Potassium fertiliser requirements of fodder beet

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Abstract

In the last five years there has been a four-fold increase in area under fodder beet (*Beta vulgaris* L.) production in New Zealand. This has been attributed to demand for high yielding and high energy feeds for wintering of livestock. However, fodder beet yields are frequently lower than their potential, often because of sub-optimal soil fertility management and general crop health issues. Recommendations for potassium (K) fertiliser applications have been derived from limited and dated local or international research. Four experiments on timing [all at sowing, or split at sowing, canopy closure and mid-season (February)] and five rates [0–450 kg/ha] of K were carried out at four locations in the South Island of New Zealand in 2016–2017. Background exchangeable K at the sites varied from 2.8 to 4.0 Quick test units, and the reserve K (tetraphenylboron K; TBK) from 0.3–2.8 me/100 g. At the final harvest, neither the rate nor the timing of K application had any strong effect on biomass yield of fodder beet at each of the four sites. However, K uptake (91–700 kg K/ha) increased with the rate of K applied, but was unaffected by timing of application. The apparent recovery of K fertiliser was moderate, at 28–45%. The rest of the total uptake was attributed to the soil K reserves. Therefore K fertiliser rates should be adjusted according to the potential of soil to supply K and feeding strategy (i.e. grazed *in situ* or lifted). If crops are lifted and fed off the source paddock, more fertiliser K may be required to replace the K offtake; and if grazed *in situ,* a maintenance rate should be applied, as most of the K will be returned in urine.

Additional keywords: *Beta vulgaris* L., feed quality, grazing utilisation, *in situ*, yield potential.

Introduction

Fodder beet production is increasing rapidly in New Zealand as farmers look to benefit from its high yield potential and desirable feed quality characteristics (Chakwizira *et al*., 2013; 2014a) for enhancing animal body condition during wintering and finishing animals. This has seen the area under fodder beet increase four–fold in the last 5 years, to about 60,000 ha in the 2016–17 growing season (Gibbs, 2014; Milne *et al*., 2014; Chakwizira *et al*., 2016a). Favourable crop attributes include a high potential dry matter (DM) yield (>20 t/ha), high feed quality (Matthew *et al*., 2011; Chakwizira *et al*., 2014a; 2014b), high (>90%) grazing utilisation (Edwards *et al*., 2014a; 2014b) and perceived lower risks of nitrogen (N) leaching losses in comparison with alternative winter-fed forages (Edwards *et al*., 2014a; Malcolm *et al*., 2016; Dalley *et al*., 2017; de Ruiter *et al*., 2018).

Although there is increasing farmer interest in fodder beet as a late-autumn or winter fed crop in New Zealand, the yields at farm level are frequently below the genetic potential, which reduces the profitability of the crop. The yield potential in most regions is between 25 and 28 t DM/ha (Chakwizira *et al*., 2018), but reported yields are often much lower (13–20 t DM/ha) (Milne *et al*., 2014; Judson *et al*., 2016). Factors contributing to yield reductions include sub-optimal crop management and related soil fertility and crop health issues. There is a significant opportunity to improve productivity and profitability of fodder beet through improved crop management and consistent advice to farmers on fertiliser management.

Current information on K fertiliser requirements for fodder beet has been derived from limited (Chakwizira *et al*., 2013) and dated local (Stephen *et al*., 1980; Magat and Goh, 1988; Goh and Magat, 1989) and international research (Draycott and Christenson, 2003a). Further information has also been derived from related crop species such sugar beet (*Beta vulgaris* L.) (Draycott *et al*., 1974; Draycott and Christenson, 2003b; Khan *et al*., 2013). Therefore, updated information is needed to refine recommendations to better match plant nutrient requirements for optimum growth, as well as optimising the feed value for livestock and recommendations for sustainable management of nutrients. It is unclear if the results and recommendations from recent work on K in Central Canterbury (Chakwizira *et al*., 2013) can be applied to other regions in New Zealand, given the soil and climatic differences.

Most crops, including fodder beet are capable of extracting large amounts of K from soils even if the readily available K concentrations are low as reported previously (Craighead and Martin, 2003; Wilson *et al*. 2006; Trolove, 2010). High-yielding (20–30 t DM/ha) crops of fodder beet have been shown to take up more than 500 kg K/ha (Chakwizira *et al*., 2013), similar to the amounts reported for both fodder beet and sugar beet (Draycott and Christenson, 2003a, b). International literature suggests that both fodder and sugar beet require moderate amounts of K fertiliser (Draycott and Christenson, 2003a, b), but K can be taken up in excess of plant requirements, i.e. 'luxury consumption'. Overseas K fertiliser recommendations (Draycott and Christenson, 2003a) suggest application rates of between 80 and 250 kg K/ha are required for fodder beet production, on soil K status equivalent to <3 to >12 quick test K (QTK) units (Chapman and Bannister, 1994). The optimum rates and timing of K application for fodder beet, are not known for the different agroecological zones in southern New Zealand. The aim of these experiments were to validate the growth and yield responses of fodder beet in regional experiments, to confirm general recommendations for differing soil and climatic conditions.

Materials and Methods

Experimental details

A total of four on-farm sites were selected for the experiments where fodder beet is commonly grown in the South Island of New Zealand (Table 1): Southland (Gore; 45°56'32.46"S 168°59'27.84"E and Riverton; 46°20'38.40"S 167°52'58.37"E); representing Eastern and Western Southland, respectively and Canterbury (Southbridge; 43°50'4.10"S 172°14'5.10"E and Orari; 44° 4'58.89"S 171°16'48.82"E), representing Central - and South Canterbury, respectively. All crops were for winter grazing and had similar seasonal growth duration (Table 1), except for the Western Southland (Riverton) site (Table 1). Both Canterbury sites were irrigated, and the Southland sites were rain-fed. Four cultivars (Table 1) were grown, which are classified as low (≤15% e.g. 'Brigadier'), moderate (15-18%, e.g. 'Blaze' and 'Geronimo') and high (>18% e.g. 'Rivage') DM percent (DM%) cultivars (Milne *et al*., 2014). These authors have also reported that three of the four cultivars used in the current experiments ['Rivage', 'Brigadier' and 'Blaze'] produce similar biomass yields, in work carried out in different South Island regions: Canterbury, Otago and Southland.

Table 1: Crop details (cultivar, sowing details, final harvest date and season duration) at each of the four fodder beet experimental sites.

Site	Cultivar	Sowing date	Sowing rate (plants/ha)	Final harvest	Season duration (days)
Southbridge	'Rivage'	26 Oct. 2016	83,000	29 May 2017	224
Orari	'Geronimo'	11 Oct. 2016	90,000	22 May 2017	224
Gore	'Brigadier'	17 Oct. 2016	90,000	10 May 2017	206
Riverton	'Blaze'	3 Dec. 2016	85,000	9 May 2017	158

Both Canterbury sites were on Recent soils but of different properties; shallow (0.2–0.45 m deep) and low to moderate water holding capacity (WHC; 60–89 mm/ m depth) at Orari, and moderately deep (0.45–1 m), with moderate WHC of 90–119 mm/ m depth at Southbridge. At the Southland sites, soils at Riverton are Podzols, which are deep [>1m], moderately drained, with high WHC of >250 mm/ m depth. At the Gore site, predominant soils are Anthropic, derived mainly from gold mining, very shallow (<0.2 m), low WHC of < 30 mm/ m depth and moderately drained. Key soil characteristics are fully described in McLaren and Cameroon, (1966).

Base soil fertility at each site was determined to 15 cm depth (Table 2), before cultivation of the paddocks. The base paddock fertiliser at each site was applied based on that particular site's background fertility in relation to the established optimum fertility for general crop production (Table 2). The soil pH, Ca, Mg, Na and B concentrations were adequate for general crop production on all the sites. However, only one of the sites had adequate Olsen P, while both anaerobically mineralisable nitrogen (AMN) and quick test K (QTK) values were low for all sites. Furthermore, the tetraphenylboron K (TBK) values were lower at the Riverton site, but high at the other three sites.

Basal fertiliser was applied at 200 kg N/ha, as urea (46%N), split equally and broadcasted at sowing and canopy cover. Other base fertilisers were broadcast evenly at sowing, at rates of 50 kg P/ha as triple superphosphate (0–20.5–0–1), 150 kg/ha sodium chloride (40% Na and 60% Cl) and 25 kg/ha borate 46 (15% B) at sowing for each of the site. Potassium was not applied as a base fertiliser but to the relevant plots as designated treatments (Table 3).

Agrichemicals were applied to the crop when needed so that crop yield was not compromised by weeds, insects or disease infection; similar rates to those described by Chakwizira *et al.* (2014b) were used.

Table 2: Soil properties[1] measured before establishment of the experiments at each site. The optimum values are for general crop production (Nicholls *et al*., 2012).

Site	pH	Olsen P (µg/mL)	Ca	Mg	K[2]	Na	B ppm	TBK me/100 g	AMN (kg/ha)
			---------	QT Units	-------				
Southbridge	6.3	17.0	9.8	18.0	2.8 (1, 2)	11.0	1.0	2.3	39
Orari	6.1	17.8	11.5	16.5	4.0 (3, 4)	8.5	1.2	2.3	62
Gore	6.2	32.0	11.5	25.5	3.0 (2, 3)	8.5	1.8	2.8	88
Riverton	5.7	11.3	10.0	18.8	3.3 (2, 4)	12.0	1.2	0.3	80
Opt. amount	5.8-6.2	20–30	4–10	8–10	5–10	5–8	1.0	1.0	100-200

[1]Phosphorus (P), Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Boron (B), Tetraphenylboron K (TBK) and available mineralisable N (AMN).
[2]Numbers in parenthesis represent QTK at the final harvests for the 0 and 450 kg K/ha treatments, respectively.

Experimental design

The experimental treatments comprised four different K rates and two timings (all at sowing; or split of K application at sowing, full canopy cover and mid-season (mid-February) (Table 3), arranged in a randomised complete block design with four replications at each site. Plots were 3 m (6 rows) wide by 15 m long, at all the sites. Total K applications were 0, 150, 300 and 450 kg K/ha, applied as potassium chloride (KCL; 50%K). The range of treatments were set to represent the current industry recommendations, and applied at all the four sites irrespective of the actual soil tests results, although every effort was made to select for low soil K status (Table 2). Treatments with split applications (K4 and K5) supplied 100 or 150 kg K/ha at each application (Table 3). The K fertiliser was broadcast by a Solo Hand Spreader (SOLO Kleinmotoren GmbH. Stuttgart Straße 41. 71069 Sindelfingen, Germany) in each of the relevant plot.

Measurements

The DM yield harvests were taken three times during the growing season: at canopy cover, mid-season (February) and end-of-season (May), the first two coinciding with the timing of in-season K application (Table 3). Only the central two rows were harvested during the season, and the two outside rows were used as guard rows, to cater for overlaps in fertiliser application between treatments. The area harvested per plot differed with the size of the crop and purpose for harvesting. At the first harvest, a 0.5 m^2 quadrat was taken from each plot at canopy cover to measure nutrient (K) uptake. At the second (mid-season) and third (end of season) harvests, a 6 m^2 quadrat was harvested for both biomass and nutrient uptake. Plant density and total fresh weight per plot were determined in the field at each harvest. A representative two-plant subsample was retained to determine whole-plant DM percentage, K concentration and K uptake. Dry weight was determined by drying in a forced-air oven at 60°C to constant weight.

Table 3: Potassium (K) treatments showing initial rates of K applied at sowing (KI–K3); and additional treatments with split application of K (K4–K5) at the seven sites.

Treatment	K application (kg/ha)[1]			Total K applied (kg/ha)
	Sowing	Canopy closure	Mid-season (end of February)	
K1	0			0
K2	150			150
K3	300			300
K4	100	100	100	300
K5	150	150	150	450

[1]Actual dates varied with site, but for the first application at sowing, see Table 1.

Calculations

Potassium use efficiency (KUE) and its components

Potassium use efficiency was reported for one site (Southbridge), and defined as the ratio of additional DM yield to fertiliser K input (Equation 1); often termed 'agronomic efficiency' (Fageria *et al*., 2001). We used the Southbridge site for these calculations as it was the only site with positive differences (although very small) between the control and the rest of the treatments. In this calculation, yield response is adjusted for the yield achieved without added fertiliser K (i.e. control plots) and therefore does not account for the response due to residual soil K.

$$\text{KUE} = \frac{\text{Crop biomass at } K\text{x} - \text{Crop biomass at } K\text{o}}{\text{kg of K applied at } K\text{x}} \qquad \text{----------------- (1)}$$

where Kx = K rate > 0 and K_0 is crop yield for the control crops.

The KUE was also expressed as the product of K uptake efficiency (KupE; the ability of plants to remove nutrients from the soil) and the K utilisation efficiency (KutE; the ability of plants to use nutrients to produce biomass yield) as (Zhu *et al*., 2017):

$$\text{KUE} = \text{KupE} \times \text{KutE} \qquad \text{----------------- (2)}$$

And:

$$\text{KupE (\%)} = (\text{Ykf} - \text{Yk}_0) \times \frac{100}{\text{kf}}$$, and

$$\text{KutE (g/ g per m}^{-2}) = \frac{\text{Crop biomass at } K\text{x} - \text{Crop biomass at } K\text{o}}{\text{Ykf} - \text{Yko}}$$

where Ykf is the crop K yield with application of fertiliser K, and Yk_0 is the corresponding crop K yield without fertiliser application for the same treatment and replication.

Statistical analysis

Data analyses for each site were analysed using analysis of variance (ANOVA) fitted with least squares in GenStat version 17 (VSN International, Hemel Hampstead, UK). This was followed by a meta-analysis of data from all four experimental sites; by using a mixed model fitted with the restricted maximum likelihood (REML) programme in GenStat version 17. This was made possible as three of the four cultivars have been reported to produce similar biomass yield in different agroecological regions of the South Island of New Zealand (Milne et al., 2014). An estimate of the variation associated with treatment means was given by least significant difference ($LSD_{5\%.}$) with associated degrees of freedom (df). Data were graphed in Microsoft® Excel. Where values show $P < 0.1$, a trend is indicated in the text.

Results

Biomass yield

At the final harvest, neither the rate nor the timing of K application had any strong effect (*P*=0.29) on biomass yield of fodder beet (Figure 1). The mean overall biomass yield per site were 31 t DM/ha at Orari, 25 t DM/ha at Southbridge, 12.6 t DM/ha at Riverton and 23 t DM/ha at Gore. For the Orari site, DM yield increased (*P*<0.001) with each successive harvest, at an average rate of 268 (240-330) kg DM/ha/day for period between canopy cover and mid-season (February) harvests, compared with 110 and 122 kg DM/ha/day for the period before canopy cover and the period from mid-season (February) to final harvests, respectively.

Potassium concentration

At the final harvest, the K concentration in the tissues increased (*P*<0.012) with increasing rate of K application across the four sites (Figure 2). The effect of timing of K application (single vs triple applications for a total of 300 kg/ha K applied) on plant K concentration was significant (*P*<0.001) for all sites except Orari. This effect was due primarily to the uptake difference at the first and second harvests but not at maturity (Figure 2). The overall K concentration within each application rate and timing treatment decreased with time after sowing.

Potassium uptake

The overall K uptake (product of total biomass yield and K concentration), increased with K application at all the four sites (Figure 3) with a significant (*P<0.03*) linear trend with rate of K applied. At the final harvest, K uptake increased from 91 kg/ha for the control crops to 330 kg/ha when 450 kg K/ha was applied at Riverton.

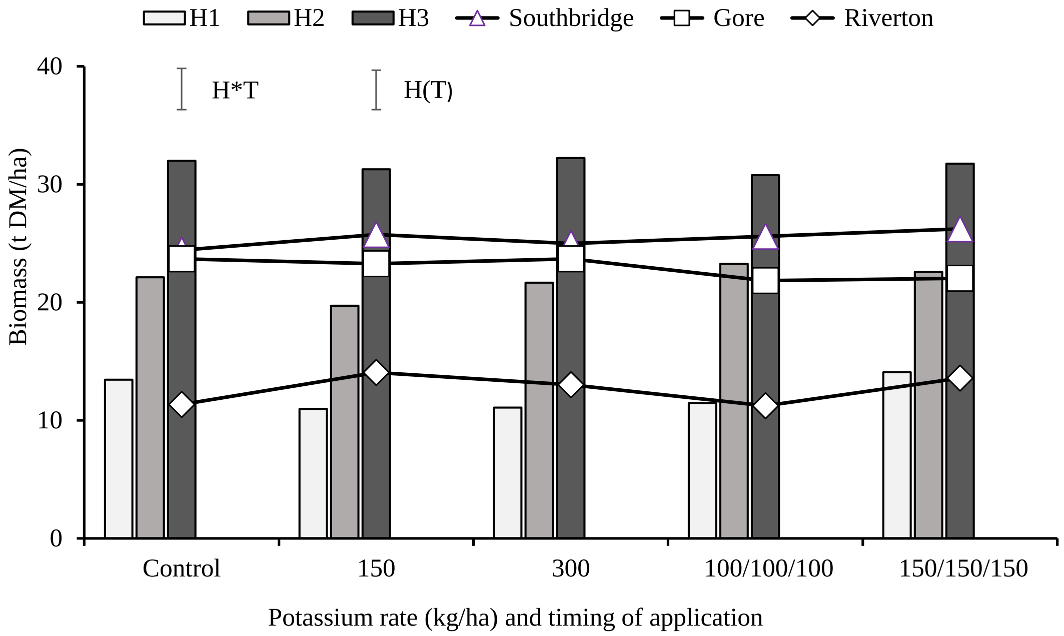

Figure 1: Biomass yield (t DM/ha) for fodder beet crops grown under different rates of potassium (K; 0–450 kg K/ha) and different timings of K application (sowing only, or sowing, canopy cover and mid-season). Crops were harvested three times during the season at canopy closure (Harvest 1, H1), mid-season (H2), and at the end of the season in May (H3). Bars are the yield for Orari (Canterbury) site. Error bars are least significant difference ($LSD_{5\%.}$) to compare treatment means across harvests events (H*T) and for treatments within same harvest (H (T)) for the Orari site only. The line graphs represent the final biomass yield for the other three sites.

Similarly, K uptake increased from 550 kg/ha to 690 kg/ha for the same respective treatments at Orari (Figure 3). Similar trends were observed at Gore and Southbridge; with intermediate uptake values. At Riverton, K uptake was lower than for the other sites, across the treatments (Figure 3). The difference between K uptake in the control treatments compared with those with K applied (contrast with single applications only) was significant ($P<0.003$) at all sites. At the Orari site, timing of application (contrast between single and multiple applications totalling 300 kg/ha K applied) did not affect ($P=0.76$) total K uptake. This effect of timing was, however, significant at the Southbridge ($P=0.03$), Gore ($P<0.02$) and Riverton ($P<0.001$) sites.

Potassium uptake and utilisation efficiency

The calculated K uptake efficiency (KupE) for the Southbridge (Table 4) site increased from 28% for the 300 kg K treatment, applied as a split throughout the season (Table 3), to 45% for the 150 kg K/ha treatments applied at sowing. When the same rate was applied at different times (e.g. 300 kg/ha), crops tended to take up more K from the single early application, than when K was split three times during the season. There was no difference in KUE, averaging 5 (2-9) g DM/ g K_{uptake} /m^2.

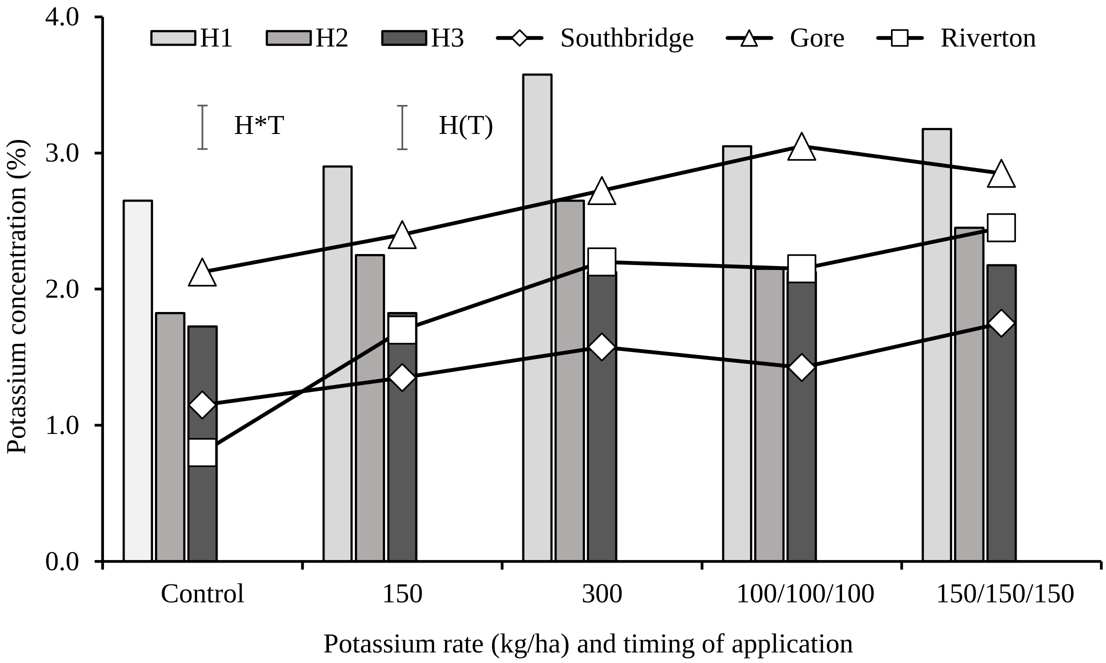

Figure 2: Potassium (K) concentration (%) for fodder beet crops grown under different rates of potassium (K; 0–450 kg K/ha) and different timings of K application (sowing only, or sowing, canopy cover and mid-season). Crops were harvested three times during the season at canopy closure (Harvest 1, H1), mid-season (H2), and at the end of the season in May (H3). Bars are the yield for Orari (South Canterbury) site. Error bars are least significant difference ($LSD_{5\%}$) to compare treatment means across harvests events (H*T) and for treatments within same harvest (H (T)) for the Orari site only. The line graphs represent the K concentration at the final harvest for the other three sites.

Table 4: Potassium fertiliser applied, final harvests biomass yield, additional biomass yield (difference between final biomass and control crops) and potassium use efficiency components: uptake efficiency (KupE; %) and utilisation efficiency (KutE; g DM/ g K_{uptake} /m^2) for fodder beet grown at Southbridge, Central Canterbury in the 2016-17 season.

Fertiliser applied[1]	Biomass yield (kg DM/ha)		KUE components	
kg K/ha	Total	Additional	KupE	KutE
0	24,400	-	-	-
150	25,800	1,400	45.3	20.6
300	25,000	600	36.7	5.5
300 (100/100/100)	25,600	1,200	28.7	14.0
450 (150/150/150)	26,200	1,800	39.1	10.2

[1]Timing of application is described in Table 3.

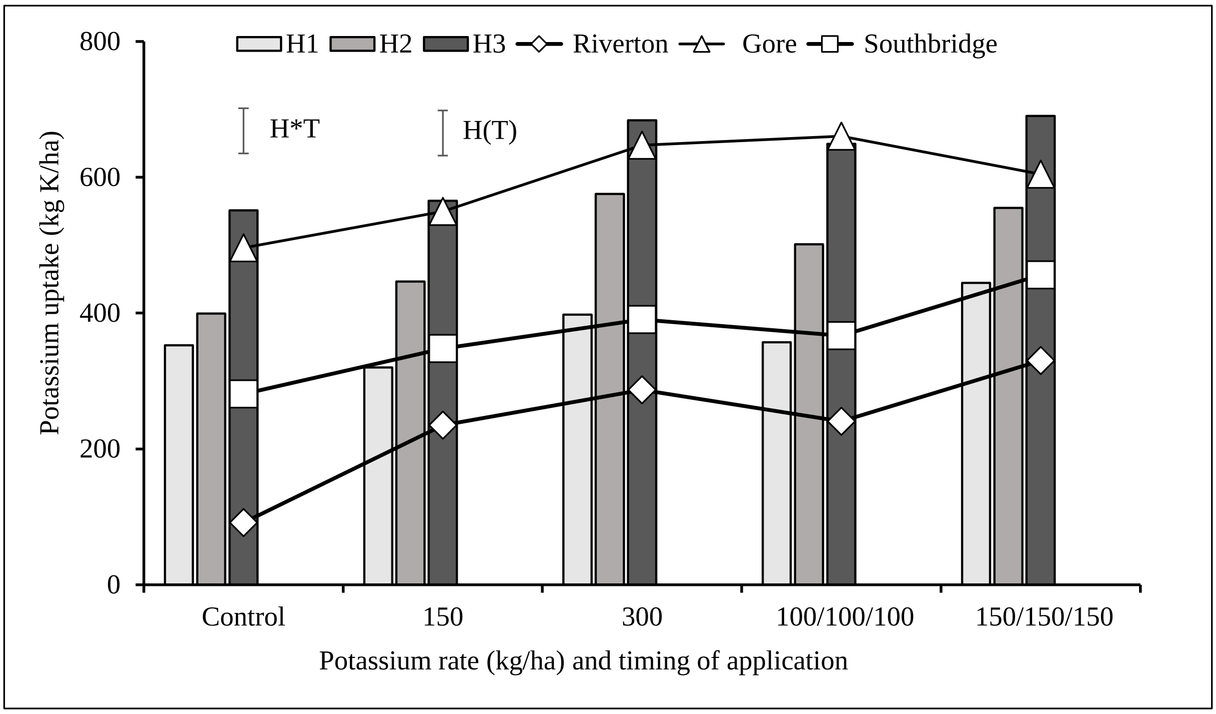

Figure 3: Potassium (K) uptake (kg/ha) for fodder beet crops grown under different rates of potassium (K; 0–450 kg K/ha) and different timings of K application (sowing only, or sowing, canopy cover and mid-season). Crops were harvested three times during the season at canopy closure (Harvest 1, H1), mid-season (H2), and at the end of the season in May (H3). Bars are the yield for Orari (South Canterbury) site. Error bars are least significant difference ($LSD_{5\%}$.) to compare treatment means across harvests events (H*T) and for treatments within same harvest (H (T)) for the Orari site only. The line graphs represent the K uptake at the final harvest for the other three sites.

Discussion

Biomass yield, K concentration (%K) and K uptake response data from the four experimental sites indicated that K was not a nutrient limiting crop performance. Even though the residual soil K content (QTK) were relatively low (≤4.0, Table 2), there was no effect of K rate or timing on DM yield. Despite there being no effect of K application on yield, the capacity of plants to utilise either residual K or applied K was evident, with effects on the %K in whole plants and the amounts of K uptake in response to rate of K applied. Fodder beet showed a capacity for efficient uptake of K from the soil (Table 4). Similar high K uptake efficiency has been reported for sugar beet (Samal *et al.*, 2010), when compared with maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) and was attributed to higher K influx (K uptake per cm of root per second) for sugar beet, thus more efficient acquisition in low available soil K. Because of a strong root system, fodder beet may be able to derive significant amounts of K from below the soil depth tested (Jackson, 1985; Carey and Metherell, 2003). Furthermore, fodder beet has been shown to extract water from depth of up to 1.4 m (Chakwizira *et al.*, 2014b) and as K uptake is mainly driven through the transpiration stream (Mengel and Kirkby, 2001), this could explain the high K uptake. Another possible explanation is that most New Zealand sedimentary soils have high K reserves (Craighead and Martin, 2003) and K that was released by mineralisation during the growing season (Carey *et al*., 2011; Moir *et al*., 2013) was sufficient for unrestricted growth.

The lack of yield response to K fertiliser was consistent with reports in recent published work in Canterbury for fodder beet (Chakwizira et al. 2013) and seed potatoes (*Solanum tuberosum* L.) (Craighead and Martin, 2003). Similar results have also been reported overseas for a range of crops, including a related species, sugar beet (Draycott *et al*., 1974; Khan *et al*., 2013). The sites chosen for the current study had lower than the recommended optimum QTK values (≥5.0, Table 2). However, the TBK ranges of 2.3 – 2.8 at three of these sites (Table 2), indicated high K reserves, as both Edmeades *et al*. (2010) and Carey *et al*. (2011) have shown that near-maximum pasture production corresponds to TBK > 1.0. At these amounts, crops usually do not require high rates of K fertiliser to support high yield. Previous K research on other crops in New Zealand, such as forage brassicas (Wilson *et al*., 2006) and seed potatoes (Craighead and Martin, 2003), showed that K fertiliser did not significantly increase the DM yield, even when initial soil K amounts (QTK, TBK) were lower than recommended optima. These results also suggested that K fertiliser is necessary only as a replacement for the K taken up by the crop and removed from the paddocks (Trolove, 2010), to ensure K deficiencies do not occur in future from over-mining the soil reserves. Furthermore, as the fodder beet crops grow at high rates during the bulb expansion phase (Figure 1), with K uptake reaching over 10 kg K/ha/day (Buzas and Johnston, 1999), moderate K fertiliser may be beneficial to ensure crop demand for K does not exceed the supply of K from soil reserves (Trolove, 2010). In cereal crops, simulations of K requirement (Curtin *et al*., 2004) showed that K fertiliser should be applied to avoid deficiency during the rapid growth phase, when demand for K can reach 4–5 kg K/ha/day. The rate of release of K on differing soil types may be important in formulating K fertiliser recommendations.

Increasing the supply of K did result in higher tissue concentration and consequently total K uptake (Figures 2, 3). The increase in K concentration in the plant tissues across the sites was consistent with earlier findings on fodder beet (Chakwizira *et al*., 2013). The decrease of K concentration through the season (Figure 2), termed the nutrient dilution, has been reported for other nutrients in fodder beet (e.g. nitrogen; Chakwizira *et al*., 2016b) and was consistent with reports for other crops from similar photosynthetic group (C_3), such wheat (Justes *et al*., 1994; Ziadi *et al*., 2010), and forage kale (*Brassica oleracea var. acephala* L.) (Fletcher and Chakwizira, 2012; 2015). This was attributed to the increased DM as the season progressed. The K uptake values at crop maturity, excluding the late sown Riverton site (330 kg/ha) of 450 to 690 kg/ha were similar to the 500 kg/ha reported in an earlier study in Central Canterbury (Chakwizira *et al*., 2013) and overseas reports of 450-480 kg/ha for both fodder and sugar beet (Draycott and Christenson, 2003a, b). The lower K uptake at Riverton (Figure 3) was attributed to the late sowing of the crops (Table 1) because the paddock was wet and inaccessible in spring. These crops were still immature when harvested in May 2017, and had accumulated less K because of the shorter crop duration (Table 1). The high K uptake at the Orari and Gore sites (Figure 3) was associated with high K concentrations in the herbage (Figure 2) at Gore and high DM yield at Orari, and also the longer crop-growing duration at both sites. Whole-plant K uptake was comparatively low at the Southbridge and Riverton sites. At Southbridge this could also be related to the relative differences in biomass and a low K tissue concentration (Figure 3), and at Riverton, due to the low biomass yield (Figure 1) as a results of the shorter crop-growing duration (Table 1).

There was no significant treatment effect on potassium use efficiency (KUE) at the Southbridge site (Table 4), a reflection of the similar DM yields observed across the treatments and across the site. At all the sites, the soils were able to provide enough K for maximum production. There is a paradox here, as all the sites had QTK values below the reported optima for maximum production of crops (Nicholls *et al*., 2012), and yet similar yields were observed between the control crops and those receiving higher K fertilisers (e.g. 450 kg K/ha). These results could be attributed to the fact that up to one-third of New Zealand agricultural soils (soils derived from sedimentary parent materials) are typically high in reserve K (TBK) (Carey *et al*., 2011; Moir *et al*., 2013; 2017a), and can supply large amounts of K for plant uptake; therefore they are not likely to require high rates of K fertiliser (Chakwizira *et al*., 2013).

The QTK values measured at the final harvests for the 0 kg K/ha plots were consistently lower than the initial amounts determined before the crops were sown (Table 2). The differences between initial and the final QTK for the control crops meant that the fodder beet crops were mining soil K, which may have an effect on the following crops in the rotation, particularly if the fodder beet crops are lifted and fed off the paddock.

The amount of K taken up by crops was related to the rate of K fertiliser applied. The apparent recovery of K (KupE) was moderate, and ranged between 28% and 45% of the applied K fertiliser, with better recovery where less K was applied. The implication is that the crops took up K from both the applied fertilisers and residual K in the soil, either as available or reserve K. As the K fertiliser recovery rate was ≤45% (Table 4), the rest of the total uptake was attributed to the soil reserves. This is important, as it implies that K fertiliser requirements of fodder beet crops should be managed within the background of residual soil nutrient availability, and adjusted according to the K requirement of crops. The demand for nutrients by the crop following fodder beet, as well as the economics of production should also be considered in determining actual amounts of K applied. If fodder beet is lifted and fed off the source paddock, more fertiliser K may be required to restore the K offtake (Trolove, 2010). If animals are grazed *in situ*, then a maintenance rate of K should be applied, as most of the K will be returned in urine. Where farmers use a pasture block between daily grazing of fodder beet, the paddock should be treated as for lifted crops, as most of the K returns are deposited off the fodder beet paddock.

Results reported here show that even at low QTK, fodder rarely respond to K application, but take up large amounts of K, a sign that soils are able to provide K to the plant and this is mostly from the soil reserves. It is therefore suggested that soil tests methods should take more into account the K reserves of the soil. To this, the TBK test of Jackson (1985) can be used, particularly on sedimentary soils.

Conclusions

Potassium (K) treatments (rate and timing) did not affect DM yield, but the fodder beet crops took up large amounts of K. Potassium uptake increased linearly with increasing K applied across the sites. The K fertiliser recovery efficiency ranged between 28 and 45%, and utilisation efficiency was negligible, as there were no biomass differences among the treatments. These moderate K recovery rates mean background soil K amounts should be used to derive K recommendations.

Acknowledgements

This work is part of the Sustainable Farming Fund (SFF) project number 404915: Agronomic solutions for fodder beet, administered by The New Zealand Institute for Plant and Food Research Limited (PFR). The project was funded by the Ministry for Primary Industries, with industry partners: Foundation for Arable Research, DairyNZ, Beef + Lamb NZ, Ballance Agri-Nutrients, Ravensdown, Agricom, Agriseeds, Cropmark, DLF Seeds, Seed Force, Bayer CropScience and the South Island Dairying Development Centre.

We thank the four farmers who allowed us to set up our experiments on their properties and granted us access throughout the year. We also acknowledge the huge contribution by PFR technical teams from Lincoln and Gore, and the various industry partners who provided further technical support throughout the year.

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