Water use efficiency of raphanobrassica and forage rape

E. Chakwizira[1]*, S. Maley[1] and A. Dumbleton[2]

[1]The New Zealand Institute for Plant and Food Research Limited, Lincoln,

[2]PGG Wrightson Seeds, Lincoln 7676

emmanuel.chakwizira@plantandfood.co.nz

Abstract

Forage rape has traditionally been used as supplementary feed in the beef and sheep sector throughout New Zealand. However, the availability of sufficient soil water under rain-fed conditions and poor field/ crop hygiene has often limited biomass yield. To this end, Forage Innovation Limited (FIL) have bred and released 'Pallaton' raphanobrassica, an intergeneric hybrid between forage kale and radish that combines the superior biomass yield and quality of kale and increased drought, insect and disease tolerance of radish. Quantitative data describing the total water use (WU; mm) and water use efficiency (WUE; kg DM/ha/mm) of raphanobrassica is not available for New Zealand conditions. This study reports the yield and water use of rain-fed 'Goliath' rape and 'Pallaton' grown in shallow Lismore stony silt loam soil. The cumulative biomass yields did not differ between 'Goliath' rape and 'Pallaton' at ~ 6.9 t/ha. However, the WUE for 'Pallaton' was 38.2% higher than for 'Goliath' rape. This difference was associated with the lower WU for the 'Pallaton' (574 mm) compared with 'Goliath' (595 mm). Results also showed that the nutritive composition did not differ between the species and was similar or higher than the recommended ranges for animal production except for neutral detergent fibre (NDF) and soluble sugars (SS). High crude protein and lower SS and NDF, confirmed the negative relationships reported previously. This study shows that 'Pallaton' is therefore a possible substitute for forage rape in areas experiencing summer dry conditions.

Additional keywords: kale, 'Goliath' rape, nutritive values, 'Pallaton' raphanobrassica, radish, water extraction patterns/ depth, water use (WU), water use efficiency (WUE)

Introduction

The east coast and central North Island regions of New Zealand are characterised by dry summers (Moot and Davison, 2021), which leads to low pasture growth rates and a decline in feed quality (Mills et al., 2015). Summer forage brassica crops such as rape (*Brassica napus* L. *spp*. *biennis*) (Percival *et al*., 1986*)* are frequently used to fill this feed gap, particularly in the beef and sheep sector. In the absence of irrigation, soil moisture deficit is the major factor limiting productivity of spring sown forage rape (Banfield and Rea, 1986; Chakwizira and Fletcher, 2012), with dry soils resulting in highly variable biomass yield (3-8 t/ha). There is little relevant trial data showing the effects of water availability on the yield potential of field grown forage rape in shallow soils or of rape crops grown in the summer-dry east coast regions of New Zealand. There has been some recent research on the effects of moisture deficit on a range of forage brassicas (Fletcher *et al*., 2010); however, these experiments were on deep soils (> 1.6 m) with high water holding capacity (WHC; 190 mm/m depth) (Jamieson et al., 1995). This is atypical of the beef and sheep farms in New Zealand, which are mostly situated on shallow soils of low WHC, where summer supplementation is required when pasture biomass production and quality declines. In these situations, yield may be compromised when the crop is exposed to extended periods of restricted water availability, and therefore, species and cultivar selection is important for maximising profitability.

In addition to soil moisture stress, forage brassica crop failures have been attributed to poor cultivation techniques, nutrient deficiencies and disease incidence such as clubroot (*Plasmodiophora brassicae*) (Percival *et al*., 1986). Recent improvements in our understanding of cultivation techniques (de Ruiter *et al*., 2009) and better knowledge of soil and plant nutrition (Wilson *et al*., 2006; Bell *et al*., 2020) has meant fewer crop failures. However, diseases are still a major cause of many brassica crop failures (Bell *et al*., 2020). Forage rape is particularly susceptible to poor crop hygiene practices. To this end, Forage Innovations Limited (FIL; a joint venture company between PGG Wrightson Seeds and The New Zealand Institute for Plant and Food Research Limited) have bred and released raphanobrassica (*Brassica oleracea var. acephala* × *Raphanus sativus L*. cv. 'Pallaton') (Dumbleton *et al*., 2021), which is an intergeneric hybrid between kale (*Brassica oleracea*) and radish (*Raphanus sativus*) (Williams and Hill, 1986). The hybrid combines the superior biomass yield, quality and palatability of kale (Edwards *et al*., 2014; Chakwizira *et al*., 2015), with the increased drought, insect and disease tolerance of radish (Percival *et al*., 1986; Kaneko and Matsuzawa, 1993). Historical studies have shown that its biomass yield is comparable with that of forage rape (6-8 t/ha) (Harper and Compton, 1980). Raphanobrassica is therefore a possible substitute for forage rape crops in areas susceptible to clubroot, and summer dry conditions. However, the yield response of raphanobrassica to water deficit is unknown. The objective of this study was to determine the water extraction patterns, water use and use efficiency of two lines of raphanobrassica crops and the standard dryland forage rape, 'Goliath', on shallow soils.

Materials and Methods

The experiment was conducted at Lincoln University's Ashley Dene Research and Development Station (ADRDS) (45° 9' S 172° 19' E, 30 m a.s.l.). The site was situated on a shallow Lismore stony silt loam soil (Udic Haplustept loamy skeletal) (Hewitt, 2010), which has a shallow topsoil (0.2 m), that contains 30-40% stones overlaying coarse gravels and is of moderate fertility (Table 1). The soil has a WHC of about 130 mm/m (Sim *et al*., 2017). The site had been under Lucerne (*Medicago sativa*) from 2008 to 2011, followed by kale in 2011-2013.

The rain-fed experiment was a complete randomised block design with three brassica cultivars as the treatments ('Goliath' rape, 'Pallaton' a tall statured and A13.4 a short statured raphanobrrassica), replicated four times. Cultivation involved deep ploughing followed by power harrowing. The crops were sown in 150 mm wide rows with a 'Taege' drill on 21 October 2013. The sowing rate based on seed weight, was 4 kg/ha for 'Goliath' rape and 8 kg/ha for the two raphanobrassicas.

Soil samples to 150 mm depth were taken on 10 October 2013 and the average soil test results are shown in Table 1. Based on these results, fertiliser was applied on 19 October 2013, as 250 kg/ha DAP (18-20-0-1; N: P: K: S, respectively), which provided, 45 kg/ha N, 50 kg/ha P and 2.5 kg/ha S. Boron was applied as 15 kg/ha boronate (10% B). Additional nitrogen fertiliser was applied as urea (46%) at 100 kg N/ha on 22 November 2013, 80 kg N/ha on 14 February 2014 and 50 kg/ha on 4 April 2014, to give a total of 275 kg N/ha through the season.

Table 1: Mean values of soil analysis test results in Quick test units (QTU) for the experimental site located at Ashley Dene Research and Development Station at Lincoln in New Zealand. The optimum nutrient requirements are for general crop production (Nicholls *et al*., 2012).

	pH	Olsen P mg/kg	K	Ca	Mg	Na	AMN kg/ha
			QTU				
Exp. Site	5.8	16	8	8	9	5	78
Optimum	5.8–6.0	20–25	4–8	5–10	8–10	2–3	200–300

Weed control was through application of Roundup® (a.i. 450 g/L glyphosate) at 4 L/ha on 2 September 2013 and Treflan® (a.i. 480 g/L trifluralin) on 20 October 2013. Perfekthion® (a.i. 400 g/L dimethoate) was applied at 800 ml/ha to control leaf miners on 10 December 2013. On 5 February, 800 ml/L of Attack (a.i. 25 g/L permethrin, 475 g/L pirimiphos-methyl and 375 g/L hydrocarbon liquid) and 50 ml/100 L water of Contact low foam (100% w/v a.i. non-ionic surfactant) were also applied to control white butterflies and aphids.

Measurements

Water

A single neutron probe (NP) access tube and a time domain reflectometer (TDR) wave guide were installed in each plot following seedling emergence, for the duration of the experiment. Measurements of volumetric soil water content were made for each plot at weekly intervals beginning on 18 November 2013 (29 days after sowing (DAS)). Measurements were made in 200 mm increments to a depth of 1600 mm. The 0–200 mm depth was measured using TDR, while all other measurements were made using NP.

Seasonal crop water use (WU, mm) was calculated as the change in volumetric soil water content during the period from the start of measurements (29 DAS) to the subsequent measurements and adjusted for rainfall inputs. The water extraction pattern and calculated total WU were determined for all treatments throughout the growing period. Water use efficiency (WUE; kg DM/ha/mm) was calculated from regression of the sequential crop dry matter (DM) measurements against the WU (Fletcher *et al.* 2010). The fitted slope for the period when measurements were taken defined the WUE. The measurements of soil water from the start of measurements, not sowing, meant that the linear regressions could not be forced through the origin. Early in the season, before crop canopy closure, a considerable part of total WU comes from soil evaporation, termed unproductive WU (Fletcher *et al.* 2010). When WU and crop biomass measurements were on different days, WU was estimated by linear interpolation between two measurements.

Dry matter yield

Three successive crop biomass measurements were taken from the same area at 93, 156, and 205 DAS (representing approximate grazing time), with the second and third harvest being regrowth biomass. A forage chopper (Wintersteiger Cibus) was used for harvesting 7.8 m row length × 1.2 m width for all the three harvests, leaving a stubble of ~10 cm. Total fresh mass for the crops was determined in the field at each harvest. A sub-sample of approximately 500 g fresh mass was taken from each plot harvest and separated into respective crop and weed fractions. Plant population was determined after each harvest by counting the number of plants in a 0.5 m^2 quadrat. Samples were dried in a forced draught oven at 90°C until constant weight was achieved. Cumulative biomass yield was calculated from the successive DM biomass assessments. Separate samples for nutritive values were taken at the final harvest only (205 DAS) and were combined for all replications for each cultivar. These were processed by freeze drying and subsequent grinding to pass through a 1 mm screen. The nutritive values (expressed as % of DM) were determined on a whole crop basis at Hill Laboratories, Hamilton, New Zealand. Nutritive quality attributes included crude protein (CP), acid detergent fibre (ADF) neutral detergent fibre (NDF), ash, soluble sugars (SS) and metabolisable energy (ME; MJ/ kg DM). Nutritive values are reported in comparison with other common forage brassica crops grown in New Zealand.

Meteorological data

Weather details (Figure 1) were from a weather station situated at the experimental site. Total rainfall during the experimental period (October-May) was 638 mm, compared with a longterm average of 415 mm over the same period. The mean temperature for the growing period was 14.4°C; with a minimum temperature of 1.1°C recorded on 27 April 2014 and a maximum of 32.7 °C recorded on 18 February 2014. Mean photosynthetically active radiation (PAR; MJ/m^2) for the main growing period (December-March) was consistent with the long-term average.

Data analyses

Data were analysed using multivariate analysis of variance (MANOVA) for repeated measures (harvest timing) and analysis of variance (ANOVA) for data within harvest date. Significant interactions and main effects were separated using Fisher's protected least significant difference (LSD) tests (α=0.05). All analyses were performed in GenStat v.14 (VSN International, Hemel Hampstead, UK) and figures were prepared in Sigma Plot v. 10.0 (Systat Software Inc., San Jose, CA, USA).

Results

Biomass yield

At establishment, plant population among the three cultivars was similar at ~54 plants per m^2, and was unaffected by the successive DM samplings. However, there was an interaction ($P<0.001$) between crop cultivar and harvest date (Figure 2) for the biomass yield. Specifically, forage rape, cv. 'Goliath' had the highest yield at the first harvest but lowest yield at the second harvest compared with the raphanobrassicas. There were no yield differences ($P=0.27$) between the species at the final harvest, at a mean yield of ~1.76±0.10 t/ha.

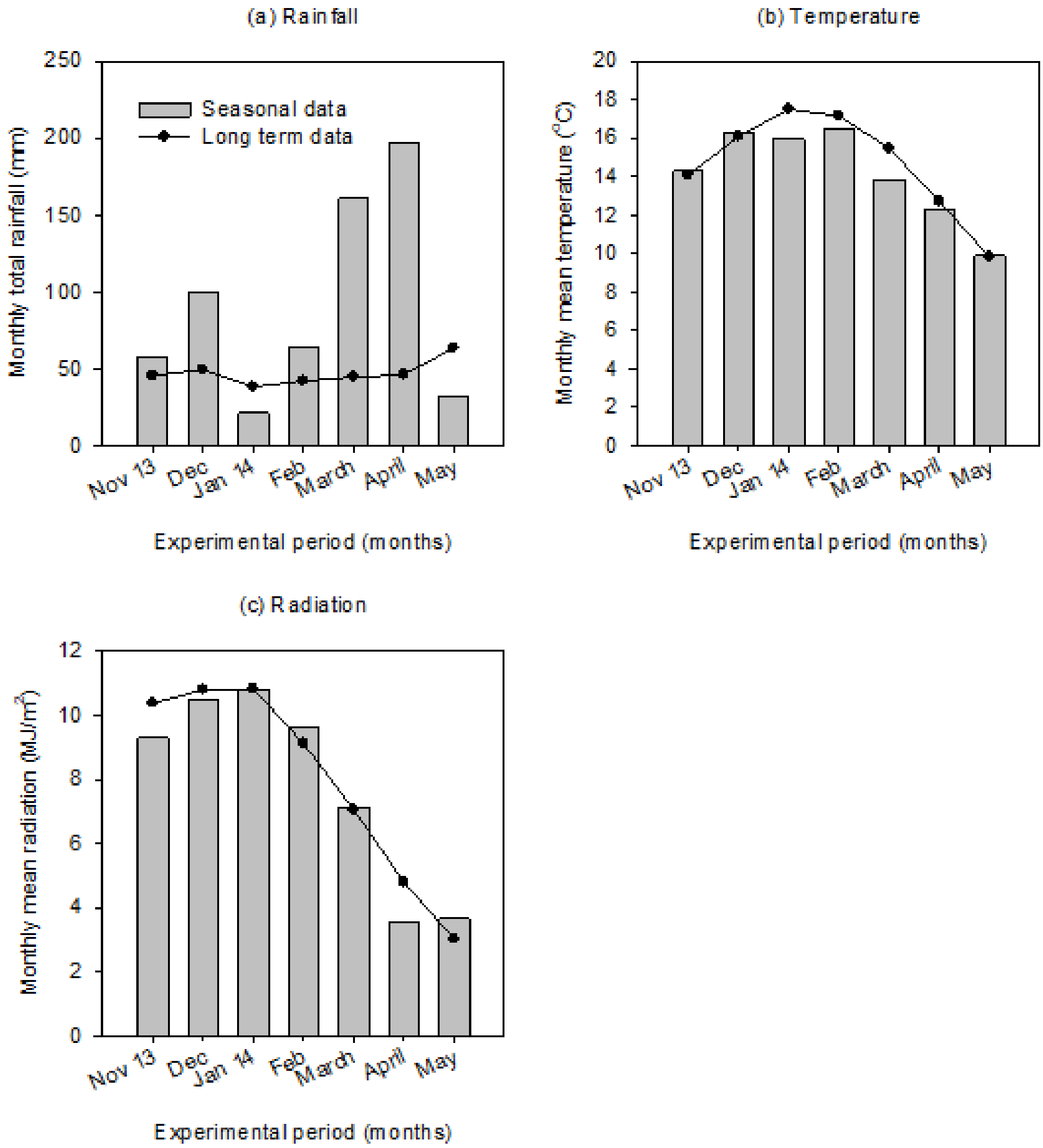

Figure 1: Monthly (a) total rainfall (mm), (b) average temperature (°C) and (c) average photosynthetically active radiation (PAR; MJ/m^2) for the growing season (bar graphs) and long-term average (line graph) data at Ashley Dene Research and Development Station, Canterbury, New Zealand. Long-term data is from 1970 to 2010 (NIWA, 2019).

These results show that 'Goliath' rape established quickly (Figure 2), hence the high biomass yield at the first harvest. The raphanobrassica cultivar 'Pallaton' caught up at the second harvest. On the whole, the cumulative biomass yield was lower (P<0.001) for the 'A13.4' raphanobrassica line, at 6.4 t/ha compared with the ~ 6.9±0.2 t/ha for 'Goliath' rape and 'Pallaton' raphanobrassica.

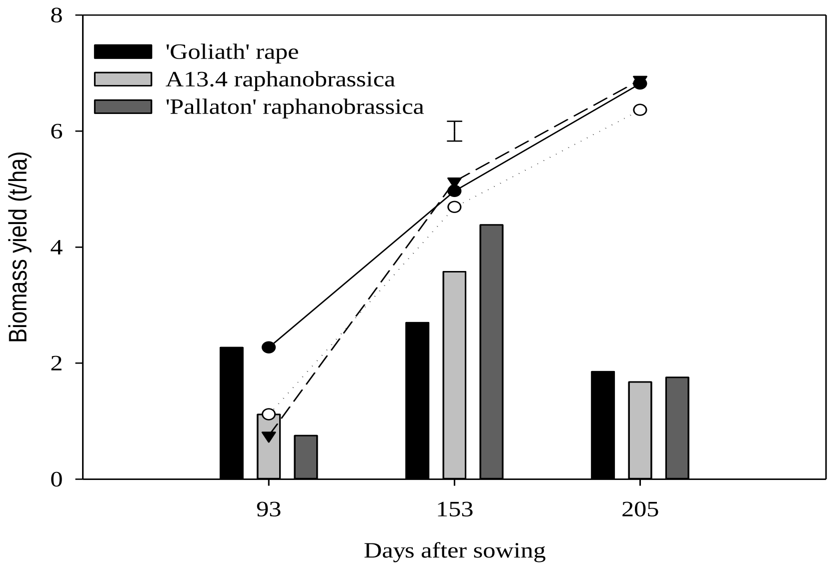

Figure 2: Biomass yield for forage rape and raphanobrassica cultivars grown at Ashley Dene Research and Development Station, in the 2013–14 season. Bar graphs represent yield at each harvest date and line graphs (● 'Goliath' rape, ○ 'A13.4' (short), and ▼ 'Pallaton' (tall) raphanobrassica) show cumulative biomass yield through the season. The vertical bar represents the LSD at 5%.

Feed quality attributes

The key nutritive value attributes (Table 2) did not differ among the species, but were higher or similar to the recommended ranges for animal production except for NDF and SS, which were below the optimum range. For example, the mean CP content of ~ 23% across the species was 93% above the optimum value (12%), while the SS content was ~ 137% lower than the recommended values (36–44%; Table 2).

Table 2: Feed quality (% DM, unless stated otherwise) at the third harvest (205 DAS) for forage rape ('Goliath') and raphanobrassica ('Pallaton', A13.4) cultivars grown at Ashley Dene Research and Development Station in the 2013–14 season and the optimum concentrations for beef cattle production (NRC, 2000; Nichol et al., 2003).

Feed value[1,2]	Brassica cultivar			
	Goliath	Pallaton	A13.4	Optimum values
CP	23.7	24.2	21.5	> 12
ADF	23.3	25.4	22.4	> 21
NDF	19.8	21.7	20.9	> 33
Ash	15.7	16.5	13.5	> 0.5
SS	16.7	16.5	17.4	36-44
DOMD	77.6	80.5	79.3	> 70
ME (MJ/ kg DM)	12.7	12.4	12.9	10-11
NSC	38.9	35.4	41.6	34-38

CP = crude protein, ADF = acid detergent fibre, NDF = neutral detergent fibre, SS = soluble sugars, DOMD = dry organic matter digestibility, ME = metabolisable energy and NSC = non soluble carbohydrates

Water extraction and use

All cultivars were extracting water from about 1300 mm depth during the measurement period (Figure 3 a, b & c): between 36 DAS (25 November 2013) and 64 DAS, and 64 and 92 DAS (20 January 2014). However, there was very little water extraction in the 0-300 mm depth between 36 and 64 DAS for all cultivars. Furthermore, there was little water extraction below 700 mm for raphanobrassicas and 900 mm for forage rape between 64 and 92 DAS.

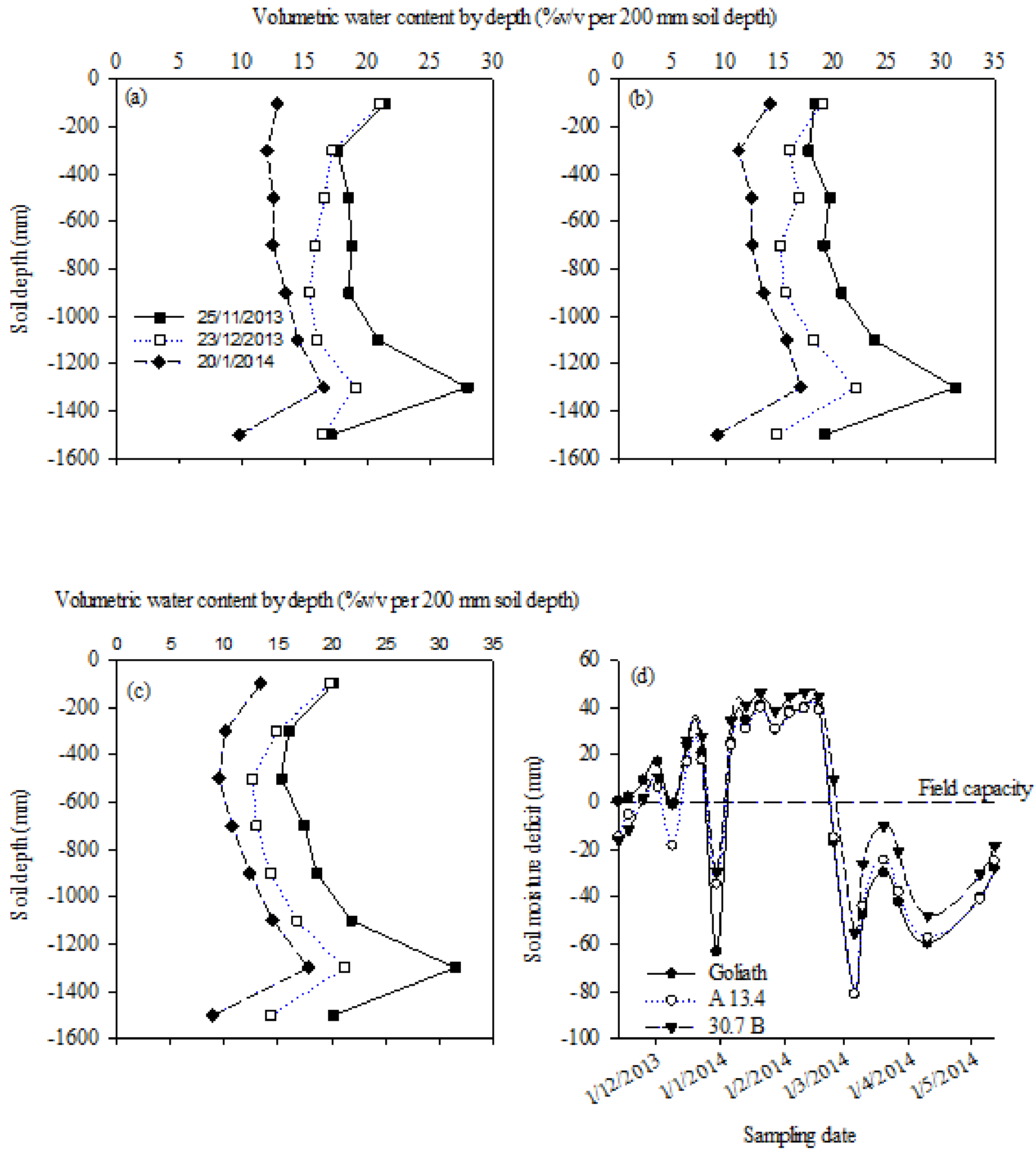

Figure 3: Mean water extraction pattern for: (a) Goliath rape, (b) A13.4 (short), and (c) 'Pallaton' (tall) raphanobrassica cultivars three dates before the first harvest (■ 25 November 2013, □ 23 December 2013 and ◆ 20 January 2014) and (d) water deficit for ● Goliath rape, ○ A13.4 (short), and ▼ 'Pallaton' (tall) raphanobrassica) cultivars grown at Ashley Dene Research and Development Station, in the 2013–14 season.

As expected, the soil water deficit responded to rainfall events. For example, in December the site received 82 mm of rainfall in the last week of that month; 71% of the total for the whole month. The season was unusually wet (Figure 1) and this was shown in the soil moisture levels (Figure 3d) through the season. Total rainfall for January was lower than the long-term average (Figure 1) and hence the rapid increases in water deficit. However, from February the site received large amounts of rainfall, representing 51%, 259% and 326% of the long-term average for February, March and April, respectively. These are reflected as excess water in Figure 3d, which could have been lost from the soil as drainage. This meant that the crops at this stage did not experience water stress as days with soil moisture deficits below field capacity were few and far apart.

The WU differed with both time of sampling ($P<0.001$) and crop cultivar ($P=0.02$) (Figure 4). Water use increased from 70±6.71 mm at the first harvest in January to 583 mm at the final harvest. At the final harvest, the cumulative WU of 575 mm for the 'Pallaton' (tall) raphanobrassica was lower than the mean of 587 mm for the forage rape and A13.4 (short) raphanobrassica. These WU values were 45–63 mm lower than the total amount of rainfall received at the site (Figure 1).

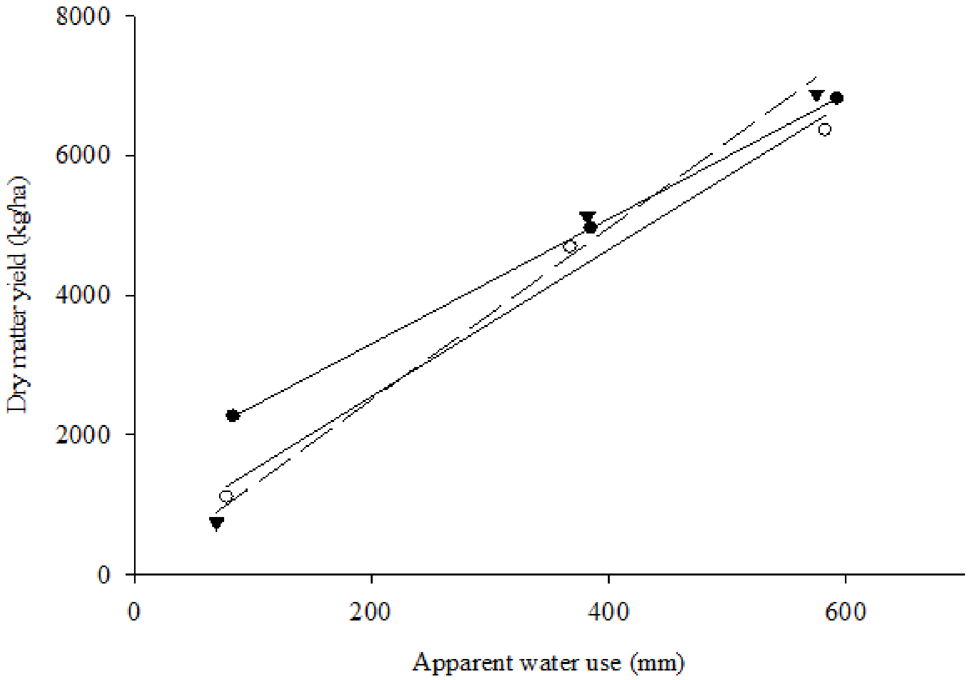

Figure 4: The relationship between dry matter yield and apparent water use for the different forage brassica cultivars: Goliath rape (●; Y=8.9x + 1519 (R^2=0.99)), A13.4 raphanobrassica (○; Y=10.5x + 450 (R^2=0.97)), and 'Pallaton' raphanobrassica (▼; Y=12.3x + 45 (R^2=0.98)), grown at Ashley Dene Research and Development StationAshley Dene, in the 2013–14 season. The gradient of the regression lines represents the water use efficiency.

As there were no yield differences between the forage rape and 'Pallaton' (tall) raphanobrassica (Figure 2), the WUE (determined as the slope of regression in

Figure 4) of 12.3 kg DM/ha/mm for 'Pallaton' (tall) raphanobrassica was 38.2% higher than the 8.9 kg DM/ha/mm forage rape. The WUE for the 'A13.4' (short) raphanobrassica was intermediate at 10.5 kg DM/ha/mm.

Discussion

This work reports the biomass yield, water extraction patterns, WU and WUE of 'Pallaton', a new-to-market multi-graze tall raphanobrassica cultivar, A13.4, a short raphanobrassica line and the standard dryland forage brassica, 'Goliath' rape when these crops are grown in shallow soils of low WHC. Results showed that the WUE for 'Goliath' rape was 18% and 38.2% lower than for A13.4 and 'Pallaton', respectively. These difference were a result of lower WU for the raphanobrassica, as the biomass yield were similar for 'Pallaton' and 'Goliath', being higher than A13.4. Results also showed similar nutritive composition among the three cultivars.

The cumulative biomass yields of 6–7 t/ha (Figure 2) were similar to those reported by Harper and Compton (1980) for the early summer sown forage rape and raphanobrassica crops. Higher cumulative biomass yields for 'Pallaton' raphanobrassica crops have been reported for irrigated crops, grown in deeper soils (Dumbleton *et al.*, 2021). The lower biomass yield in our study could be attributed to the fact that 230 kg N/ha, i.e. 84% of the total N fertiliser, was applied during the growing period (November, February & April) and was followed by unusually high rainfall (Figure 1). This meant that it was exposed to losses through leaching, not measured, but highly likely as a results of the high drainages shown in this study (Figure 3d). This could have compromised growth, resulting in lower biomass yields.

The rapid establishment and development of forage rape contrasted with late-season higher biomass accumulation of 'Pallaton' raphanobrassicas. The implication from this trial was that if more feed was needed earlier, forage rape would have been the ideal choice, while raphanobrassica would have filled in the feed deficit at the tail end of the season. Thus, these crops can be used strategically to provide high biomass (Figure 2) and quality feed (Table 2) during the typical summer–autumn pinch periods.

Although both species extracted water to a soil depth of 1300 mm, there was an indication that they were extracting more soil water from depths between 700 mm (raphanobrassica) and 900 mm (forage rape). This was consistent with those reported previously (Fletcher *et al.*, 2010) for turnips (*B. rapa var. rapa* L. cv. 'Barkant') and forage rape (cv. 'Titan'), respectively. The WUE was higher for the 'Pallaton' raphanobrassica crops. As 'Goliath' rape and 'Pallaton' had the same biomass yield, the differences in WUE was therefore explained by the difference in WU, lower for 'Pallaton' through-out the season. The WUE values reported in this study (Figure 4) were within the 5–11 kg DM/ha/mm range reported for a forage turnip crop (cv. 'Vollenda') grown in a light, sandy loam soil in Australia (Jacobs *et al.*, 2004). However, the values are lower than the 32–34 kg DM/ha/mm reported for forage rape and turnip crops grown in deep and well drained Templeton silt loam soil in New Zealand (Fletcher *et al.*, 2010). The overall lower WUE could be attributed to the moderate yield achieved and higher crop WU in this study. A significant contribution to the total WU could have been from soil water evaporation during regrowth, as the biomass was taken from the same area, and compared with other, previous experiments where consecutive harvests were from different areas of the plot (e.g. Fletcher *et al*., 2010).

The nutritive values across the cultivars (Table 2) are consistent with those reported for 'Titan' and 'Pallaton' (Dumbleton *et al*., 2021). However, similar values between the species and across cultivars was inconsistent with previous reports on other forage brassica (Westwood and Mulcock, 2012), which showed difference between species, and among cultivars. These authors reported higher ME for swedes (*B. napus* ssp. *napobrassica*) compared with kale, and CP levels increasing in ascending order of 'Gruner,' 'Regal' and 'Kestrel' kale cultivars. These differences in CP are a reflection of the proportion of the leaf to total DM, which increases in the respective order of the cultivars. The high CP and low SS and NDF in the current study (Table 2) was consistent with the negative relationship between CP and these two components as reported previously (Thant *et al*., 2020). Furthermore, the SS:CP ratio of 0.68—081 could result in negative environmental outcomes, as it was markedly lower than the ratio of 3, regarded as standard for minimising the risk of nitrate leaching from deposited urine (Dalley *et al*., 2017; de Ruiter *et al*., 2019). The results also support previous studies (e.g. de Ruiter *et al*., 2007; Kaur *et al*., 2011) showing that forage brassicas in general yield forage of superior quality compared to perennial ryegrass dominant pastures.

Conclusions

Cumulative biomass yield for forage rape 'Goliath' and 'Pallaton' was similar at 6.9±0.2 t/ha. The WU was lower for 'Pallaton', resulting in higher WUE compared with forage rape. All key nutritive attributes, except for NDF and total SS, were above or within the recommended ranges for animal production. The high nutritive values during this period, when pastures are struggling to grow and/ or of low quality, supports the use of these crops at this critical period in animal production cycles.

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