CLIMATE CHANGE ADAPTATION PROGRAM

Strategies to Improve Forage Yield and Quality While Adapting to Climate Change

Funding for this project has been provided by the Governments of Canada and British Columbia through Growing Forward 2, a federal-provincial-territorial initiative. The program is delivered by the Investment Agriculture Foundation of BC.

DELIVERED BY

Investment Agriculture Foundation

FUNDING PROVIDED BY

Growing Forward 2

British Columbia

Canada

STRATEGIES TO IMPROVE FORAGE YIELD AND QUALITY WHILE ADAPTING TO CLIMATE CHANGE

Optimizing water applications to maximize forage yield during dry summers while at the same time minimizing nutrient losses

The Pacific Field Corn Association

April 2015 - February 2018

Growing Forward 2 | Investment Agriculture Foundation of British Columbia | BC Agricultural Research & Development Corporation ardcorp | Climate Action Initiative BC Agriculture & Food | British Columbia | Canada

Acknowledgments 3

Executive Summary 4

Overall Objectives. 4

Specific Objectives. 4

Background. 4

Previous Study 5

Study Materials and Methods. 5

Measurements 7

Results. 8

Soil physical characteristics 8

Weather data 9

2015 grass yield, N uptake and protein (Table A1). 12

2016 grass yield, N uptake and protein (Tables A2, A4, A6 and A8). 15

2017 grass yield, N uptake and protein (Tables A3, A5, A7 and A9). 18

Appendix 22

Acknowledgments

Funding and in-kind support for this project has been provided in part by the Pacific Field Corn Association, the BC Dairy Association, the BC Forage Council and farmer co-operators. Funding has been provided in part by the Governments of Canada and British Columbia through the Investment Agriculture Foundation of BC under *Growing Forward 2*, a federal-provincial-territorial initiative. The program is delivered by the BC Agriculture & Food Climate Action Initiative.

The Pacific Field Corn Association would like to especially thank the farmer co-operators for their generous contribution of land and time.

Executive Summary
Increased home grown feed production is important for improving sustainability of the dairy industry because it can reduce feed imports (purchase) and hence farm nutrient imbalances. Irrigating grass crops during the typically dry mid-summer can help farmers increase yield of dry matter and protein. This study evaluated grass response to the two limiting factors, irrigation and nitrogen. In two of three years there was a very significant response to irrigation increasing yield; in 2015 and 2017 N increased yield by about 1 t/ha with no irrigation but irrigation plus the same amount of N increased yield by 3-5 t/ha. In 2016, the grass responded more to N than to water due to moist conditions, water holding capacity of soils and deep roots in orchardgrass. It is important to avoid leaching nitrate below the root zone with irrigation water. The data in this study should be subjected to economic analysis to determine the overall cost and benefit of watering relative to purchasing additional feed.

Overall Objectives.
The overall objective of this study is to enhance and stabilize farm production of feed and feed nutrients through strategic and judicious use of irrigation water.

Specific Objectives.
The specific objectives of this study were to:

- Optimize water applications to maximize forage yield during typically dry summers in the Lower Fraser Valley while at the same time minimize nutrient losses.
- The approach is to find the ideal combination of timing and quantity of water application using various water deficit indictors.

Background.
Some of the overall impacts of climate change for BC agriculture have been identified as follows: http://www.bcagclimateaction.ca/overview/why-adaptation/

- More frequent occurrence and severity of summer drought; water shortages in more regions. Hotter and drier summers.
- Decreased snowfall in alpine areas leading to reduced snowpack and to water shortages
- Increased precipitation (frequently through more extreme events) and subsequent vulnerability to flooding, erosion, nutrient loss. Wetter and milder winters.
- More frequent and intense “extreme” weather events (wind-storms, forest fires, hail, droughts and floods)
- Increase in growing degree days (heat units) and a longer frost free season. Hotter summers with milder winters.
- Potential for broader range of viable crops in some regions. Milder winters.
- Increase in pest and disease pressure due to winter survival of pests.

Previous Study.

Previous work at Agassiz showed annual yield increases of 13 to 35% from summertime irrigation for different grass species and varieties. The work showed substantial potential to increase grass production with irrigation during the dry summer months. Yield increases ranged from about 13 to 29% for three orchardgrass varieties and 17 to 35% for four perennial ryegrass varieties (Table 1).

Table 1. Grass yield with and without irrigation for two years at Agassiz (t DM ha^{-1})

Species	Variety	No Irrigation	With Irrigation	Increase in yield (%)
Orchardgrass	Hallmark	15.0	17.7	17.7
	Prairial	13.8	15.5	12.7
	Mobite	11.5	14.8	28.8
Tall fescue	Johnstone	13.4	16.4	22.4
Perennial ryegrass	Frances	10.0	11.7	17.1
	Melle	8.9	11.0	23.6
	Bastion	9.2	12.5	35.3
	Condesa	9.7	11.8	22.3
Timothy	Toro	13.2	16.3	24.0
Reed canarygrass	Palaton	10.5	13.3	27.3
Meadow brome	Regar	12.5	14.5	16.1

Study Materials and Methods.

The study examined four combinations of water application on an orchardgrass crop planted in 2015. Different soil moisture sensors were used in 2016 and 2017 to monitor soil water deficit measured in units of water potential (negative pressure or suction) called centibars (cbar). At -80 cbar most of the easily available water is gone so growth slows down. If the deficits are short-lived plants can compensate. Most of plant roots are in the top 15 cm of soil, so water lower down is less rapidly available. Different degrees of soil moisture deficit were then used as triggers for irrigation. Four water application strategies were compared to no watering for 2015, 2016 and 2017.

In 2015 the newly seeded orchardgrass crop was watered using the following strategies: Frequent & Light, Frequent & Heavy, Infrequent & Light, Infrequent & Heavy. In 2016 and 2017 soil moisture sensors were installed at three depths and used as a guide for water applications as outlined in Table 2 for three watering treatments. The fourth watering treatment used Evapotranspiration data (ET) to determine timing of water application. Water application rates for 2016 and 2017 are summarized in Table 3.

Table 2. Irrigation treatments 2016 and 2017.

Irrigation treatment	Sensor depth (cm)	Trigger value
2016		
15 cm – 30 cbar	15	-30 cbar
30 cm – 30 cbar	30	-30 cbar
45 cm – 30 cbar	45	-30 cbar
15 cm – ET -10 cbar	15	ET – 10 cbar
2017		
15 cm – 60 cbar	15	-60 cbar
30 cm – 60 cbar	30	-60 cbar
45 cm – 60 cbar	45	-60 cbar
15 cm – ET -10 cbar	15	ET

Table 3. Water application amounts to cuts 3 and 4, 2016 and 2017.

Irrigation treatment	Water applied (mm)
2016	
15 cm – 30 cbar	200
30 cm – 30 cbar	204
45 cm – 30 cbar	275
15 cm – ET -10 cbar	300
2017	
15 cm – 60 cbar	250
30 cm – 60 cbar	254
45 cm – 60 cbar	325
15 cm – ET -10 cbar	425

Nitrogen fertilizer was applied at 50 kg N ha^{-1} (45 lb acre^{-1}) at seeding in 2015. Growth was trimmed off to control weeds and N applied at 0, 50 and 100 kg N ha^{-1} before a single harvest in September. Individual N applications and total annual amounts for each N treatment (N Trt) are detailed in Table 4 for 2016 and 2017. Harvest dates are listed in Table 5. Other nutrients (phosphorus, potassium, sulphur, magnesium, micro-nutrients) and Calpril lime were applied according to soil test recommendations. Statistically, the design of the study is a randomized block design with 5 watering treatments and 3 nitrogen application rates. Each individual study treatment was repeated four times.

Table 4. Nitrogen application rates (kg N ha^{-1}) 2016-2017.

Year	N Trt name	Spring	After Harvest #1	After Harvest #2	After Harvest #3	Annual
2016	0	50	0	0	0	50
	50	50	50	50	50	200
	100	50	100	100	100	350
2017	0	70	0	0	0	70
	50	70	50	50	50	220
	100	70	100	100	100	370

Table 5. Grass harvest dates 2015-2017.

Year	Harvest #1	Harvest #2	Harvest #3	Harvest #4
2015	September 21	.	.	.
2016	June 1	July 13	August 17	October 5
2017	May 25	July 6	August 11	September 7

Measurements

For each grass harvest dry matter yield, moisture content and nitrogen content were measured. Nitrogen capture is important because it means less lost to the groundwater and more in the plant contributing to protein formation. There is a direct relationship between plant protein and plant nitrogen. Soil was sampled immediately after each grass harvest and analyzed for moisture, nitrate and ammonia content. Samples were collected from 4 depth increments of 0-15, 15-30, 30-45 and 45-60 cm. Detailed soil texture analysis was conducted on one set of soil samples (Table 6). Soil moisture sensor data, weather data and Evapo-Transpiration (ET) were recorded throughout the study. Evapotranspiration is available on www.farmwest.com

Results.

Detailed result tables are compiled in the Appendix.

Soil physical characteristics

Results from detailed texture analysis classify the study site as a silt loam soil (Table 6, Figure 1). The top two sampling depths of 0-15 and 15-30 cm have very similar percentages of sand, clay and silt due to several years of plowing and mixing which commonly occurs to 30 cm depth. With increasing depth the profile increases in sand content with decreasing clay and silt content but still classifies as a silt loam soil. Using pedotransfer functions the 60 cm profile is estimated to have a plant available water holding capacity of 0.275 which equates to about 16.5 cm of water that is held by the soil against drainage by gravity and available to the grass.

Table 6. Soil texture analysis for study site

Soil depth (cm)	Sand (%)	Clay (%)	Silt (%)	Texture
0-15	14.6	19.2	66.2	Silt loam
15-30	14.4	17.8	67.8	Silt loam
30-45	24.6	14.0	61.4	Silt loam
45-60	36.6	10.4	53.0	Silt loam

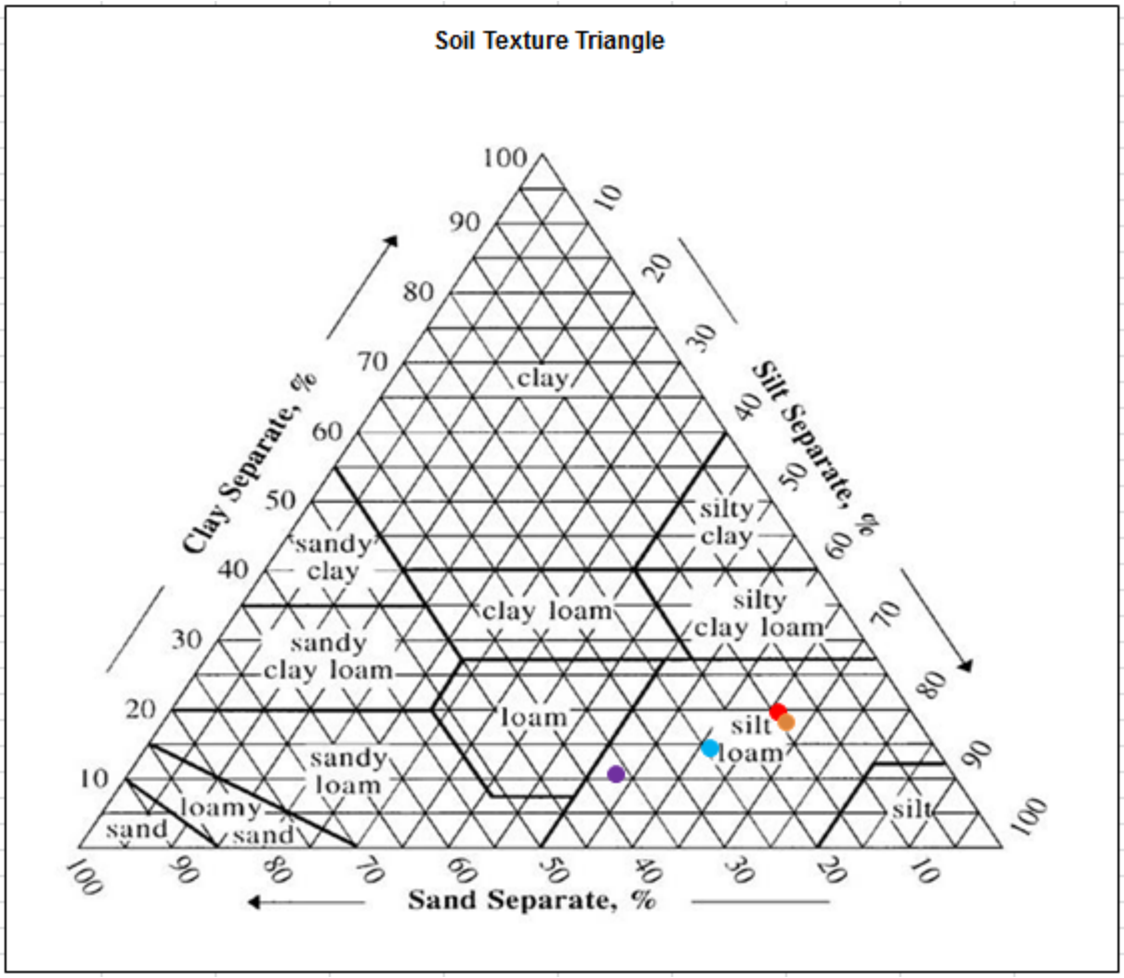

Figure 1. Soil texture triangle for study site showing texture for four depth increments 0-15 (red), 15-30 (orange), 30-45 (blue) and 45-60 cm (purple).

Weather data

- Annual daily 2016 and 2017 weather data for precipitation, daily maximum temperature and daily minimum temperature are shown in Figures 2 and 3. Annual averages and interval averages for individual harvests are summarized in Table 7.
- Annual precipitation was very similar for 2016 (1605 mm) and 2017 (1595 mm) but the distribution of this rainfall was very different for the four grass harvests in each year.
- Rainfall over the intervals for cuts 2 to 4 was significantly higher for 2016 (219 mm) compared to 2017 (76 mm)
- In 2016 the summer dry period lasted approximately 45 days from July 17 to August 30 over which time there was only 7.6 mm of rainfall. This period coincided only with cut number 3 (July 14 to August 17) although rainfall was low for the early growth interval of cut 4 (August 17 to October 5) with much of 108 mm falling mid-September. There was a slight soil moisture deficit indicated of 60mm for cut 2 (Table 6) but with a plant available water content of 165 mm it is unlikely the grass lacked water for this cut. Cut

number 3 had a deficit of 137 mm indicating that available soil moisture was depleted through the growth period and into cut 4.

- The 2017 summer dry period was more intense, lasting about 79 days from June 21 to September 7 with only 19.6 mm of rainfall. Over this period cuts 2, 3 and 4 had moisture deficit values of 129, 161 and 100 mm respectively. Dry and warmer weather began part way through cut 2 grass growth about two weeks before harvest. The deficit of 129 mm would mean the grass was depleting available soil water such that grass growth starting for the third growth phase was likely moisture deficient.
- Based on average annual maximum and minimum air temperatures 2016 was warmer than 2017 (Table 7). When examined on an individual grass cut basis 2017 was cooler than 2016 for cut 1 with average Tmax being 3.7 ºC lower and average Tmin being 2.3 ºC lower. However, 2017 was warmer during the growth intervals for cuts 2, 3 and 4 with Tmax values all higher.

Table 7. Summary of annual and harvest interval weather data for 2016 and 2017.

Year	Interval	Days	Precip (mm)	Average Air Tmax (ºC)	Average Air Tmin (ºC)	ET (mm)	Precip less ET (mm)
2016	Annual	366	1605	15.3	8.0	833	
	Cut 1*	93	339	16.8	8.5	265	74
	Cut 2	42	103	21.1	12.7	163	-60
	Cut 3	35	8	24.9	13.6	145	-137
	Cut 4	49	108	22.0	11.6	147	-39
2017	Annual	365	1595	14.7	6.7	860	
	Cut 1	86	560	13.1	6.2	191	369
	Cut 2	42	56	22.9	12.5	185	-129
	Cut 3	36	10	26.4	13.5	171	-161
	Cut 4	27	9	27.1	13.7	110	-100

* Intervals for each grass cut are determined from one harvest date to the next harvest date. For cut number 1 the interval starts March 1.

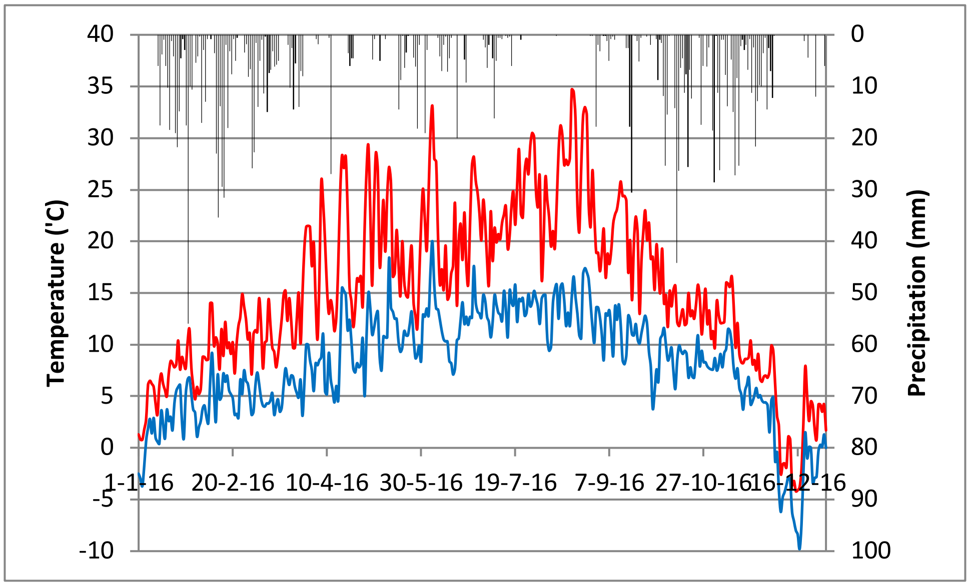

Figure 2. 2016 precipitation (black), daily maximum (red) and minimum (blue) air temperatures.

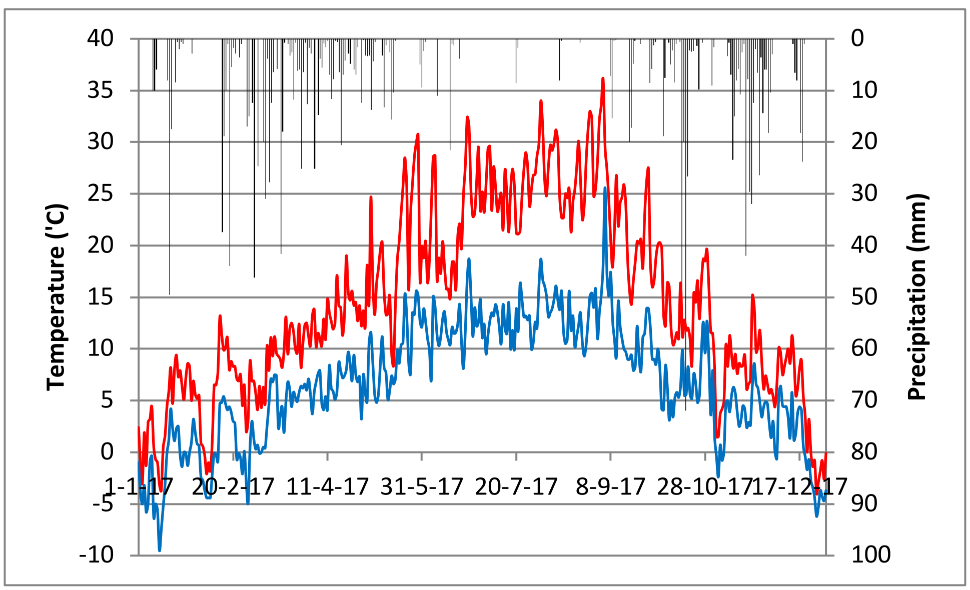

Figure 3. 2017 precipitation (black), daily maximum (red) and minimum (blue) air temperatures.

2015 grass yield, N uptake and protein (Table A1).

- All four irrigation treatments significantly increased yield for the single harvest of newly established orchardgrass in 2015. Averaged across N application rates the yield increase from irrigation was 1.5 to 1.7 t DM ha^{-1} (207 to 229%). Average yield increase from the four irrigation treatments at N applications of 0, 50 and 100 kg N^{-1} were 217, 112 and 94% respectively (Figure 4).
- There was very little difference in grass yield and N uptake between the four irrigation treatments. Only the largest water application strategy of "Frequent and Heavy" was significantly higher than "Infrequent and Light" by 0.3 t DM $ha^{-1}$and 7 kg N ha^{-1} (Table A1).
- N uptake was significantly increased by irrigation. Averaged across N application rates N uptake increased 29 to 36 kg N ha^{-1} (76 to 95%). Average N uptake increase from the four irrigation treatments at N applications of 0, 50 and 100 kg N ha^{-1} were 157, 83 and 63% respectively (Figure 5).
- Protein content was significantly higher for the non-irrigated treatment compared to the four irrigation treatments by 2.4 to 2.9% (Table A1).
- Grass yield, N uptake and protein content were all increased significantly by by n application with N100 > N50 > N0. There were no interactions between N application rates and irrigation treatments.

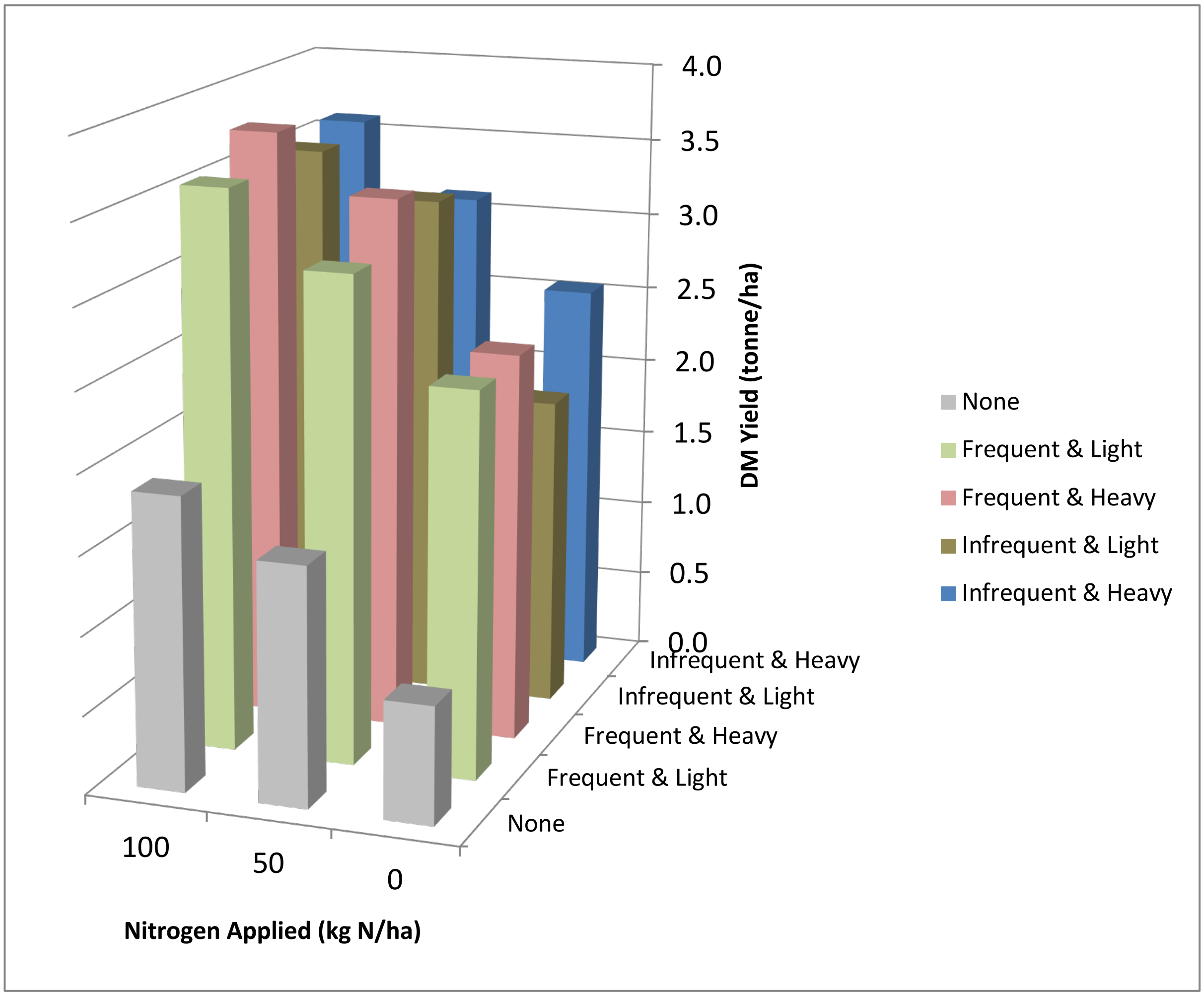

Figure 4. Grass yield for single harvest in 2015 establishment year.

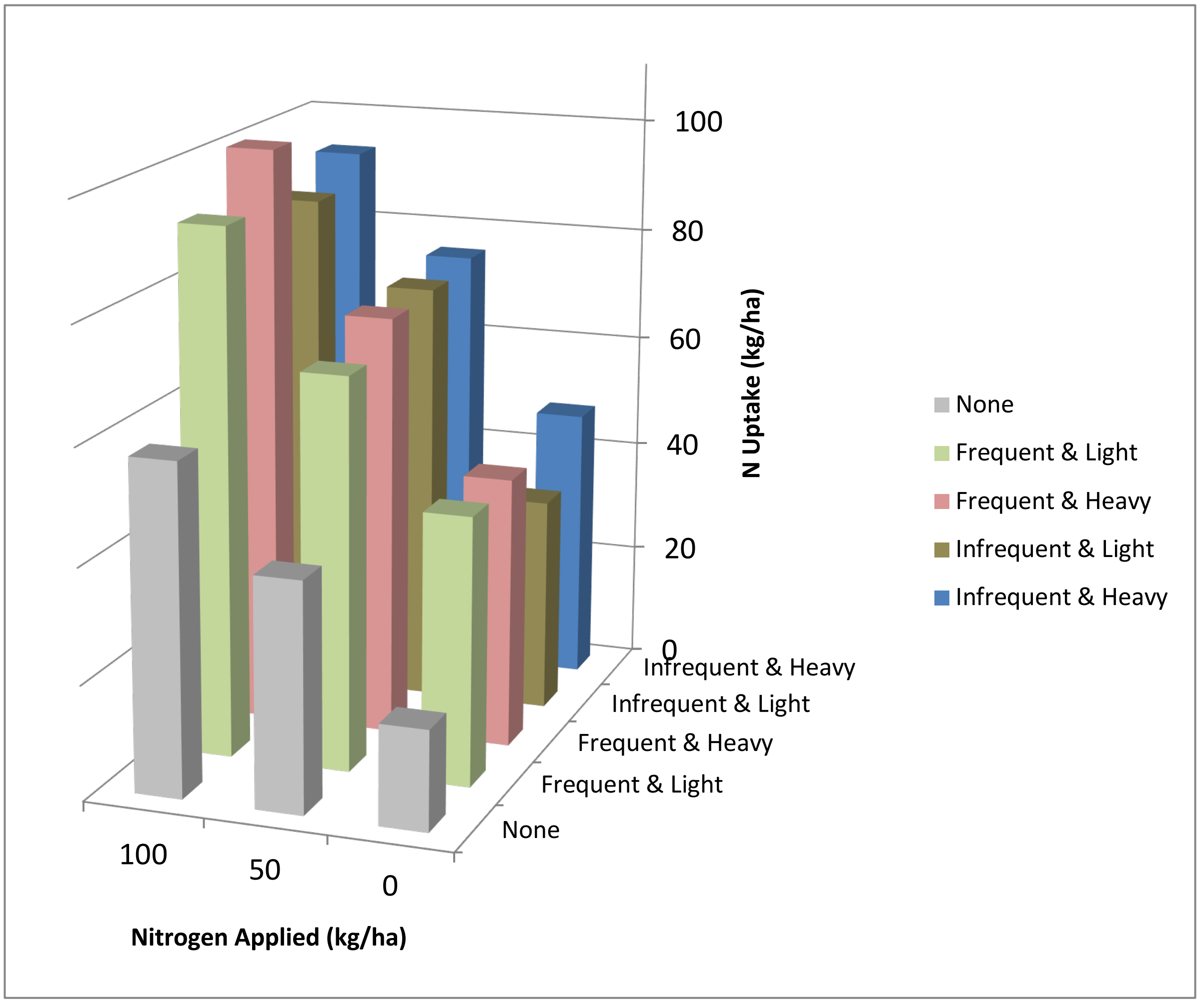

Figure 5. N uptake for single harvest in 2015 establishment year.

2016 grass yield, N uptake and protein (Tables A2, A4, A6 and A8).

- On an annual basis there was no significant increase in yield from summer time irrigation of cuts 3 and 4. Annual yield increases from irrigation ranged from 0.2 to 0.5 t ha^{-1} (Table A2).
- Similarly there was no significant difference in N uptake between irrigated and non-irrigated treatments. N uptake increases ranged from 8 to 16 kg N ha^{-1} from irrigation compared to no irrigation (Table A2).
- Irrigation significantly increased summertime yield. Combined yield of Cuts 3 and 4 was 0.8 to 1.0 t ha^{-1} higher with irrigation compared to no irrigation.
- Yields were higher under irrigation by about 0.5, 1.0 and 1.2 t $ha^{-1}$for N applications of 100, 50 and 0 kg/ha respectively (Figure 6).
- Irrigation significantly increased summertime N uptake. Combined N uptake of Cuts 3 and 4 was 22 to 26 kg N ha^{-1} higher with irrigation compared to no irrigation.
- N uptakes were higher under irrigation by about 12, 27 and 34 kg N ha^{-1} for N applications of 100, 50 and 0 kg/ha respectively (Figure 7).
- There were few differences in grass protein content. Only the cut 4 non-irrigated treatment had significantly higher protein content (21.2%) compared to the four irrigation treatments (18.3 to 18.8%).
- There were no differences between the four irrigation treatments likely due to the fact that all water applications (200 to 300 mm) were close to the estimated soil water deficit of 236 mm. Given also that plant available water was about 165 mm through the soil profile it is not surprising there were no differences between irrigation treatments and overall response to irrigation was fairly small.
- Calculating water usage (net of non-irrigated) in terms of yield per cm of water applied or kg N uptake per cm of water applied clearly shows advantage to the two treatments that applied lower amounts of water (Table A8). The 15cm-30cbar and 30cm-40cbar treatments (which applied about 2/3's as much water) produced significantly more yield and N uptake compared to higher water applications of the 45cm-30bar and ET treatments.
- Calculating the efficiency of N use (net of the zero N applications) in terms of yield per kg N applied and N recovery as N uptake per kg N applied shows no difference between irrigated and non-irrigated (Table A8).

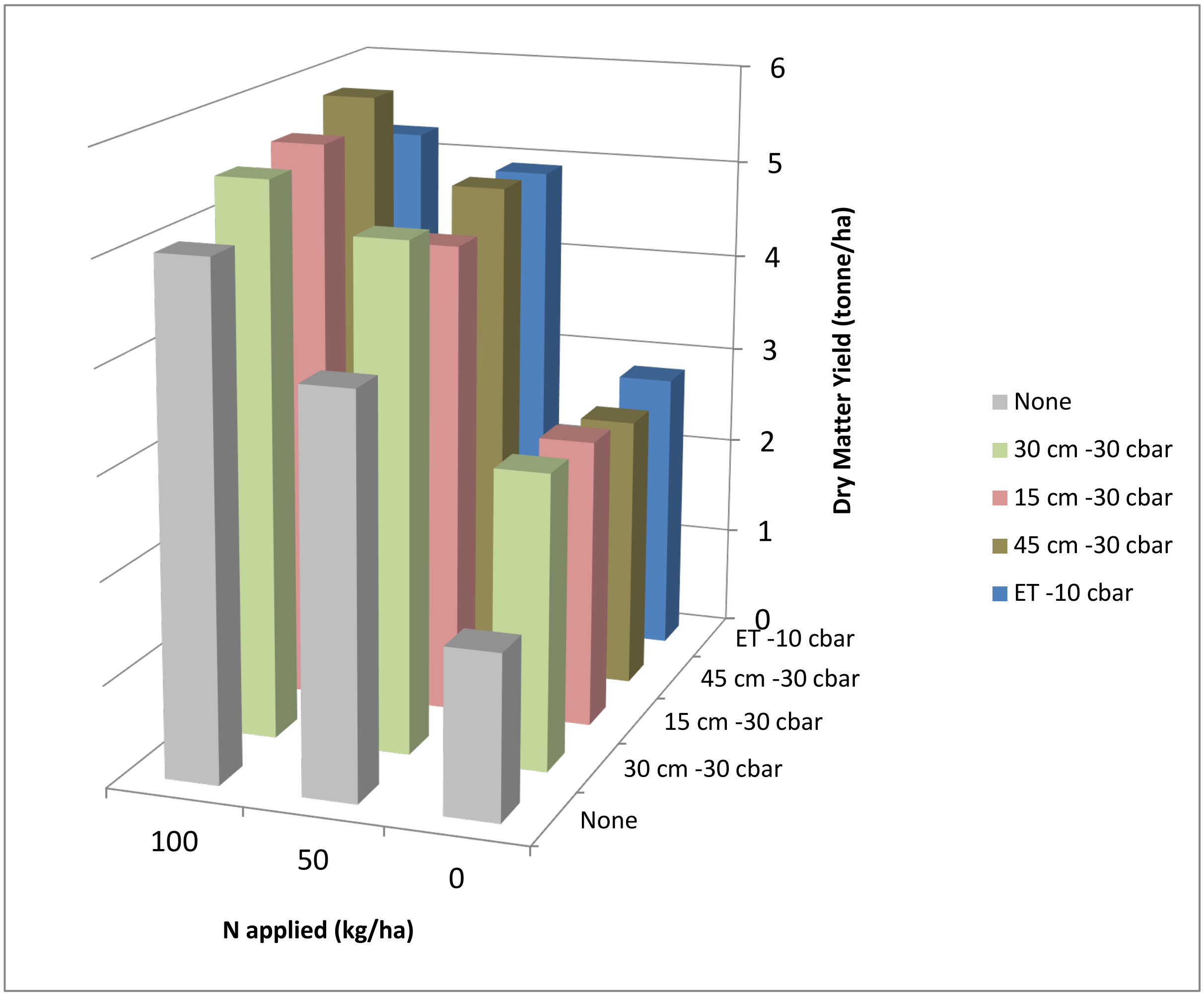

Figure 6. Grass yield for cuts 3 and 4 in 2016.

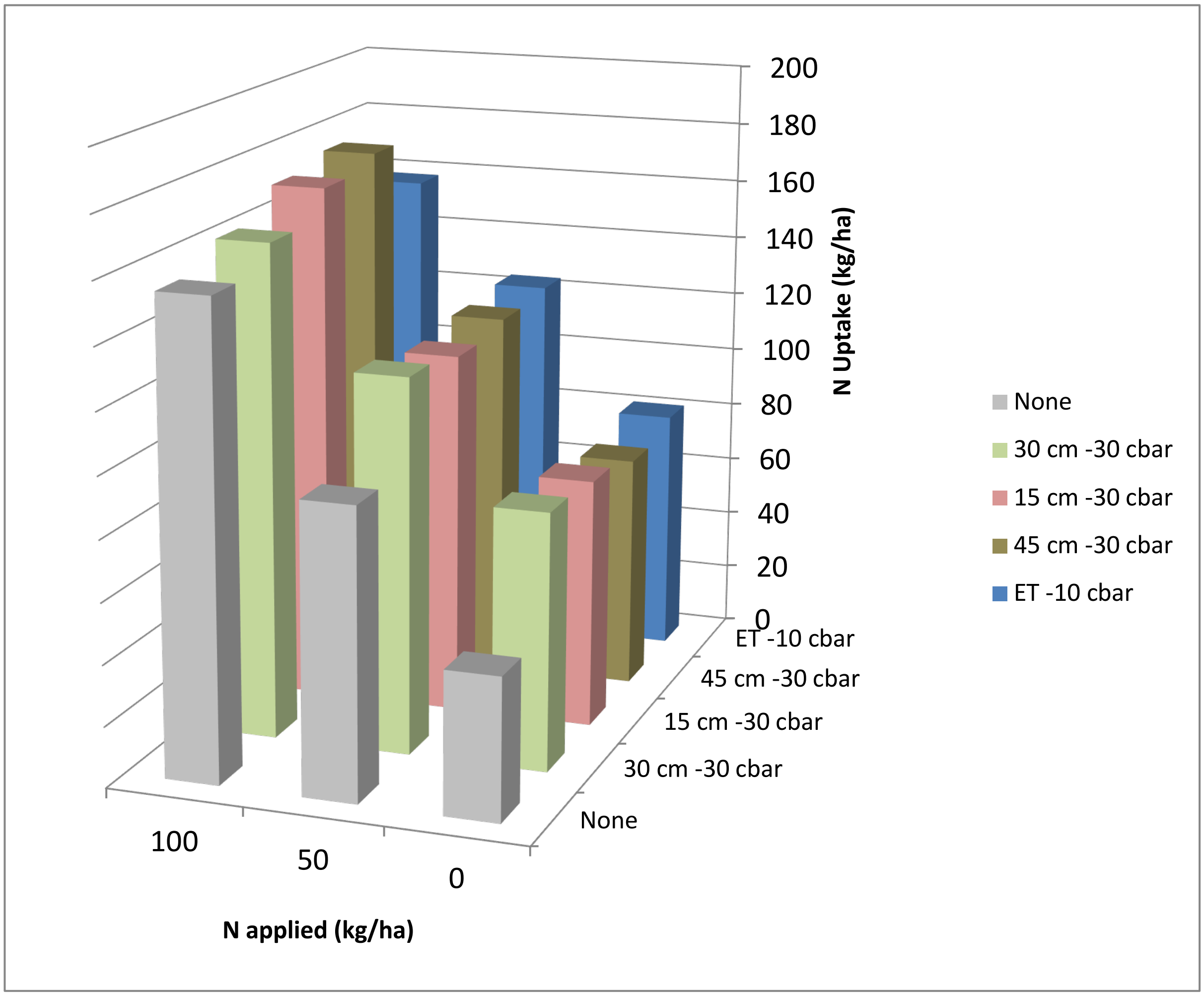

Figure 7. N uptake for cuts 3 and 4 in 2016.

2017 grass yield, N uptake and protein (Tables A3, A5, A7 and A9).

- On an annual basis there was a significant increase in yield from summer time irrigation of cuts 3 and 4. Annual yield increases from irrigation ranged from 1.4 to 2.3 t ha^{-1} (18 to 30 %) (Table A3). Increase in yield was obtained for both cuts 3 and 4 and was especially significant for cut 4 where drought conditions resulted in a crop failure without irrigation.
- Combined yield for irrigated cuts 3 and 4 was significantly higher than non-irrigated by 1.9 to 2.6 t ha^{-1} or 136 to 186 % (Table A3).
- The ET, 15cm and 45cm irrigation treatments produced significantly higher yield that the 30cm treatment.
- Similarly there was a significant increase in annual N uptake between irrigated and non-irrigated treatments. N uptake increases ranged from 59 to 85 kg N ha^{-1} (41 to 59%) from irrigation compared to no irrigation (Table A5).
- Combined N uptake for irrigated cuts 3 and 4 was significantly higher than non-irrigated by 67 to 92 kg N ha^{-1} or 109 to 271 % (Table A5).
- There were significant differences in N uptake for both annual and combined cuts 3 and 4 between the irrigation treatments. The ET and 45cm treatments resulted in greater N uptake than the 15cm and 30cm treatments. There is a direct linear relationship between N uptake and the amount of water applied for 2017 which is shown in Figure 8.

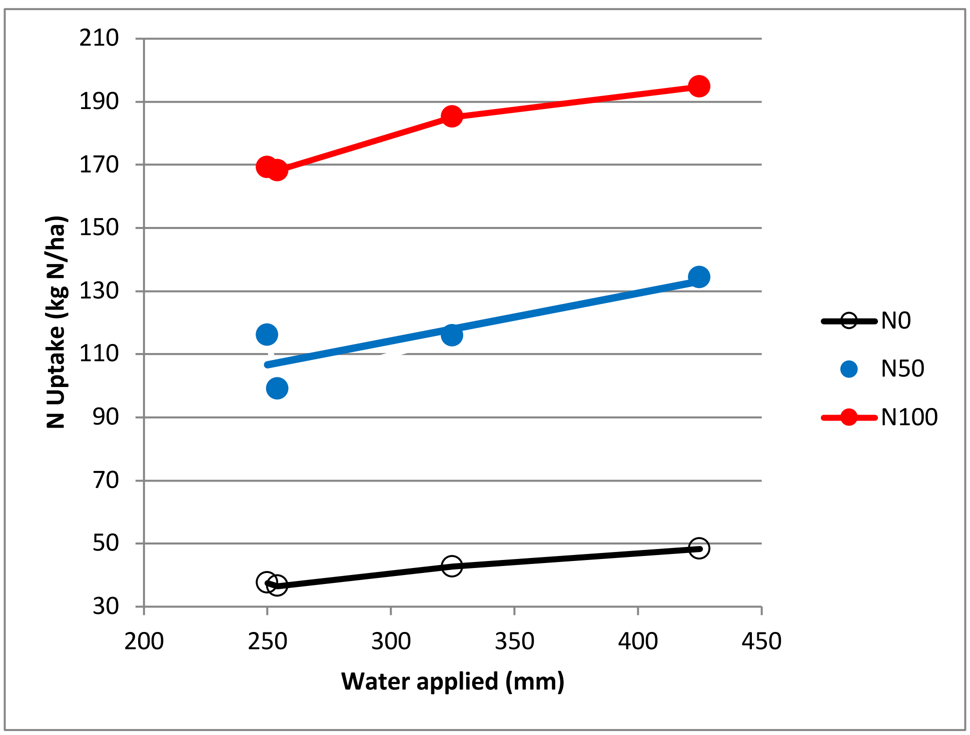

Figure 8. Near linear increase in N uptake with increasing amounts of applied water for 2017.

- Yields were higher under irrigation by about 3.1, 2.6 and 0.9 t ha^{-1} for N applications of 100, 50 and 0 kg/ha respectively (Figure 9).

- N uptakes were higher under irrigation by about 121, 83 and 30 kg N ha^{-1} for N applications of 100, 50 and 0 kg/ha respectively (Figure 10).
- Irrigation significantly increased protein content for cuts 3 and 4.
- The higher irrigation water applied by the ET and 45cm treatments resulted in significantly higher protein (16.8 to 17.1%) for cut 3 compared to the lower water applied by the 15cm and 30cm treatments (15.8-15.9%).
- Differences between the four irrigation treatments is closely related to the amounts of water applied and the soil moisture deficit calculated from rainfall and ET. The 15cm and 30cm treatments applied about 250 mm of water below the moisture deficit calculation of 390 mm estimated for cuts 2, 3 and 4. Considering the plant available water holding capacity of the soil at 165 mm places the water 'supply' of 415 mm close to the water consumption of 390 mm.
- The higher yield and especially N uptake from the ET treatment shows that there was additional benefit to be gained from water addition up to 425 mm.
- Calculating water usage (net of non-irrigated) in terms of yield per cm of water applied or kg N uptake per cm of water applied clearly shows advantage to the two treatments that applied lower amounts of water (Table A8). The 15cm-30cbar and 30cm-40cbar treatments (which applied about 2/3's as much water) produced significantly more yield and N uptake compared to higher water applications of the 45cm-30bar and ET treatments.
- Calculating the efficiency of N use (net of the zero N applications) in terms of yield per kg N applied and N recovery as N uptake per kg N applied shows no difference between irrigated and non-irrigated (Table A8).
- The efficiency of water use was highest for the 15cm treatment with 89 kg DM produced per cm of water and 2.16 kg of N uptake per cm of water (Table A9). The ET treatment had the lowest efficiency due to the higher amount of water being applied.
- Nitrogen use efficiency was significantly higher for irrigation with 19-22 kg DM/kg N applied being produced compared to no irrigation at 8 kg DM/kg N applied.
- Apparent N recovery was significantly higher
- Apparent N recovery was significantly higher for the ET treatment with 80% compared to 72% for 15cm and 45cm treatments and 64% for 30 cm treatment.

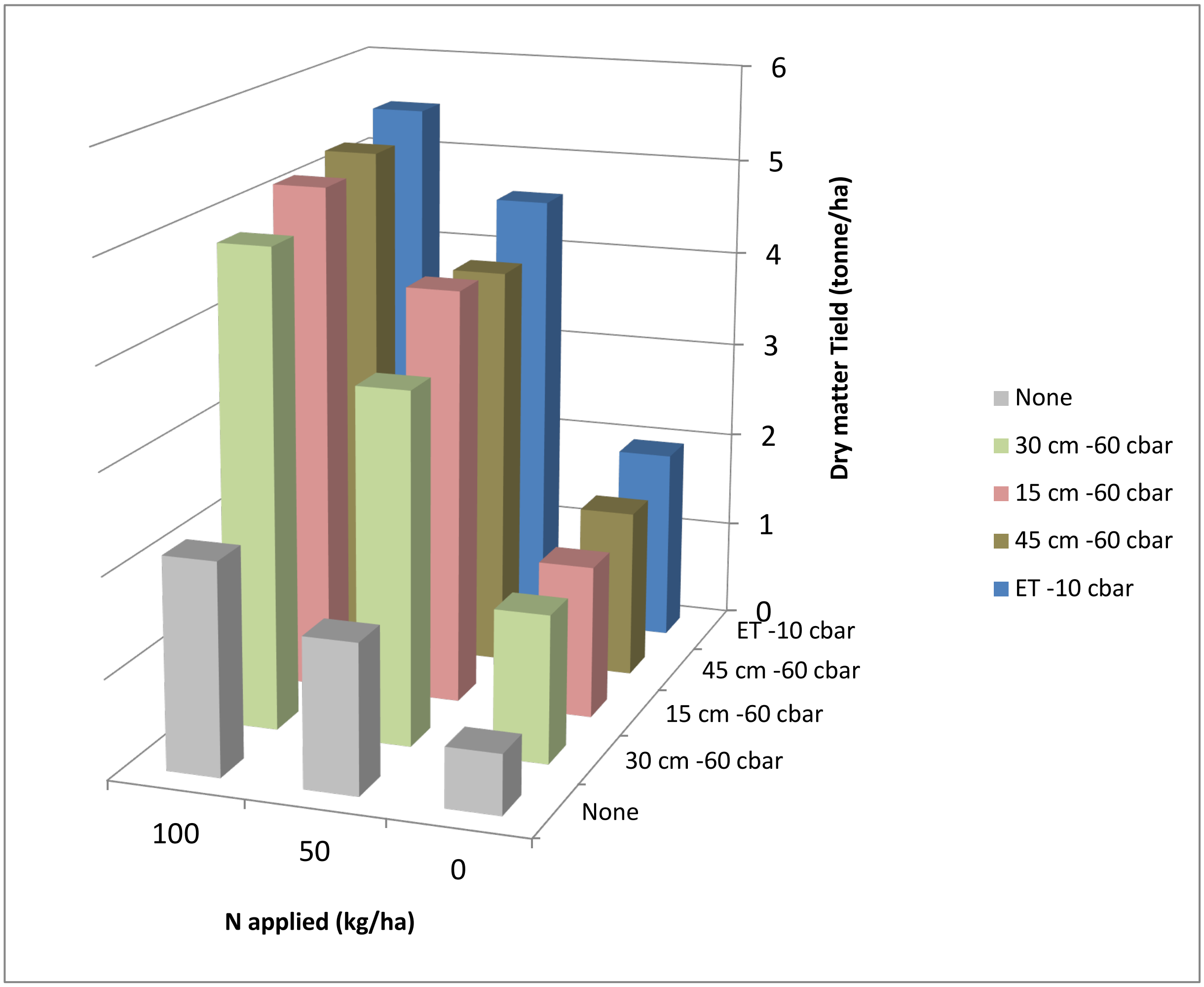

Figure 9. Grass yield for cuts 3 and 4 in 2017.

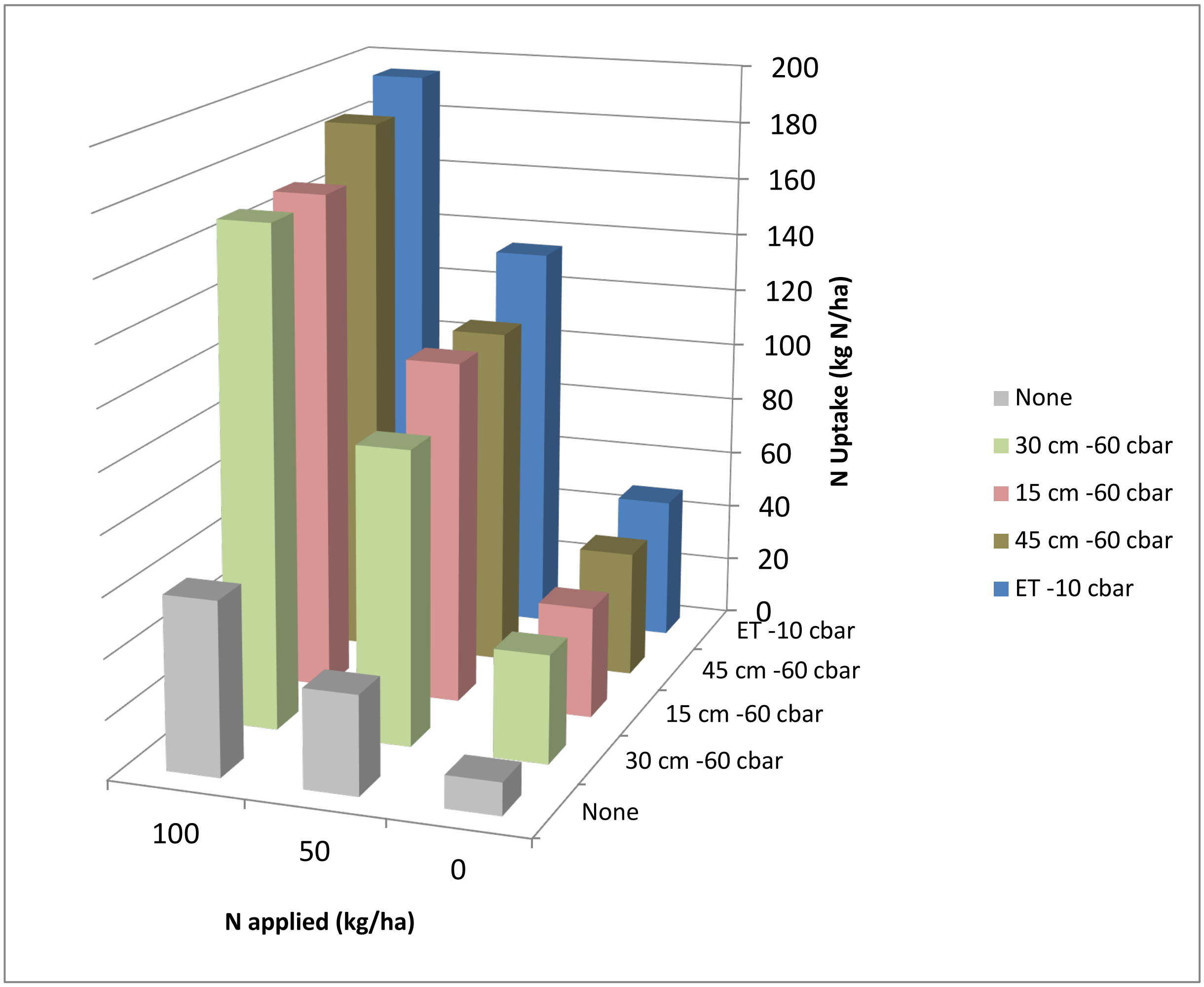

Figure 10. N uptake for cuts 3 and 4 in 2017.

Appendix

Table A1. Whole crop yield, nitrogen uptake and protein for 2015.

Harvest N Rate	None		Frequent & Light		Frequent & Heavy		Infrequent & Light		Infrequent & Heavy		**Average**	
	Irrigation treatment											
Cut# 1 2015 Yield (t DM ha^{-1})												
0	0.7	g	2.4	d	2.5	d	2.0	e	2.6	d	**2.0**	**C**
50	1.5	f	3.1	c	3.4	abc	3.2	bc	3.1	c	**2.9**	**B**
100	1.9	ef	3.6	ab	3.8	a	3.5	ab	3.6	ab	**3.3**	**A**
Average	**1.4**	**C**	**3.0**	**AB**	**3.2**	**A**	**2.9**	**B**	**3.1**	**AB**	**2.7**	
Cut# 1 2015 N uptake (kg N ha^{-1})												
0	17	g	47	ef	47	def	37	f	48	de	**39**	**C**
50	40	ef	68	c	73	c	74	c	76	c	**66**	**B**
100	57	d	92	ab	101	a	88	b	93	ab	**86**	**A**
Average	**38**	**C**	**69**	**AB**	**74**	**A**	**67**	**B**	**72**	**AB**	**64**	
Cut# 1 2015 Protein (%)												
0	14.6	bcde	11.9	f	11.9	f	11.8	f	11.7	f	**12.4**	**C**
50	16.4	b	13.8	def	13.5	ef	14.2	cde	15.1	bcde	**14.6**	**B**
100	19.3	a	16.2	bc	16.7	b	15.7	bcd	16.2	bc	**16.8**	**A**
Average	**16.8**	**A**	**14.0**	**B**	**14.0**	**B**	**13.9**	**B**	**14.4**	**B**	**14.6**	

Table A2. Whole crop yield (t/ha) 2016

Harvest N Rate	None		15 cm 30 cbar		30 cm 30 cbar		45 cm 30 cbar		ET		**Average**	
	Irrigation treatment											
Cut# 1 2016												
0	4.6	a	4.2	a	4.3	a	4.3	a	4.3	a	**4.3**	**A**
50	4.5	a	4.1	a	4.3	a	4.6	a	4.4	a	**4.4**	**A**
100	4.6	a	4.5	a	4.5	a	4.5	a	4.5	a	**4.5**	**A**
Average	**4.6**	**A**	**4.3**	**A**	**4.4**	**A**	**4.5**	**A**	**4.4**	**A**	**4.4**	
Cut# 2 2016												
0	1.4	f	1.0	g	1.0	g	1.0	g	1.0	g	**1.1**	**C**
50	2.5	bcd	2.1	de	2.2	de	2.1	e	2.5	bcd	**2.3**	**B**
100	3.2	a	2.7	bc	2.4	cde	2.7	bc	2.8	ab	**2.7**	**A**
Average	**2.4**	**A**	**1.9**	**BC**	**1.8**	**C**	**1.9**	**BC**	**2.1**	**B**	**2.0**	
Cut# 3 2016												
0	1.1	g	1.4	g	1.4	g	1.4	g	1.4	g	**1.3**	**C**
50	2.6	f	2.7	ef	2.9	def	3.1	bcde	3.0	cdef	**2.8**	**B**
100	3.4	ab	3.3	abc	3.2	abcd	3.6	a	3.0	bcde	**3.3**	**A**
Average	**2.4**	**B**	**2.5**	**AB**	**2.5**	**AB**	**2.7**	**A**	**2.5**	**AB**	**2.5**	
Cut# 4 2016												
0	0.5	f	1.5	de	1.5	de	1.3	e	1.5	de	**1.3**	**C**
50	1.3	e	1.9	c	2.1	abc	1.9	c	2.0	bc	**1.9**	**B**
100	1.6	d	2.2	ab	2.2	ab	2.3	a	2.2	abc	**2.1**	**A**
Average	**1.2**	**B**	**1.9**	**A**	**2.0**	**A**	**1.8**	**A**	**1.9**	**A**	**1.7**	
Cuts 3 & 4 2016												
0	1.6	h	2.9	g	2.9	g	2.7	g	2.8	g	**2.6**	**C**
50	3.9	f	4.7	e	5.0	cde	5.0	cde	4.9	de	**4.7**	**B**
100	5.0	cde	5.6	ab	5.5	abc	5.8	a	5.2	bcd	**5.4**	**A**
Average	**3.5**	**B**	**4.4**	**A**	**4.5**	**A**	**4.5**	**A**	**4.3**	**A**	**4.2**	
Annual 2016												
0	7.6	f	8.1	f	8.1	f	8.0	f	8.1	f	**8.0**	**C**
50	10.9	e	10.9	e	11.5	de	11.7	cde	11.8	bcde	**11.3**	**B**
100	12.8	ab	12.8	a	12.4	abcd	13.0	a	12.6	abc	**12.7**	**A**
Average	**10.4**	**A**	**10.6**	**A**	**10.7**	**A**	**10.9**	**A**	**10.8**	**A**	**10.7**	

Table A3. Whole crop yield (t/ha) 2017

	Irrigation treatment											
Harvest N Rate	None		15 cm 60 cbar		30 cm 60 cbar		45 cm 60 cbar		ET		**Average**	
Cut# 1 2017												
0	4.1	def	4.3	bcde	4.0	def	3.7	f	3.9	ef	**4.0**	**C**
50	4.3	bcde	4.1	def	4.2	cde	4.2	cde	4.4	bcd	**4.3**	**B**
100	5.0	a	4.8	ab	4.4	bcd	4.7	abc	4.7	abc	**4.7**	**A**
Average	**4.4**	**A**	**4.4**	**A**	**4.2**	**A**	**4.2**	**A**	**4.3**	**A**	**4.3**	
Cut# 2 2017												
0	1.2	f	1.1	f	1.1	f	1.1	f	1.1	f	**1.1**	**C**
50	1.9	bcd	1.8	de	1.6	e	1.8	de	1.9	cd	**1.8**	**B**
100	2.4	a	2.1	bcd	2.0	bcd	2.2	ab	2.1	abc	**2.1**	**A**
Average	**1.8**	**A**	**1.7**	**B**	**1.6**	**B**	**1.7**	**AB**	**1.7**	**AB**	**1.7**	
Cut# 3 2017												
0	0.6	h	0.8	gh	0.7	gh	0.9	gh	1.0	g	**0.8**	**C**
50	1.5	f	2.4	bc	2.0	e	2.3	cd	2.5	bc	**2.1**	**B**
100	2.1	de	3.2	a	2.7	b	3.0	a	3.3	a	**2.8**	**A**
Average	**1.4**	**D**	**2.1**	**AB**	**1.8**	**C**	**2.1**	**B**	**2.3**	**A**	**1.9**	
Cut# 4 2017												
0	0.0	h	0.7	g	0.7	fg	0.9	fg	1.0	f	**0.7**	**C**
50	0.0	h	1.8	de	1.6	e	1.8	cd	2.0	abc	**1.5**	**B**
100	0.1	h	1.9	bcd	2.2	ab	2.2	a	2.2	a	**1.7**	**A**
Average	**0.0**	**C**	**1.5**	**B**	**1.5**	**B**	**1.6**	**A**	**1.7**	**A**	**1.3**	
Cuts 3 & 4 2017												
0	0.6	j	1.5	i	1.5	i	1.7	hi	2.0	gh	**1.5**	**C**
50	1.5	i	4.2	de	3.5	f	4.1	e	4.6	cd	**3.6**	**B**
100	2.1	g	5.1	ab	4.8	bc	5.3	a	5.5	a	**4.6**	**A**
Average	**1.4**	**D**	**3.6**	**B**	**3.3**	**C**	**3.7**	**B**	**4.0**	**A**	**3.2**	
Annual 2017												
0	5.8	i	6.9	h	6.7	h	6.5	hi	6.9	h	**6.6**	**C**
50	7.7	g	10.2	de	9.3	f	10.1	de	10.8	cd	**9.6**	**B**
100	9.5	ef	12.0	ab	11.3	bc	12.1	ab	12.3	a	**11.4**	**A**
Average	**7.7**	**C**	**9.7**	**A**	**9.1**	**B**	**9.6**	**A**	**10.0**	**A**	**9.2**	

Table A4. Whole crop N uptake (kg/ha) 2016

	Irrigation treatment											
Harvest N Rate	None		15 cm 30 cbar		30 cm 30 cbar		45 cm 30 cbar		ET		**Average**	
Cut# 1 2016												
0	59	ab	52	b	51	b	52	b	55	ab	**54**	**B**
50	60	ab	54	b	60	ab	59	ab	57	ab	**58**	**AB**
100	63	a	58	ab	60	ab	54	b	59	ab	**59**	**A**
Average	**60**	**A**	**55**	**B**	**57**	**AB**	**55**	**B**	**57**	**AB**	**57**	
Cut# 2 2016												
0	28	f	20	f	21	f	19	f	21	f	**22**	**C**
50	59	de	52	e	51	e	50	e	60	de	**54**	**B**
100	91	a	78	bc	69	cd	77	bc	87	ab	**80**	**A**
Average	**59**	**A**	**50**	**BC**	**47**	**C**	**49**	**C**	**56**	**AB**	**52**	
Cut# 3 2016												
0	29	f	39	f	40	f	38	f	39	f	**37**	**C**
50	56	e	67	de	69	de	72	cd	69	cde	**66**	**B**
100	95	ab	98	ab	89	ab	102	a	84	bc	**93**	**A**
Average	**60**	**B**	**68**	**AB**	**66**	**AB**	**70**	**A**	**64**	**AB**	**66**	
Cut# 4 2016												
0	18	f	43	cde	44	cde	40	e	43	de	**38**	**C**
50	39	e	53	bc	55	b	51	bcd	55	b	**50**	**B**
100	60	b	74	a	73	a	74	a	74	a	**71**	**A**
Average	**39**	**B**	**57**	**A**	**57**	**A**	**55**	**A**	**57**	**A**	**53**	
Cuts 3 & 4 2016												
0	47	e	82	d	85	d	77	d	81	d	**74**	**C**
50	95	d	120	c	123	c	122	c	124	c	**117**	**B**
100	155	b	172	ab	162	ab	176	a	158	ab	**165**	**A**
Average	**99**	**B**	**125**	**A**	**124**	**A**	**125**	**A**	**121**	**A**	**119**	
Annual 2016												
0	133	c	154	c	156	c	149	c	158	c	**150**	**C**
50	214	b	225	b	234	b	231	b	242	b	**229**	**B**
100	309	a	308	a	291	a	306	a	304	a	**304**	**A**
Average	**219**	**A**	**229**	**A**	**227**	**A**	**229**	**A**	**235**	**A**	**228**	

Table A5. Whole crop N uptake (kg/ha) 2017

	Irrigation treatment					
Harvest N Rate	None	15 cm 60 cbar	30 cm 60 cbar	45 cm 60 cbar	ET	**Average**
Cut# 1 2017						
0	72 abc	75 a	75 a	69 abcd	65 abcde	**71 A**
50	58 de	60 cde	60 bcde	55 e	60 bcde	**58 B**
100	73 ab	68 abcde	60 bcde	62 abcde	66 abcde	**66 A**
Average	**68 A**	**67 A**	**65 A**	**62 A**	**64 A**	**65**
Cut# 2 2017						
0	22 e	20 e	22 e	21 e	20 e	**21 C**
50	41 c	39 c	32 d	38 cd	39 c	**38 B**
100	65 a	57 b	55 b	58 b	60 ab	**59 A**
Average	**42 A**	**39 B**	**36 B**	**39 AB**	**40 AB**	**39**
Cut# 3 2017						
0	10 i	19 h	17 hi	21 h	22 h	**18 C**
50	33 g	57 e	46 f	58 e	66 d	**52 B**
100	56 e	92 b	81 c	98 ab	106 a	**87 A**
Average	**33 D**	**56 B**	**48 C**	**59 B**	**65 A**	**52**
Cut# 4 2017						
0	1 g	18 f	20 ef	22 ef	26 e	**17 C**
50	1 g	59 d	53 d	58 d	68 c	**48 B**
100	2 g	77 b	87 a	87 a	89 a	**68 A**
Average	**1 D**	**51 C**	**53 BC**	**56 B**	**61 A**	**45**
Cuts 3 & 4 2017						
0	11 i	38 gh	36 h	43 gh	48 fg	**35 C**
50	33 h	116 d	99 e	116 d	134 c	**100 B**
100	58 f	169 b	168 b	185 a	195 a	**155 A**
Average	**34 D**	**108 C**	**101 C**	**115 B**	**126 A**	**97**
Annual 2017						
0	104 g	132 f	134 f	133 f	134 f	**127 C**
50	132 f	215 cd	191 e	209 de	234 c	**196 B**
100	196 de	294 b	283 b	306 ab	321 a	**280 A**
Average	**144 D**	**214 BC**	**203 C**	**216 B**	**229 A**	**201**

Table A6. Protein content (%) 2016

Harvest N Rate	None		15 cm 30 cbar		30 cm 30 cbar		45 cm 30 cbar		ET		**Average**	
	Irrigation treatment											
Cut# 1 2016												
0	8.1	ab	7.7	ab	7.5	ab	7.6	ab	8.1	ab	**7.8**	**A**
50	8.3	ab	8.2	ab	8.6	ab	8.1	ab	8.2	ab	**8.3**	**A**
100	8.6	a	8.0	ab	8.2	ab	7.4	b	8.1	ab	**8.1**	**A**
Average	**8.4**	**A**	**8.0**	**A**	**8.1**	**A**	**7.7**	**A**	**8.1**	**A**	**8.0**	
Cut# 2 2016												
0	12.6	ef	12.9	def	13.1	cdef	12.3	f	13.1	cdef	**12.8**	**C**
50	14.9	cd	15.2	bc	14.9	cd	14.8	cde	15.2	cd	**15.0**	**B**
100	18.0	a	18.0	a	17.5	ab	18.2	a	19.6	a	**18.3**	**A**
Average	**15.2**	**A**	**15.4**	**A**	**15.2**	**A**	**15.1**	**A**	**16.0**	**A**	**15.4**	
Cut# 3 2016												
0	16.0	bcd	17.5	ab	17.9	ab	16.6	abc	17.5	ab	**17.1**	**A**
50	13.5	e	15.4	cd	14.9	cde	14.7	de	14.7	de	**14.6**	**B**
100	17.7	ab	18.3	a	17.2	ab	17.7	ab	17.2	ab	**17.6**	**A**
Average	**15.7**	**B**	**17.0**	**A**	**16.6**	**AB**	**16.3**	**AB**	**16.5**	**AB**	**16.4**	
Cut# 4 2016												
0	22.5	a	18.1	c	18.3	c	18.1	c	18.0	c	**19.0**	**B**
50	18.3	c	16.9	cd	16.2	d	16.3	d	17.4	cd	**17.0**	**C**
100	22.8	a	20.7	b	20.5	b	20.5	b	20.9	b	**21.1**	**A**
Average	**21.2**	**A**	**18.6**	**B**	**18.3**	**B**	**18.3**	**B**	**18.8**	**B**	**19.0**	

Table A7. Protein content (%) 2017

	Irrigation treatment											
Harvest N Rate	None		15 cm 60 cbar		30 cm 60 cbar		45 cm 60 cbar		ET		**Average**	
Cut# 1 2017												
0	11.0	a	10.9	a	11.6	a	11.6	a	10.6	ab	**11.1**	**A**
50	8.4	c	9.0	bc	8.8	c	8.2	c	8.5	c	**8.6**	**B**
100	9.1	bc	8.8	c	8.5	c	8.3	c	8.6	c	**8.7**	**B**
Average	**9.5**	**A**	**9.6**	**A**	**9.6**	**A**	**9.4**	**A**	**9.2**	**A**	**9.4**	
Cut# 2 2017												
0	11.7	ef	11.4	f	12.3	def	11.9	ef	11.9	ef	**11.8**	**C**
50	13.3	cd	13.5	c	12.8	cde	13.3	cd	13.2	cd	**13.2**	**B**
100	17.2	ab	17.2	ab	16.9	b	17.0	ab	18.1	a	**17.3**	**A**
Average	**14.0**	**A**	**14.0**	**A**	**14.0**	**A**	**14.0**	**A**	**14.4**	**A**	**14.1**	
Cut# 3 2017												
0	11.2	h	14.5	fg	13.8	g	15.2	ef	14.1	fg	**13.7**	**C**
50	13.9	g	14.9	efg	14.7	fg	16.0	de	16.2	de	**15.1**	**B**
100	17.1	cd	18.1	bc	19.1	ab	20.2	a	20.0	a	**18.9**	**A**
Average	**14.0**	**C**	**15.8**	**B**	**15.9**	**B**	**17.1**	**A**	**16.8**	**A**	**15.9**	
Cut# 4 2017												
0	14.8	e	15.7	de	16.7	d	16.0	de	16.8	d	**16.0**	**C**
50	15.8	de	20.5	b	20.7	b	19.7	bc	20.9	b	**19.5**	**B**
100	18.5	c	24.7	a	25.2	a	24.7	a	25.4	a	**23.7**	**A**
Average	**16.4**	**C**	**20.3**	**AB**	**20.8**	**AB**	**20.1**	**B**	**21.0**	**A**	**19.7**	

Table A8. Water usage and nitrogen use efficiency for Cuts 3 and 4 2016. Yield of cuts 3 and 4 combined above the non-irrigated control to evaluate water usage and above the zero N control to evaluate NUE.

		Irrigation treatment				
Harvest N Rate	None	15 cm 30 cbar	30 cm 30 cbar	45 cm 30 cbar	ET	**Average**
Cut# 3 and 4 2016 water usage above control (kg DM/cm irrigation water)						
0		62	65	40	40	**41**
50		38	54	39	34	**33**
100		29	22	30	8	**18**
Average		**43**	**47**	**36**	**27**	**31**
Cut# 3 and 4 2016 water usage above control (kg N/cm irrigation water)						
0		1.78	1.90	1.11	1.13	**1.19**
50		1.24	1.43	0.99	0.98	**0.93**
100		0.83	0.35	0.75	0.09	**0.40**
Average		**1.28**	**1.22**	**0.95**	**0.74**	**0.84**
Cut# 3 and 4 2016 NUE above control (kg DM/kg N applied)						
0						
50	23	18	21	23	21	**21**
100	17	14	13	16	12	**14**
Average	**13**	**11**	**11**	**13**	**11**	**12**
Cut# 3 and 4 2016 N recovery above control (kg N/kg N applied)						
0						
50	0.48	0.37	0.39	0.45	0.42	**0.42**
100	0.54	0.45	0.39	0.49	0.38	**0.45**
Average	**0.34**	**0.27**	**0.26**	**0.31**	**0.27**	**0.29**

Table A9. Water usage and nitrogen use efficiency for Cuts 3 and 4 2017. Yield of cuts 3 and 4 combined above the non-irrigated control to evaluate water usage and above the zero N control to evaluate NUE.

	Irrigation treatment					
Harvest N Rate	None	15 cm 30 cbar	30 cm 30 cbar	45 cm 30 cbar	ET	**Average**
Cut# 3 and 4 2017 water usage above control (kg DM/cm irrigation water)						
0		38	35	34	32	**28**
50		108	82	80	74	**69**
100		121	103	96	79	**80**
Average		**89**	**73**	**70**	**61**	**59**
Cut# 3 and 4 2017 water usage above control (kg N/cm irrigation water)						
0		1.06	1.02	0.98	0.87	**0.79**
50		3.31	2.63	2.54	2.41	**2.18**
100		4.43	4.19	3.90	3.21	**3.15**
Average		**2.94**	**2.61**	**2.47**	**2.16**	**2.04**
Cut# 3 and 4 2017 NUE above control (kg DM/kg N applied)						
0						
50	9	27	21	24	26	**21**
100	8	18	17	18	18	**16**
Average	**8**	**22**	**19**	**21**	**22**	**18**
Cut# 3 and 4 2017 N recovery above control (kg N/kg N applied)						
0						
50	0.22	0.79	0.62	0.73	0.86	**0.65**
100	0.24	0.66	0.66	0.71	0.73	**0.60**
Average	**0.23**	**0.72**	**0.64**	**0.72**	**0.80**	**0.62**