Irrigation Management Strategies for Fodder Beet (*Beta vulgaris* L.) Crops

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Abstract

The production of fodder beet (*Beta vulgaris* L.) in New Zealand is concentrated in the South Island, and often requires irrigation to achieve high yields. Development of efficient irrigation management strategies requires information on the effect of timing and rate of irrigation on crop growth. A field study was conducted on a moderately deep soil at Chertsey, Canterbury, New Zealand, to evaluate crop growth responses to five irrigation managements: Rain-fed (control), weekly replacement of full evapotranspiration (FullET-weekly), and 50% of evapotranspiration replaced weekly (HalfET-weekly), fortnightly (HalfET-2weekly) or 3-weekly (HalfET-3weekly). Irrigation to replace ET was adjusted to account for rainfall received between irrigation events. The crop was sown on 11 October 2015. Dry matter (DM) and green leaf area index (LAI) were quantified at 4-weekly intervals from 21 December 2015 until 16 May 2016. Water use efficiency (WUE) was calculated from weekly time domain reflectometry and neutron probe measurements of volumetric soil water content (to 0.8 m depth) and crop biomass. Final yield was lowest for Rain-fed (17.1 t DM/ha) and highest for FullET-weekly (28.9 t DM/ha) treatments. The remaining treatments did not differ in yield, producing 22.4±1.6 t DM/ha, but differed significantly from the Rain-fed and FullET-weekly treatments. Yield differences were associated with the rate of leaf area expansion and duration of critical LAI values (≥ 3.0 m^2/m^2), which were greater for FullET-weekly than for other treatments. Rain-fed and FullET-weekly treatments resulted in the highest and lowest WUE (81 versus 47 kg DM/ha/mm). The remaining treatments did not differ in WUE, averaging 67±3.6 kg DM/ha/mm. Our results show yield benefits from irrigation, with the best outcome from FullET-weekly given the soil type and weather conditions. However, under water restriction conditions, the HalfET-3weekly management is recommended over more frequent partial ET replacements because it would reduce irrigation costs without penalising yield.

Introduction

In New Zealand, fodder beet (*Beta vulgaris* L.) is mainly grown in the South Island, and often requires irrigation to achieve high crop yields (Chakwizira et al. 2014; Khaembah et al. 2019). Globally, demand for food and other amenities from the growing human population is continually exerting pressure on water resources (Boretti and Rosa 2019; Reints et al. 2020). Many countries have policies in place e.g. New Zealand's National Policy Statement for Fresh Water Management (Freshwater 2017) which require crop production to comply with strict environmental limits associated with water quality and extraction volume from aquifer sources. Therefore, it is important to evaluate the impact of water availability on crop growth to provide insight into irrigation management strategies that conserve water resources while maximising crop yields.

A previous study demonstrated that fodder beet crops growing on deep soils in the South Island produced the same yield when irrigation was applied every 3 weeks to replace 50% of evapotranspiration (ET) compared with more frequent weekly application to replace full ET (Chakwizira et al. 2014). A large proportion of fodder beet growing areas in the South Island are characterised by moderately deep well drained soils that may interact differently with irrigation and affect crop yields. Therefore, the objectives of this study were to evaluate the effect of water availability on water use and yield of fodder beet, and define irrigation management options that offer high water use efficiency on a moderately deep soil type.

Materials and methods

The experiment was located at Chertsey, Canterbury, in New Zealand (43°47'30.1"S 171°57'31.4"E) on a moderately deep (~0.60 m), well drained Chertsey silt loam with an available water-holding capacity of ~120 mm/m of depth (Hayman 1985; Chynoweth et al. 2012). 'Rivage' fodder beet seed was conventionally drilled with an air seeder at 100,000 seeds/ha on 11 October 2015, to establish ≥80,000 plants/ha. The experiment was a randomized block design with four replications. Five treatments were evaluated: Rain-fed (control); weekly replacement of full evapotranspiration (FullET-weekly); and 50% of evapotranspiration replaced weekly (Half-ET-weekly); fortnightly (Half-ET-2weekly); or 3-weekly (Half-ET-3weekly). The amount of irrigation water applied was calculated from daily ET records obtained from an on-site weather station (NIWA 2020) and adjusted for rainfall.

Volumetric soil water content was measured in 20-cm increments using Time Domain Reflectometers (Model CS616, Campbell Scientific Inc., USA) and Neutron probes (NP) installed at 0–0.2 m and 0.2–0.8 m, respectively. Reflectometers were connected to a data logger (Campbell CR10X) which recorded volumetric soil water content hourly. Measurements began on 26 November 2015 and were completed at the final harvest. Apparent crop water use (WU) was calculated from the change in volumetric soil water content between the sampling day and the start of the experiment, as previously described Chakwizira et al. (2014). Drainage was assumed to be negligible. Water use efficiency (WUE) was calculated as the slope of linear regression of the sequential crop biomass measurements against the WU.

Dry matter (DM) harvests were taken from 2-m^2 quadrats (2 plant rows x 2 metres of row length) at 4-weekly intervals starting from 21 December 2015 with the final harvest completed on 16 May 2016. At each harvest, plant number and fresh weight were recorded. Sub-samples of two plants from each sample were reweighed and then separated into leaf lamina, petiole and storage root. Laminae were individually scanned through a leaf area meter (LI-COR model LI-3100; Lincoln, NE, USA) to determine leaf area index (LAI). The sub-sample fractions were then oven-dried at 60°C until constant weight to determine dry weight.

Analysis of variance was carried out using GenStat (version 17.1, VSN International Ltd, UK). Significant effects were separated by the least significant difference (LSD) at 5% level.

Results

There were yield differences among treatments, observed in late crop development (Fig. 1a). The HalfET-weekly, HalfET-2weekly, HalfET-3weekly treatment crops produced comparable yields (p=0.30) which averaged 22.4±1.1 t DM/ha. Rain-fed and FullET-weekly treatment crops produced the lowest and highest yields (17.1±0.8 and 28.9±0.7 t DM/ha, respectively), both of which differed significantly (p <0.01) from the HalfET treatment crops.

Leaf area development was influenced by irrigation treatment, with FullET-weekly treatments achieving greater LAI than crops under other treatments (Fig. 1b). Maximum LAI was achieved earlier (second sampling) in FullET-weekly crops than those under the rest of the treatments, for which LAI peaked at the third harvest (Fig. 1b). Additionally, FullET-weekly crops maintained critical LAI within the 3–4 range (i.e. critical LAI required for optimal radiation interception and storage root development) for longer than crops under other treatments (Fig. 1b). The LAI in Rain-fed crops was below critical thresholds for most of the season (Fig. 1b).

The total WU for rain-fed crops was 211 mm and increased to 332, 346, 343 and 553 mm in HalfET-3weekly, HalfET-2weekly, HalfET-weekly and FullET-weekly treatments, respectively. Yield correlated positively with WU (R^2=0.95). Water use efficiency differed among treatments (p<0.001) and was highest in rain-fed and lowest FullET-weekly crops (81 versus 47 kg DM/ha/mm). Crops under HalfET-weekly, HalfET-2weekly, HalfET-3weekly treatments had comparable (p=0.40) WUE (averaging 67±1.3 kg DM/ha/mm), and these differed significantly from values for crops under both FullET-weekly and rain-fed treatments (p<0.03).

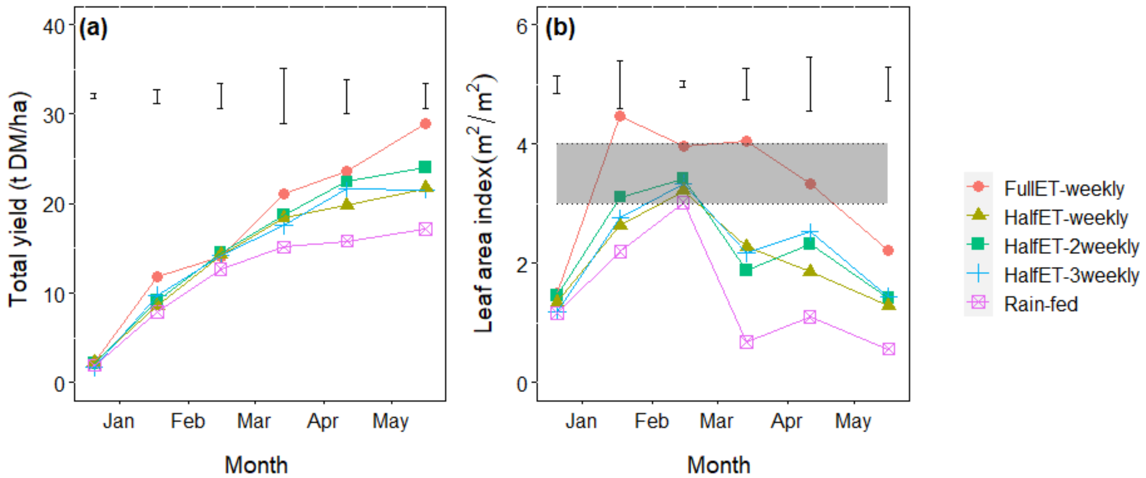

Figure 1: Total dry matter (a) and leaf area index (b) for fodder beet crops grown under different amounts and frequency of irrigation at Chertsey, New Zealand during the 2015-16 growing season. FullET-weekly = full evapotranspiration [ET] replacement per week, HalfET-weekly = 50% ET replacement weekly, HalfET-2weekly = 50% ET replacement fortnightly, HalfET-3weekly = 50% ET replacement every three weeks, Rain-fed = nil irrigation. The shaded region represents critical leaf area index range (3–4). Bars represent the least significant difference at 5% ($LSD_{0.05}$).

Discussion

Yield of fodder beet crops was enhanced by irrigation, with the greatest benefits from full irrigation and lowest yields from rain-fed crops. The HalfET treatments produced the same yield, and differed marginally in the amount of irrigation water applied, indicating that volume of water supplied to crops was more important than frequency of application. On deep soils, Chakwizira et al. (2014) also reported yield benefits from irrigating fodder beet crops, but FullET-weekly crops yielded the same as HalfET-3weekly crops. Such differences in response to irrigation may be attributed to higher water holding capacity of the soil (~190 mm/m of depth) used in the Chakwizira et al. (2014) trial than the ~120 mm/m of depth for the soil in the current trial. Also, there was a difference in the distribution of rainfall during the season, with our experimental site receiving 105 mm less rainfall, which was more sporadic, than that in the Chakwizira et al. (2014) study. As a result, crops in our study were subjected to frequent or longer periods of water deficits which negatively affected the yield of HalfET-3weekly crops. This finding suggests that irrigation management may differ depending on soil type, and amount and distribution of rainfall during the crop season.

Irrigation affected fodder beet yield via canopy development as demonstrated by a greater decline of LAI in rain-fed than in irrigated crops. Studies have shown that LAI determines the capacity of the crop to intercept solar radiation, which ultimately determines yield (Martin 1986; Jaggard et al. 2009). For fodder beet, research has shown LAI of 3–4 (critical LAI) is required to maximise radiation interception (Matthew et al. 2011; Chakwizira et al. 2014). In our study, FullET-weekly crops reached critical LAI values in mid-January when solar radiation was near its seasonal peak, and maintained these values through to early autumn. In contrast, water stress in rain-fed crops slowed canopy expansion and there was accelerated leaf senescence, indicated by a sharp decline in LAI. Consequently, LAI in rain-fed crops was restricted to values below 3 for most of the season. Thus, the high and low yields of FullET-weekly and Rain-fed crops can be attributed to optimal and sub-optimal radiation capture, respectively.

Fodder beet yield increased with WU and decreased with higher apparent WUE, similar to previous findings in fodder beet and other crops (Jacobs et al. 2004; Fletcher et al. 2010; Chakwizira et al. 2014). The apparent inverse correlation of WUE with yield needs to be considered in a wider context of the system, considering other factors such as feed quality and economics. However, the negligible differences in yield and WUE in HalfET crops indicates that under water restriction conditions, the HalfET-3weekly management shows promise over more frequent HalfET-weekly or HalfET-2weekly because it would save irrigator running costs without penalising crop yield. Where water restrictions are absent, eliminating water stress is recommended.

Conclusions

Irrigation alleviated water deficit and increased fodder beet yield. The fully irrigated crops produced the highest yield, which was associated with early achievement and maintenance of critical LAI for most of the season. The HalfET crops produced the same yield, which was intermediate between those of FullET-weekly and Rain-fed crops. Rain-fed crops experienced water stress which restricted LAI development and reduced yield. Fodder beet yield correlated positively with WU and negatively with WUE. Under the conditions of this study, full irrigation minimised cumulative effects of soil water deficit and maximised yield.

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