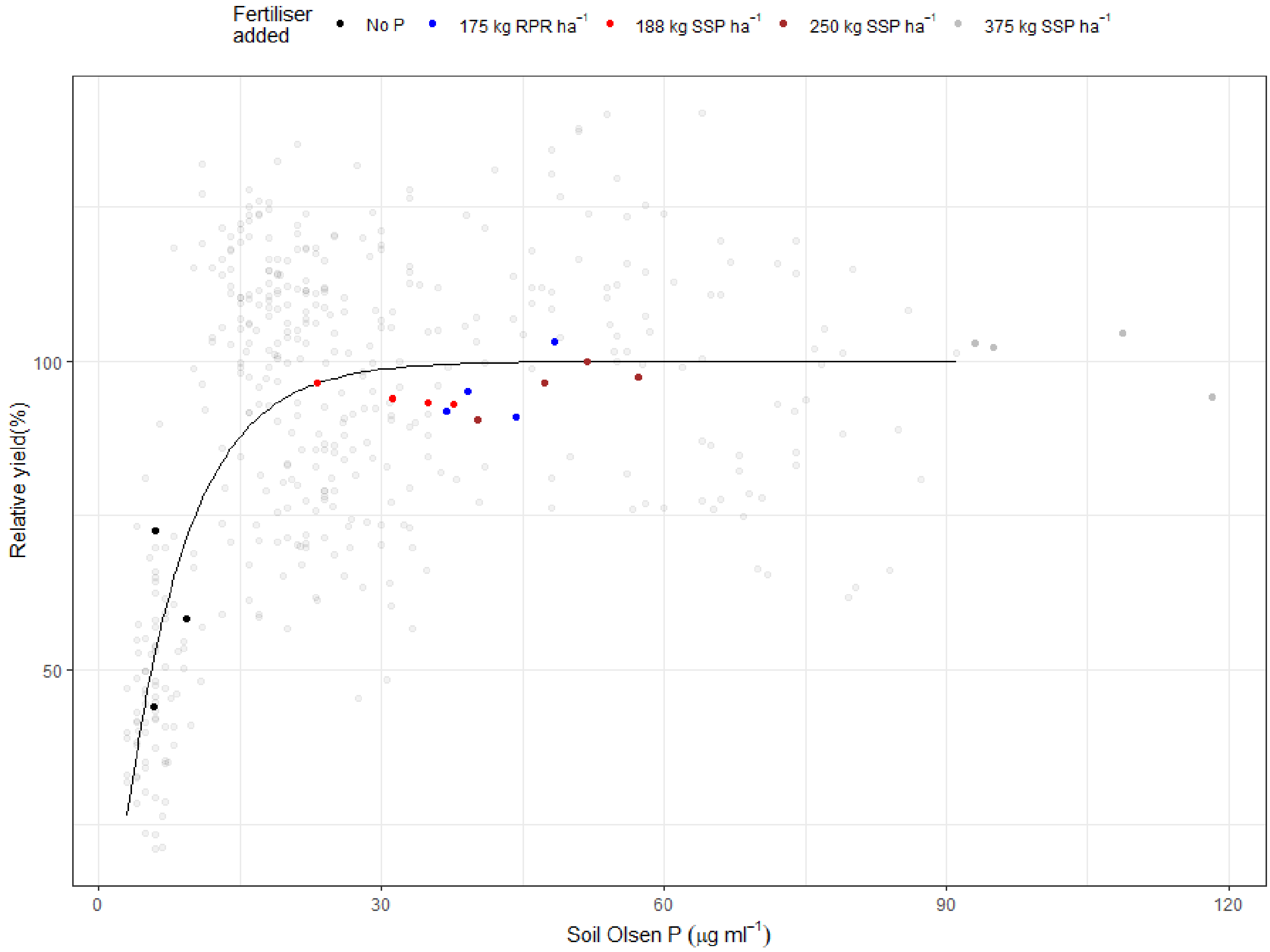

Figure 7. Pasture yields relative to soil P for the 2023-24 year for the irrigated long-term fertiliser trial at Winchmore. The solid line is the 1981-2018 pasture response curve, while the numerous grey points indicate the variation associated with the generation of the response curve. (Unfortunately, the analytical laboratory mislaid a No P sample hence only three points for this treatment).

6 Acknowledgements

We would like to acknowledge Chris Olley, the farm owner, for irrigation management and permitting access to the site, Regan Baxter from the AgResearch Lincoln farm team for supplying stock and overseeing their welfare and Charlotte Scott, for their onsite management, and the Fertiliser Association of New Zealand for their continued funding of this trial.

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