The effect of potassium fertilisation and timing on potassium uptake, grain yield and grain quality in a spring sown wheat crop

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Abstract

Potassium (K) is a key nutrient required by wheat for crop quality, pest and disease tolerance, flowering quality and straw strength. Potassium was applied to an irrigated spring sown wheat crop at rates of 0, 50, 100, 200 and 400 kg K/ha, either at sowing or with the first nitrogen side dressing, to determine if there would be an effect on potassium uptake, grain yield and grain quality. Results indicated that grain yield was not significantly affected by K fertilisation. However, grain protein content increased significantly with high rates of K application. Although QTK tests were below optimum, TBK tests were high indicating that the supply of K from soil reserves were able to keep up with spring wheat demands. Analysis of K concentration in the herbage demonstrated that K at sowing was more beneficial to increasing K uptake compared to K at side-dressing treatment. Potassium application increased QTK and TBK in the post-harvest plot soil tests; indicating that the wheat plant regulated its K uptake at excess K application.

Additional keywords: *Triticum aestivum*, Canterbury, potassium chloride fertiliser, herbage test, grain protein, TBK

Introduction

Wheat (*Triticum aestivum*) yields in New Zealand have been increasing steadily since the 1990s (Millner and Roskruge, 2013). Canterbury is the largest wheat growing area, with 82% of the wheat area, planted in New Zealand (Statistics New Zealand, 2016). Wheat grown in Canterbury is part of a typical arable crop rotation of cereals, grass, clover and vegetable seeds, process vegetables and silage crops (Ministry for Primary Industries, 2012).

Potassium (K) is a key nutrient required by plants and is considered essential for crop growth and yield (Pettigrew, 2008). Plants use K for physiological processes such as enzyme activation, stomatal activity, photosynthesis, sugar, water and nutrient transport, and protein and starch synthesis (Prajapati and Modi, 2012). In wheat, K has a key role in crop quality, pest and disease tolerance, flowering quality and straw strength.

Soil K is found in three forms: unavailable, fixed, and readily available (Prajapati and Modi, 2012). Potassium content in the soil depends on the soil type, with the majority of total soil K found in the unavailable form. Soil minerals such as feldspars and micas contain high amounts of K and as the soil weathers over time, K is released. Fixed or non-exchangeable K is trapped between layers of clay minerals and can become available in small amounts during a growing season. The sodium tetraphenyl boron method (TBK test) can measure non-exchangeable K and therefore give an indication of the long-term store of K. Quick-test K (QTK) measures readily available K that is held in soil solution or on exchange sites on soil colloids. The youthfulness of soils in New Zealand mean they generally have naturally high available K (Kirkman *et al.*, 1994). However, in high rainfall environments or in soils with a low cation exchange capacity, available K can be leached resulting in lower QTK values.

International research has demonstrated a potassium fertiliser response in wheat grain yield in both low and high available K soils (Chapman and Mason, 1969; Megnel *et al.*, 1981; Singh and Sharma, 2001; Sweeney *et al.*, 2000; Wani *et al.*, 2014). However, research completed in New Zealand has shown no response to potassium fertiliser (Hudson and Woodcock, 1934; Lynch, 1956; Stephen, 2001). With wheat yields on the rise and no recent local data published, further investigation in to potassium application and uptake by the plant is required. The aim of this research was to identify whether the application of potassium fertiliser would increase grain yield and quality in spring-sown wheat at a low K soil test level in Canterbury.

Materials and Methods

Experimental details

The field trial site was established 20km south west of Christchurch, New Zealand (43˚ 36 46.4292” S; 172˚ 29’ 8.3904” E) to determine the effect of potassium fertiliser on potassium uptake and wheat yield. The soil at the site was a deep moderately drained Templeton silt loam (Typic Immature Pallic Soil, New Zealand Soil Classification (Hewitt, 1992), Udic Haplustept, USDA classification (Soil Survey Staff, 1998)). Irrigation occurred at the site through a hard hose lateral.

In May 2017, grid soil testing of the paddock was completed. This enabled identification of a low QTK site in the north-western corner of the paddock. Soil tests for this area were (optimum ranges from Morton *et al*. 1998 are in brackets) pH 5.7 (5.8-6.2), Olsen P 15 mg/L (>15), QTK 3.5 (6-10), QT Mg 10 (>10), QT Na 5, Sulphate-S 9 mg/kg (10-15) and TBK 4.8 me/100g.

The wheat cultivar *Discovery* (a high yielding spring milling or feed wheat cultivar developed by PGG Wrightson Grain) was sown at 140 kg seed/ha on 18 August 2017 with 250 kg/ha of Triple Super (0-20.4-0-0) broadcast before sowing on 9 August 2017. Nitrogen side-dressings were applied on the 12 October, 10 November and 24 November at rates of 180, 140 and 140 kg/ha of urea (46-0-0-0) respectively. Fifty-four 12 m x 2.5 m experimental plots were established on 1 September 2017. Treatments were applied to plots using a randomised block design. Four application rates; 50, 100, 200, 400 kg K/ha were applied at two timings; base (1 September 2017) and side-dressing (3 November 2017). Potassium treatments are described further in Table 1. All potassium was applied as potassium chloride (0-0-50-0) (Muriate of Potash).

The staff at PGG Wrightsons Limited, Kimihia, managed all crop agronomy, outside of potassium fertiliser applications, including pest, weed and disease management.

Table 1: Potassium treatments applied as KCL.

Treatment number	Potassium application (kg K/ha)	
	Base	Side dressing
1	0	0
2	50	0
3	100	0
4	200	0
5	400	0
6	0	50
7	0	100
8	0	200
9	0	400

Measurements

To determine establishment across the plots, plant counts occurred on the 21 of September and 11 of October. Two counts 1m in length were taken per plot randomly along a drill row.

Destructive sampling areas were allocated to each plot to ensure the grain harvest area was left intact. To determine K uptake, composite herbage tests were taken of each treatment on the 21 September, 13 October, 20 October, 20 November, 14 December 2017 and 11 of January 2018 using herbage shears.

Harvest of the wheat occurred on the 30 January 2018. Individual plot soil tests were taken to a depth of 150 mm to determine soil test levels on the 8 February 2018. Sampling cores were taken randomly through the middle of each plot and analysed as a composite sample.

Soil and herbage tests were analysed by RJ Hill Laboratories Ltd, Hamilton, New Zealand. Soil was analysed for QTK and TBK using methods described in Blakemore *et al.* (1987) and Carey and Metherell (2003) respectively. Herbage tests were analysed for K content (%) using methods detailed in Anderson (1996). Screenings, test weight, thousand grain weight and protein content was carried out by NZ Grainlab, Christchurch, New Zealand.

Statistical analysis

Wheat grain yield and quality values and post-harvest soil tests were statistically analysed through analysis of variance (ANOVA) using Microsoft Excel 2016. Four replicates were used in the analysis of grain yield and quality due to bird damage in replicate one and two. Using Statistical Tool for Agricultural Research (STAR), an ANOVA and Tukeys Honest Significant Difference (HSD) test was used to evaluate statistical significance for herbage nutrient uptake, utilising the sampling dates as replicates.

Results

Plant counts

Overall, potassium application did not significantly affected wheat establishment compared to the control. A decline in plant counts from the 21 September to the 11 October occurred in all treatments suggesting some seedling death. However, this was not influenced by fertiliser application.

Potassium uptake and concentration

Potassium content (%) of herbage followed a similar trend for each of the K at sowing treatments, with the K content peaking in the 13/10/2018 sample and then steadily declining as the crop developed (Figure 1).

Initially, the addition of K at sowing increased the K content compared to the control. With K content increasing in the 21/09/2018 herbage sample from 2.3% in the control to 3.6% in the 400 kg K/ha treatment. However, by the 13/10/2018 herbage sample, the highest K content was in the 100 kg K/ha treatment. As the K content declined in the herbage, the range of K content between the treatments became smaller.

All of the K treatments, K at sowing and K at side-dressing, were sampled on the 20/11/2015, 14/12/2018 and 11/01/2018. When comparing the K at sowing and K at side-dressing treatments, the K at sowing had higher K contents than the K at side-dressing treatments for all of the application rates and across all of the sampling dates.

Statistical analysis of the mean K concentration utilised the herbage sampling dates as replicates (Table 2). Potassium application at sowing did not significantly increase the herbage K concentration compared to the control. Furthermore, K at side-dressing did not increase the K concentration compared to K at sowing. In contrast, K at sowing did significantly increase the herbage in the 100 kg K/ha, 200 kg K/ha and 400kg K/ha treatments.

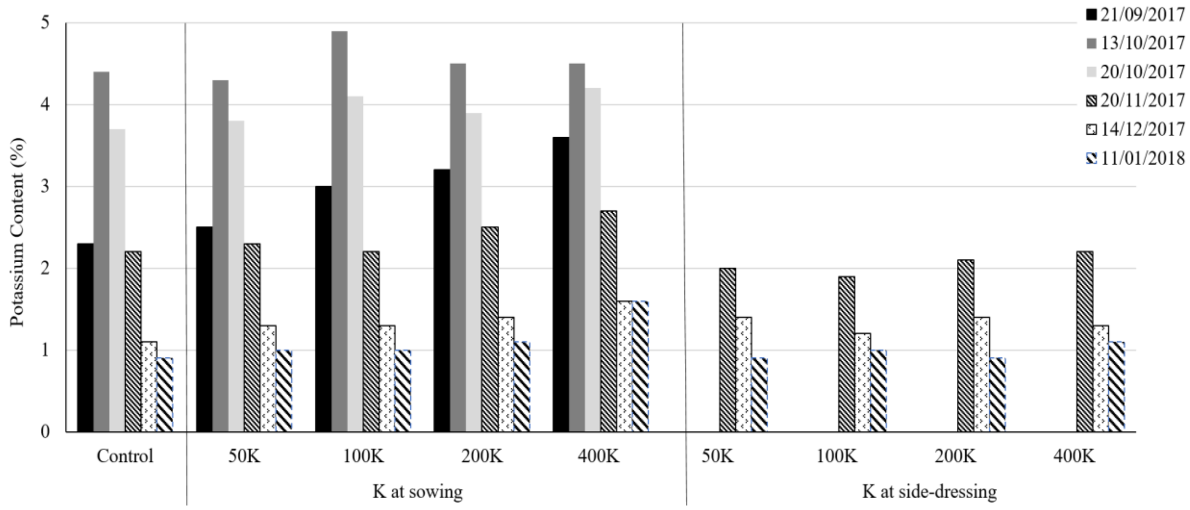

Figure 1: Composite herbage potassium content for control, potassium at sowing treatments and potassium side-dressing treatments. Application of side-dressing potassium occurred on 3 November 2018 hence only three sampling dates for K at side-dressing treatment.

Other nutrient concentration

Statistical analysis of the mean nutrient concentrations utilised the herbage sampling dates as replicates (Table 2). There was no significant impact of K application rates or timing on the mean nutrient concentrations for nitrogen (N), phosphorus (P), sulphur (S), calcium, (Ca), iron (Fe), copper (Cu) and boron (B).

Mean magnesium (Mg) concentration was higher in the 200kg K/ha at sowing and side-dressing treatments, but only when compared to the 100kg K/ha at side-dressing treatments. When compared to the control there was no significant change in mean magnesium concentration.

Potassium application did decrease the sodium (Na) mean concentration in the 100kg K/ha side-dressing treatment when compared to the control. However, it did not significantly alter Na uptake for any other treatments.

Table 2: Tukeys Honest Significant Difference (HSD) test for nutrient uptake concentration in the herbage, utilising the sampling dates as replicates (N=6). Means with the same letter are not significantly different.

Treatment	N (%)	P (%)	K (%)	S (%)	Ca (%)	Mg (%)
Control	3.70	0.35	**2.43[b]**	0.30	0.41	0.15[ab]
50K @ sowing	3.73	0.36	**2.53[b]**	0.29	0.39	0.14[ab]
100K @ sowing	3.73	0.36	**2.75[ab]**	0.29	0.38	0.13[ab]
200K @ sowing	3.78	0.37	**2.77[ab]**	0.30	0.40	0.15[a]
400K @ sowing	3.80	0.37	**3.03[a]**	0.31	0.40	0.15[ab]
50K @ side-dressing	3.73	0.36	**2.45[b]**	0.29	0.37	0.13[ab]
100K @ side-dressing	3.70	0.35	**2.42[b]**	0.29	0.36	0.12[b]
200K @ side-dressing	3.77	0.36	**2.47[b]**	0.30	0.40	0.15[a]
400K @ side-dressing	3.83	0.36	**2.50[b]**	0.30	0.40	0.15[ab]
Tukeys HSD Test	**NS**	**NS**	**0.35**	**NS**	**NS**	**0.03**

Treatment	Na (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	B (ppm)
Control	0.05[a]	102	42[c]	22[c]	7[a]	3
50K @ sowing	0.04[ab]	145	45[bc]	24[abc]	7[a]	3
100K @ sowing	0.03[ab]	235	54[b]	25[ab]	7[a]	4
200K @ sowing	0.05[a]	103	44[bc]	23[bc]	6[a]	4
400K @ sowing	0.05[a]	105	45[bc]	23[bc]	6[a]	4
50K @ side-dressing	0.03[ab]	180	51[bc]	24[abc]	6[a]	4
100K @ side-dressing	0.03[b]	122	67[a]	26[a]	6[a]	4
200K @ side-dressing	0.05[a]	104	45[bc]	23[bc]	7[a]	3
400K @ side-dressing	0.05[a]	105	47[bc]	24[abc]	7[a]	3
Tukeys HSD Test	**0.016**	**NS**	**11**	**2**	**1**	**NS**

Mean manganese (Mn) and zinc (Zn) concentrations increased significantly compared to the control in the 100kg K/ha side-dressing treatment only. For all other treatments, there was no significant effect of K application rate and timing.

Grain yield and quality

For analysis of grain yield and quality, replicate 1 and 2 were removed due to decreased grain yield caused by bird damage. The average grain yield from four replicates was 9.2 T/ha, with a range of 8.85-9.62 T/ha (Table 3). Potassium application rate and timing did not significantly affect grain yield.

Grain quality was assessed through screening (%), thousand grain weight (TGW) (g), test weight (Test Wt) (kg/hl) and protein content (%) (Table 3). For statistical analysis, replicate 1 and 2 were removed due to bird damage. There was no significant difference between K treatments in the grain screening (Table 3). In the TGW there was a significant increase compared to the control for the 100, 200 and 400 kg K/ha at sowing. There was no significant difference between the control and the side-dressing K treatments. However, applying K at sowing did significantly increase the TGW compared to the K at side-dressing for the 100, 200 and 400 kg K/ha treatments.

The test weight was only found to be significantly different between the control at 79.7 kg/hl and the 100 kg K/ha at sowing treatment at 80.5 kg/hl (Table 3). For all other treatments, there was no significant difference.

Table 3: Grain yield and quality assessment for K at sowing and K at side-dressing treatments.

Treatment	Grain Yield (T/ha)	Screen (%)	TGW (g)	Test Wt (kg/hl)	Protein (%)
Control	9.01	0.7	50.8	79.7	12.4
50K @ sowing	9.14	0.6	51.0	79.4	12.5
100K @ sowing	9.62	0.5	53.2	80.5	12.7
200K @ sowing	9.34	0.5	52.9	80.1	12.8
400K @sowing	9.33	0.4	52.9	80.0	13.0
50K @side-dressing	9.17	0.5	51.2	79.4	12.4
100K @side-dressing	9.26	0.6	51.0	79.5	12.5
200K @side-dressing	9.17	0.5	51.1	79.5	12.7
400K @side-dressing	8.85	0.5	51.1	79.7	12.9
sig	**NS**	**NS**	*****	*****	*******
LSD	**0.49**	**0.2**	**1.8**	**0.7**	**0.3**

Protein content of the grain significantly increased with application of K regardless of the timing of the application (Table 3). As the application rate of K increased, the protein content of the grain also increased, with highest protein content of 13% and 12.9% was found in the 400kg K/ha at sowing and side-dressing treatment respectively.

Post-harvest soil tests

Soil QTK and TBK levels significantly increased compared to the control (Table 4). The highest QTK and TBK level was seen in the plots that received the 400 kg K/ha increasing from a QTK of 4 to 10 and TBK from 4.8 to 5.2me/100g. Application timing did not significantly change the QTK or TBK in any of the application rates treatments.

Table 4: Post harvest soil test for K at sowing and K at side-dressing treatments. Statistical difference determine by ANOVA. SS* = Sulphate Sulphur; K = Potassium; Ca = Calcium; Mg = Magnesium; Na = Sodium.

Treatment	**pH**	**Olsen P** (mg/ L)	**SS*** (mg/ kg)	**K** (MAF units)	**Ca** (MAF units)	**Mg** (MAF units)	**Na** (MAF units)	**TBK** (me/ 100g)
Control	5.7	15.3	8.5	4.0[a]	8.7	9.8[a]	5.2	4.8[a]
50K @ sowing	5.7	15.3	7.5	4.5[a]	8.3	9.7[a]	5.5	4.7[a]
100K @ sowing	5.7	17.7	7.3	5.5[b]	8.7	10.0[a]	5.2	4.8[a]
200K @ sowing	5.8	15.8	9.5	6.5[c]	8.7	9.7[a]	5.2	5.0[b]
400K @ sowing	5.7	16.2	8.0	10.0[d]	8.5	8.8[b]	5.0	5.2[c]
50K @ side-dressing	5.8	16.7	7.7	4.5[a]	9.0	9.7[a]	5.2	4.8[a]
100K @ side-dressing	5.8	16.3	8.0	4.8[a]	8.8	10.0[a]	5.5	4.8[a]
200K @ side-dressing	5.8	15.7	8.5	6.3[bc]	8.5	9.5[a]	5.2	4.9[b]
400K @ side-dressing	5.8	17.2	8.3	9.2[d]	8.5	8.8[b]	5.0	5.2[c]
significance	**NS**	**NS**	**NS**	*******	**NS**	******	**NS**	*******
LSD	**0.1**	**3.3**	**2.6**	**0.9**	**0.6**	**0.6**	**0.5**	**0.1**

Soil pH, Olsen P, Sulphate-S, QTCa and QTNa did not significantly change by the application of potassium fertiliser (Table 4). The QTMg was significantly lower in both the 400kg K/ha at sowing and side-dressing treatments compared to the control. However, this was not reflected in the Mg concentration in the herbage (Table 2).

Discussion

The uptake of potassium in the herbage indicates that as the plant develops it regulates the potassium uptake (Figure 1). Gregory *et al.* (1979) found that the majority of K was taken up by wheat during the rapid phase of growth, and then lost through efflux from the roots into the soil after anthesis. This was demonstrated by the K uptake peaking during early development, then decreasing as the plant matured, with the lowest concentration in the final herbage test, taken after anthesis (Figure 1). The lack of significant increase in mean K herbage concentration with the K side-dressing treatments indicates that K at sowing is more beneficial to increase K concentration in the herbage (Table 2). Furthermore, it demonstrates that the reserve K (TBK) was able to keep up with crop demand in the early stages of development prior to the K side-dressing application. Wani *et al.* (2014)

suggested that the non-exchangeable fraction or fixed K meets the majority of plant K requirement. In addition, potassium reserves can be greater at depths in the soil profile compared to the plough layer (Khan *et al*., 2013). In this trial, the TBK was 4.8 me/100g suggesting that there is a large store of reserve K in the soil. The lack of grain yield response from added K, even at a low QTK level, suggests that the K release from the non-exchangeable K (TBK) was occurring at a sufficient rate to keep up with plant demand. Furthermore, the deeper rooting nature of wheat, means it could potentially access K deeper in the soil profile (Khan *et al.,* 2013). This is similar findings as Bushong *et al.* (2014) where the application of K on winter wheat had no effect on yield on a soil with high reserve and fixed K. Carey and Metherell (2003) state that where QTK levels are borderline that utilising the TBK test can help indicate whether K fertiliser should be applied.

Potassium has also been demonstrated to reduce lodging and increase straw strength (Pettigrew, 2008; Prajapati and Modi, 2012). In this study, there was no lodging event to indicate if this had occurred. Furthermore, straw strength was not measured or assessed post-harvest.

Potassium has been shown to interact with soil nutrients, particularly Ca, Mg and Na (Fageria, 2001; Robson and Pitman, 1983). Ohno and Grunes (1984) showed that increasing K supply decreased Mg shoot concentrations in winter wheat in a soil culture study. In addition, Hannaway *et al.* (1982) reported similar results in a sand culture experiment with tall fescue. Although QTMg did decrease with increasing K applications in this trial, there was no significant impact on the mean Mg herbage concentration of the wheat compared to the control. Furthermore, when compared to the control, there was no impact on Ca or Na soil test or uptake. Potassium has also has been shown to increase Zn uptake in corn (Shukla and Mukhi, 1980); alter the absorption of Mn in rice (Ramani and Kannan, 1974); decrease B levels (Gupta, 1979); and reduce Cu levels in alfalfa (Smith, 1975). In this trial, Zn and Mn was only effected in the 100kg K/ha at side-dressing treatment when compared to the control. In all other treatments there was no effect of K application or timing on Zn and Mn. Copper and B levels were also not effected. This could be due to the uncontrolled nature of a field trial where wheat plants can fully explore soil depths to access nutrients compared to controlled plot trials.

Potassium application rate and timing did not have a significant impact on grain yield in spring-sown wheat. This is similar to results shown by Bushong *et al.* (2014); Hudson and Woodcock (1934); Lynch (1956); and Stephen (2001) and further supports the review paper by Khan *et al.* (2013). However, the application of potassium fertiliser did have an effect on grain quality with changes in TGW and protein quality with potassium application. Koch and Mengel (1977) found that higher K application improved the translocation of N to the grain. Bakhsh *et al.* (1986) found in a K deficient soil, K application increased protein content in the grain. In addition, Mengel *et al.* (1981) found that K application improved protein synthesis in the grain even though K content in the grain did not change. Jamieson *et al.* (2001) found no response to K fertiliser on autumn sown wheat; however, the low K soil levels did reduce response to nitrogen. If there was a reduced response of added N due to low K levels this would be shown in a reduced grain yield. However, in this trial, there was no significant difference in grain yield with and without added K suggesting that there was no reduction in N response. The application of high rates of K to increase protein levels would be a higher cost method of increasing protein concentrations in the grain. Currently, late applications of nitrogen are utilised to increase protein with a much lower cost to the farmer. However, if capital rates of fertiliser K are required, applying high rates of K will increase soil test levels as demonstrated by the significant increase in QTK and TBK in the post-harvest soil tests. Although there will be no significant effect on wheat yield, the potassium may help to enhance grain protein content and furthermore, will be available for subsequent crops.

Conclusions

Overall, K fertiliser application rate and timing did not have a significant effect on grain yield. Potassium uptake did vary through the development of the crop with declining K content after the initial growth period. Lack of K uptake after the time of K side-dressing applications indicates that K application at sowing would be more valuable to crop uptake in a spring-sown wheat. Significant protein increases were seen in high K fertiliser application (200 kg K/ha and 400 kg K/ha treatments) and may be due to improved protein synthesis. The lack of potassium yield response at low QTK and high TBK indicates that both tests should be utilised to determine if potassium is required.

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