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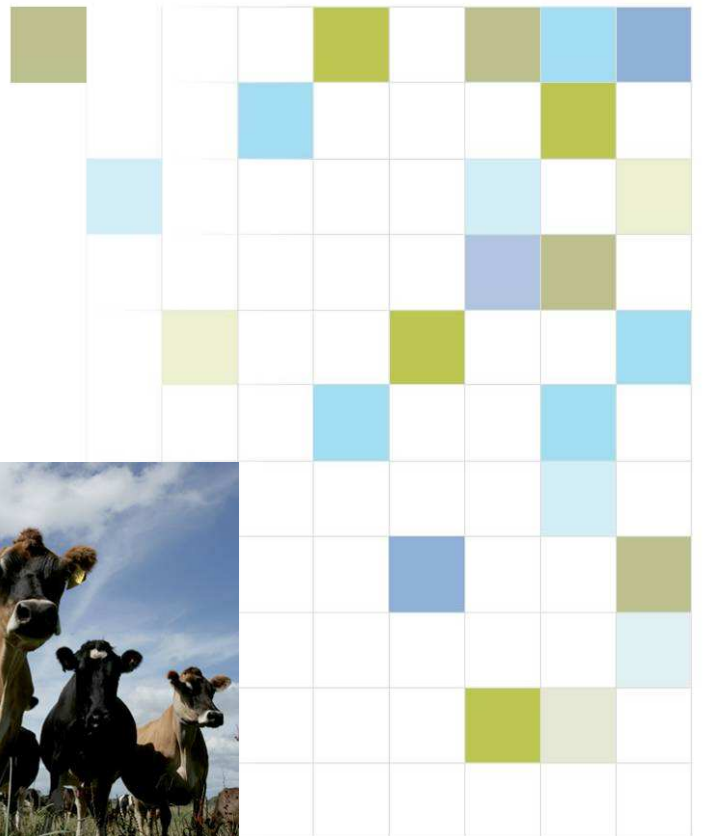
Upper Waitaki Farm Systems and Nutrient Assessment

Stage 2: Pasture and ryecorn growth modelling

May 2008



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Assessment
Stage 2: Pasture and ryecorn growth modelling**

Report prepared for GHD

May 2008

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Table of Contents

1.	Executive Summary.....	2
2.	Introduction	4
3.	Soil, Climate, Irrigation and Model Description	4
3.1	Soil Properties.....	4
3.2	Climate Data	5
3.3	Irrigation Inputs	7
3.4	Model Description	7
4.	Dryland and Irrigated Pasture Production	8
4.1	Effect of Soil, Climate, and Irrigation on Pasture Production	8
4.2	Recommended Pasture Production Values for Farm Modelling	10
5.	Dryland and Irrigated Ryecorn Production	12
5.1	Effect of Soil, Climate, and Irrigation on Ryecorn Production	12
5.2	Recommended Ryecorn Production Values for Farm Modelling	13
6.	References.....	14
7.	Appendix 1: Monthly Pasture Growth Rates	15

1. Executive Summary

- The purpose of the work described in this report is to provide seasonal values of pasture and ryecorn growth under a range of soil, climate and management conditions as inputs to farm-scale modelling.
- The soil types in the region were categorised, by Aqualinc Research, into four principle soil types based on the capacity of the soil to hold plant-available water (PAW). The categories used 30, 60, 90, and 130 mm of PAW. These categories were supplemented with information provide by Trevor Webb from a previous study to fully characterise the soils for modelling. Daily climate data from 1972 to 2007 was obtained from the NIWA Virtual Climate Station database to correspond to mapped rainfall zones of 500, 600, 700, and 800 mm per year. Irrigation inputs were calculated by Aqualinc Research using the climate and soil information above.
- Growth of pasture and ryecorn was simulated using the EcoMod simulation model. EcoMod is a biophysical model designed to simulate pastoral farm systems and includes the major processes that take place in soil-water-plant-animal system of pastoral farms. A cut-trial simulation regime with nutrient return was used to generate the modelled growth rates.
- Dryland pasture production increased with both PAW and rainfall zone. Annual dryland production under all soil and climate combinations was low, ranging from median values of 0.3 t DM /ha /yr on the 30 mm PAW soil to 5.1 t DM /ha /yr in the 130 mm PAW soil. All combinations of soil and climate showed considerable variability. Under irrigated conditions annual production was both higher, averaging 12.1 t DM /ha /yr, and much less variable between years. There was little effect of soil type but slightly lower production in the 700 and 800 mm rainfall zones because of lower temperatures.
- There was a strong response of irrigated pasture to tactical nitrogen fertilisation in late spring but decreasing effectiveness in early spring and autumn. Likely response rates within three months of application of tactical additions of nitrogen are January - 11 kg DM /kg N; February - 7 kg DM /kg N; September - 15 kg DM /kg N; October to December - 18 kg DM /kg N. Nitrogen applications in other months are not recommended as they are likely to lead to significant leaching losses.
- Under dryland conditions the ryecorn showed the same general pattern as pasture but with higher yields in the lighter soils and much less year-to-year variability. Irrigation increased yields, particularly in the lighter soils, but not to the same extent as for pasture.

- Recommended growth rates (kg DM /ha /day) for dryland pasture are:

	Rainfall Zone				
	500-800 mm	500 mm	600 mm	700 mm	800 mm
	Plant-Available Water				
	30 mm	60 – 130 mm			
Jan	0	1	7	16	14
Feb	0	0	2	2	2
Mar	0	0	0	1	1
Apr	0	0	2	3	1
May	0	0	3	2	2
Jun	0	0	0	0	0
Jul	0	0	0	0	0
Aug	0	0	0	0	0
Sep	0	3	5	3	0
Oct	0	10	21	20	13
Nov	0	9	12	17	16
Dec	0	5	12	13	14

- Recommended growth rates (kg DM /ha /day) for irrigated pasture are:

All Zones	
Jan	79
Feb	59
Mar	73
Apr	33
May	12
Jun	0
Jul	0
Aug	0
Sep	0
Oct	13
Nov	36
Dec	60

- Recommended cumulative yield (kg DM /ha) for dryland and irrigated ryecorn are:

Month	dryland			irrigated	
	Plant-Available Water Storage (mm)				
	30 mm	60-90 mm	130 mm	30 mm	60-130 mm
March	0.2	0.4	0.5	0.5	0.8
April	0.4	1.0	1.3	1.2	2.0
May	0.6	1.6	2.0	1.6	2.8
June	0.7	1.8	2.3	1.8	3.1
July	0.8	2.1	2.6	2.0	3.4
August	1.1	2.7	3.3	2.3	4.1
September	1.3	3.7	4.6	3.2	5.4
October	1.7	4.6	5.9	5.2	7.5

2. Introduction

The purpose of the work described in this report is to provide monthly values of pasture and ryecorn growth under a range of soil, climate and management conditions as inputs to farm-scale modelling. That farm-scale modelling will form Stage Three of the “Upper Waitaki Farm Systems and Nutrient Assessment” project. The work was undertaken by a combination of literature review and expert opinion (both provided in separate reports) and simulation modelling (described here).

3. Soil, Climate, Irrigation and Model Description

The simulation modelling required input data, including soil physical properties, daily climate data, and information about the irrigation, to be supplied. These data are outlined below.

3.1 Soil Properties

The soil types in the region were categorised, by Aqualinc Research, into four principle soil types based on the capacity of the soil to hold plant-available water (PAW). The four soil categories used in the irrigation design were PAW values of 30, 60, 90, and 130 mm (P. Brown, Aqualinc Research, pers. comm. 2008) so these soils were also used for the production modelling. However the simulation modelling required soil properties in addition to the PAW. These values were summarised from data provided by Trevor Webb for modelling done in the initial nutrient assessment (Green, 2005; page 10) and are shown in Table 1. For all the modelling and calculation of PAW a maximum rooting depth of 0.8 m was assumed.

Table 1: Soil physical properties used in the simulation modelling of pasture and ryecorn production.

Depth Range (m)	Volumetric Water Content (%) at:				Cumulative PAW (mm)
	Saturation	Field Capacity	Wilting Point	Air Dry	
30 mm Plant-Available Water					
0.00-0.02	45	22	10	4	2.4
0.02-0.05	40	12	8	2	3.6
0.05-0.80	40	12	8	2	33.6
0.80-1.00	40	12	8	2	
60 mm Plant-Available Water					
0.00-0.05	50	30	10	7	10
0.05-0.30	45	22	10	4	40
0.30-0.80	40	12	8	2	60
0.80-1.00	40	12	8	2	
90 mm Plant-Available Water					
0.00-0.10	50	30	10	7	20
0.10-0.60	45	22	10	4	80
0.60-0.80	40	12	8	2	88
0.80-1.00	40	12	8	2	
130 mm Plant-Available Water					
0.00-0.40	50	30	10	7	80
0.40-0.80	45	22	10	4	128
0.80-1.00	40	12	8	2	

3.2 Climate Data

Analysis of the region's climate indicated that there was a 300 mm range in annual average rainfall, ranging from 500 to 800 mm (P. Brown, Aqualinc Research, pers. comm. 2008). One point on each of these rainfall contour lines was identified and daily met data from 1962 to 2007 were obtained from the NIWA Virtual Climate Station (VCS) database (Tait & Turner 2005; Tait et al 2006; Cichota et al 2008). The resulting meteorological data did not have exactly the annual average rainfall required so these values were scaled, linearly, to the required rainfall. Previous testing, Cichota et al (2008), has shown this to provide an effective transformation of rainfall data when actual annual rainfall is known. The climate data are summarised in Tables 2 and 3 and Figures 1 and 2. The temperatures and radiation for the "600 mm" site were very close to those at the "500 mm" site and appear exactly the same when rounded off for display.

Table 2. Location of the four points used for the VCS climate data with the annual rainfall retrieved from the VCS database and the scaled values.

Nominal Rainfall	Latitude (decimal degrees)	Longitude	Annual Rainfall (mm)	
			VCS	VCS-scaled
500 mm	-44.325	170.225	442	499
600 mm	-44.275	170.125	565	600
700 mm	-44.225	170.025	667	702
800 mm	-44.125	170.075	816	803

Table 3. Average minimum temperature in July (Tmin), average maximum temperature in January (Tmax), annual average temperature (Tave) and average daily radiation for the four climate data sets.

Nominal Rainfall	Tmin (C)	Tmax (C)	Tave (C)	Radiation (MJ /m ² /day)
500 mm	-1.52	23.40	10.57	14.47
600 mm	-1.52	23.40	10.57	14.47
700 mm	-1.63	23.18	10.26	14.43
800 mm	-2.18	22.18	9.42	14.14

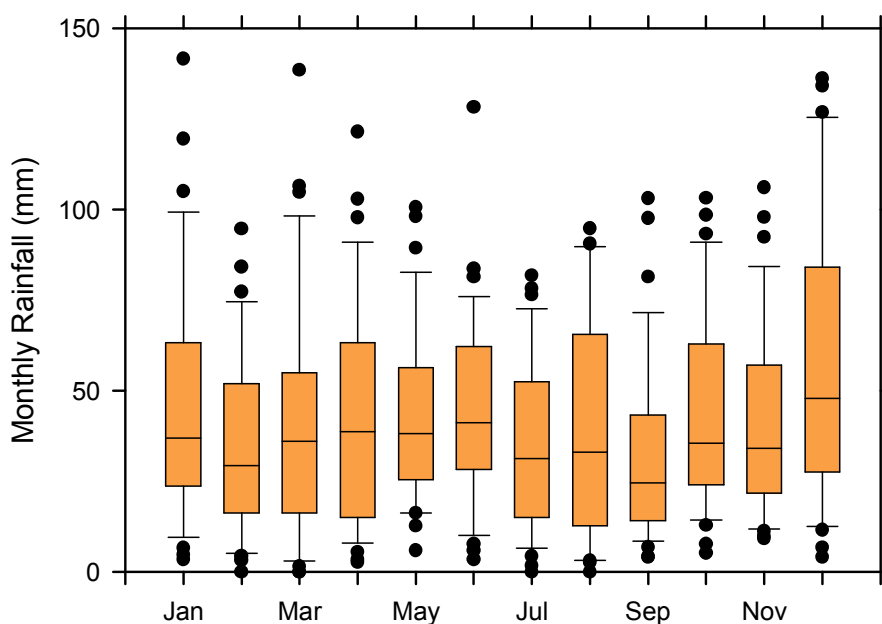


Figure 1. Monthly rainfall between 1972 and 2007 in the “500 mm” rainfall zone. The box-whisker plots show the 10th (whisker), 25th, median, 75th (bars) and 90th (whisker) quartiles, with the symbols indicating outliers.

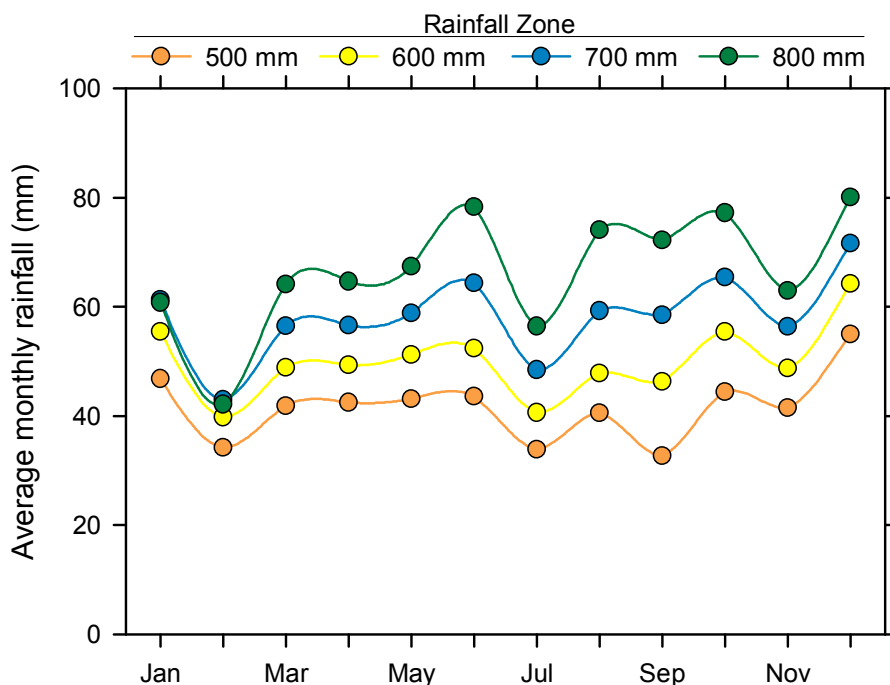


Figure 2. Monthly average (1972 to 2007) rainfall for the four rainfall zones.

3.3 Irrigation Inputs

Irrigation inputs were calculated by Aqualinc Research using the climate and soil information above with irrigation amounts scheduled on a daily basis subject to irrigation system design constraints (P. Brown, Aqualinc Research, pers. comm. 2008). Although the simulation model used in the growth modelling can calculate irrigation demand dynamically, the irrigation inputs calculated by Aqualinc Research were used in this modelling to ensure consistency with the drainage estimates used elsewhere in the nutrient assessment work. The annual average irrigation inputs are shown in Table 4.

Table 4. Annual average (1972 to 2007) irrigation input for the four rainfall zones and four soil categories used in the modelling.

Plant-available water	Rainfall zone			
	500 mm	600 mm	700 mm	800 mm
30 mm	602	569	548	531
60 mm	574	558	538	517
90 mm	538	495	467	449
130 mm	504	458	428	406

3.4 Model Description

The results described below were simulated using the EcoMod simulation model. EcoMod is a biophysical model designed to simulate pastoral farm systems of Australia and New Zealand

(Johnson et al. 2008). This model includes, with a relatively high level of detail, the major processes that take place in soil-water-plant-animal system of pastoral farms. It includes a management module, which allows the simulation of farm systems, as well as research setups, such as cutting trials. The water balance, including runoff and leaching, the nutrient and organic matter (carbon and nitrogen) dynamics, the growth of several different species of pasture and forage plants and the general animal metabolism are simulated by specific integrated modules (Johnson 2007). Comparison of EcoMod simulated growth rates against data can be found in Johnson et al. (2008), Cullen et al. (2008) and White et al. (2008).

The purpose of the modelling was to provide growth rates for the farm-scale modelling. The nutrient assessments will be done using a combination of farm-scale modelling using a combination of Farmax, UDDER, and OVERSEER[®]. Farmax and UDDER require “potential” (unconstrained by overly high or low cover) growth rates and traditionally such data is found in research trials conducted under cage-cutting regime (Radcliffe 1974). There was not sufficient literature data on pasture and forage growth rates for the farm-scale modelling so the data was supplemented with simulation results. The modelling results here are from a cut-trial regime with return of the nutrients harvested in the cut pasture or forage to the soil as dung and urine and the pasture cut to 1.5 t DM /ha every 21 days. Although this regime is a little different to the cage-cut regime, previous testing with EcoMod (I.R. Johnson, pers. comm. 2008) has shown little difference in growth rates between these two simulation set ups.

Most of the model parameters were left at their default values but the cold and heat stress parameters, previously shown to need local adjustment (White et al. 2008), were adjusted to provide reasonable agreement between literature and simulated dryland growth rates.

4. Dryland and Irrigated Pasture Production

4.1 Effect of Soil, Climate, Irrigation and Nitrogen on Pasture Production

The EcoMod model, set up as described above, was run under both dryland and irrigated conditions for the sixteen combinations of soil type and rainfall zone. Annual average production is shown in Figure 3 and the monthly production pattern, as affected by irrigation, soil type and rainfall zone, is given in Appendix 1 in Figures A1 to A4.

Under dryland conditions, as might be expected, the lighter soil (30 mm PAW) had consistently lower annual production. There was little difference in annual growth between the 60, 90 and 130 mm PAW soils. Annual pasture production increased with each incremental increase in rainfall as a result of less severe water stress. Annual dryland production under all soil and climate combinations was low, ranging from median values of 0.3 t DM /ha /yr on the 30 mm PAW soil to 5.5 t DM /ha /yr in the 130 mm PAW soil. All combinations of soil and climate showed considerable variability. For example, annual pasture production for the 60 mm PAW soil in the 800 mm rainfall zone ranged from 0 to 8.9 t DM /ha /yr with a median value of 2.8 t DM /ha /yr.

Under irrigated conditions annual production was both higher and much less variable between years. There was little effect of soil type (Figure 3) but some effect of rainfall zone with lower production in the 700 and 800 mm rainfall zones because of lower temperatures.

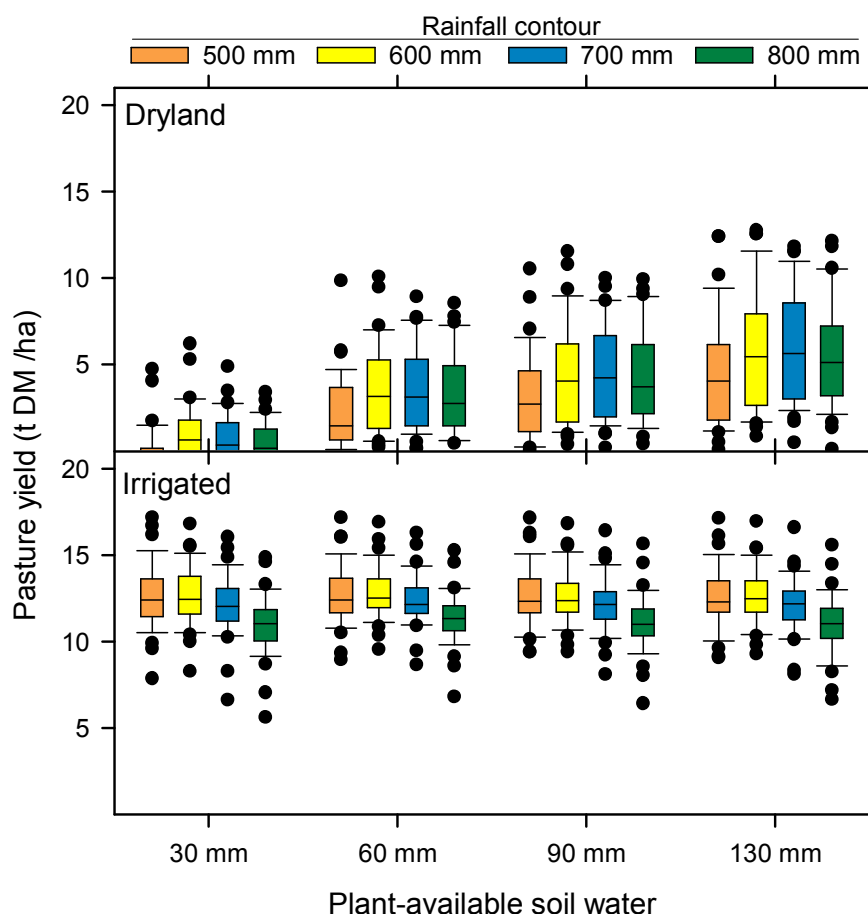


Figure 3. Annual (1972 to 2007) pasture yield for the four rainfall zones and four soil types.

The responsiveness of the irrigated pasture to nitrogen fertiliser additions was modelled using an application of 25 kg N /ha on the first of each month (separate simulations were run for each application month) and comparing the growth rate in the three months following fertilisation to that under un-fertilised conditions. The response rate, in kg additional DM growth per kg N applied, was highly variable between months (Figure 4) and for the shoulder months (February, March, August) was also very variable from year to year (Figure 4).

The median modelled response rate in late spring was 25 Kg DM /kg N. This is high compared with many fertiliser trials because the modelled rates assume perfect uniformity in fertiliser and irrigation application and that there are no urine patches (with already adequate nitrogen supply) in the pasture. We recommend that the modelled rates be reduced by 25% to account for these effects so that the recommended response rates for the farm system modelling are:

- January – 11 kg DM /kg N;
- February - 7 kg DM /kg N;
- September - 15 kg DM /kg N;

- October to December - 18 kg DM /kg N.

Nitrogen applications in other months are not recommended because they are likely to lead to significant leaching losses.

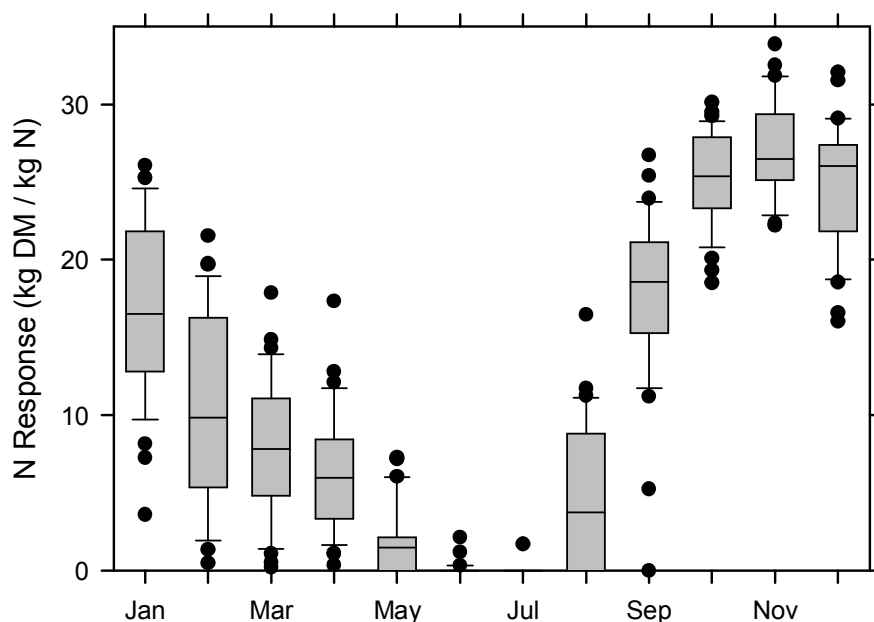


Figure 4. Modelled nitrogen fertiliser response rate in the irrigated 130 mm PAW soil in the 800 mm rainfall contour.

4.2 Recommended Pasture Production Values for Farm Modelling

The monthly growth rates (Figure A1 to A4) were analysed to produce monthly recommended values for the farm-scale modelling by grouped categories of soil type and rainfall zone. These data are given in Tables 5 (median values for dryland production), 6 (average values for dryland production) and 7 (median and average values for irrigated production). Because of the high variability and the skew in the production values (e.g. Figure A4) median values should be used but the averages are also supplied here for completeness.

Table 5. Median growth rates of dryland pasture, in kg DM /ha /day, as affected by rainfall zone and soil type.

	Rainfall Zone				
	500-800 mm	500 mm	600 mm	700 mm	800 mm
	Plant-Available Water				
	30 mm	60 – 130 mm			
Jan	0	1	7	16	14
Feb	0	0	2	2	2
Mar	0	0	0	1	1
Apr	0	0	2	3	1
May	0	0	3	2	2
Jun	0	0	0	0	0
Jul	0	0	0	0	0
Aug	0	0	0	0	0
Sep	0	3	5	3	0
Oct	0	10	21	20	13
Nov	0	9	12	17	16
Dec	0	5	12	13	14

Table 6. Average growth rates of dryland pasture, in kg DM /ha /day, as affected by rainfall zone and soil type.

	Rainfall Zone			
	500 mm	600 – 800 mm	500	600 – 800 mm
	Plant-Available Water			
	30 mm	30 mm	60 – 130 mm	60 – 130 mm
Jan	3	8	16	26
Feb	1	3	9	14
Mar	2	3	9	12
Apr	1	2	7	11
May	1	2	5	6
Jun	0	0	0	0
Jul	0	0	0	0
Aug	1	1	1	1
Sep	2	2	10	8
Oct	2	3	18	21
Nov	3	6	19	26
Dec	0	3	14	23

Table 7. Median and average growth rates of irrigated pasture, in kg DM /ha /day. Rainfall zone and soil type had no significant effect on growth rate.

	Median	Average
Jan	79	83
Feb	59	69
Mar	73	67
Apr	33	37
May	12	14
Jun	0	1
Jul	0	0
Aug	0	0
Sep	0	3
Oct	13	15
Nov	36	42
Dec	60	67

5. Dryland and Irrigated Ryecorn Production

5.1 Effect of Soil, Climate, and Irrigation on Ryecorn Production

A tested ryecorn simulation model was not available so an existing model of Italian ryegrass was used instead. Ryecorn and Italian ryegrass are both annual C3 grasses and can be managed similarly. Unpublished data from an experiment of John de Ruiter in Lincoln gave an anthesis date of only 3 days different between ryecorn (cv Rahu) and Italian ryegrass (cv Marbella) sown 4 March 1999. Therefore the pattern of growth over the spring, as they begin to bolt, is likely to be similar. Grower experience from the area indicates that Italian rye yields more than ryecorn if moist, but that ryecorn yields more in drier years and cooler conditions (S. Trolove, Crop and Food Research, pers. comm. 2008). Local experience also indicates that ryecorn is managed similarly to Italian ryegrass. Preliminary runs of the model produced similar yields to those reported in the region (Trolove 2008) and so the Italian ryegrass model was an appropriate substitute for the ryecorn.

The EcoMod model, set up as described above using an Italian ryegrass to mimic a ryecorn crop, was run under both dryland and irrigated conditions for the sixteen combinations of soil type and rainfall zone. Annual production under irrigated and dryland conditions is shown in Figure 5.

Under dryland conditions the ryecorn showed the same general pattern as did pasture production but ryecorn yields in the 30 mm PAW soil were higher than pasture in the same soil because there was less water stress during the March to October growth period. Under dryland conditions full-year production was not much different between pasture and ryecorn but there was less variability in the ryecorn production. In particular, there were few years in which the ryecorn was a complete failure and there were several years in which there was effectively no pasture growth.

Irrigation had more effect on ryecorn production in the lighter soils (Figure 5) than in the soils with more plant-available water. The greatest effect was on the March to May growth in the 30 mm PAW soil (data not shown) with the crop getting to a higher yield before temperatures dropped and growth ceased. Irrigation did not have the same dramatic effect on year-to-year variability as seen in pasture growth because the ryecorn is primarily grown after the irrigation has ceased, but is instead planted into the wetter soils. Variability in temperature was the primary reason for variation in growth of irrigated ryecorn.

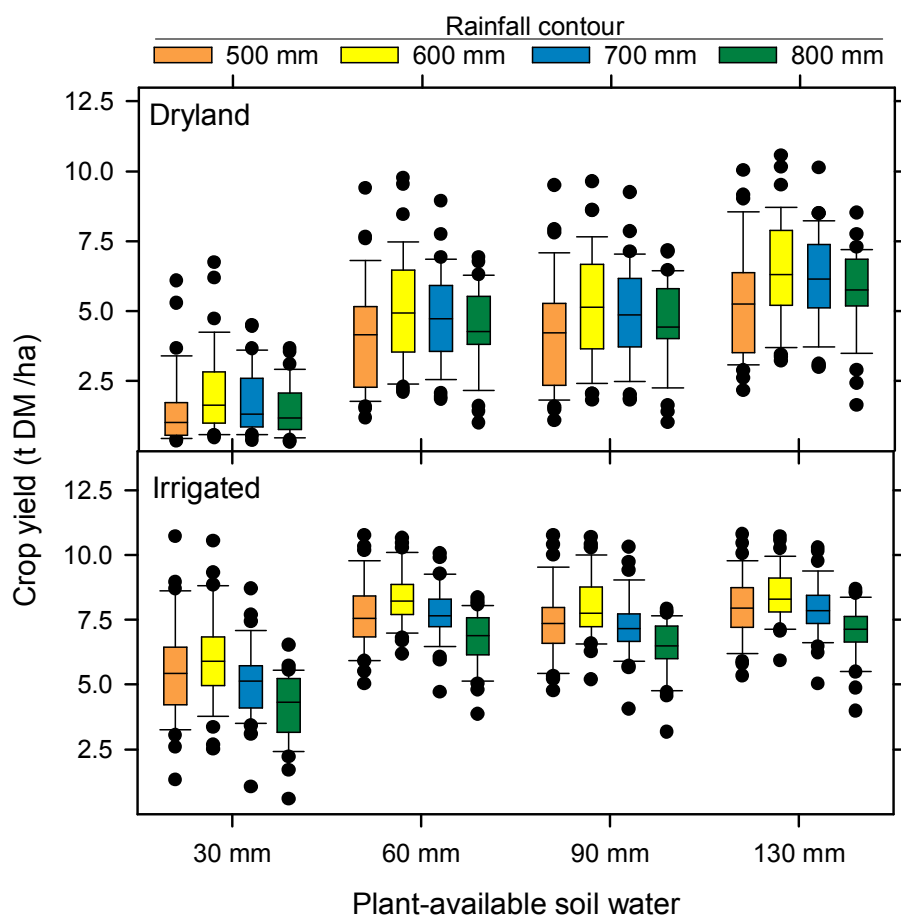


Figure 5. Annual (1972 to 2007) ryecorn yield for the four rainfall zones and four soil types.

5.2 Recommended Ryecorn Production Values for Farm Modelling

The monthly growth rates (data not shown) were analysed to produce monthly cumulative yield for the farm-scale modelling, grouped by categories of soil type and rainfall zone. These data are given in Table 8. Median values only are shown as there was little skew in the growth rates and so little difference between average and median values.

Table 8. Median cumulative yield of dryland and irrigated ryecorn grown on soils with varying PAW.

Month	dryland			irrigated	
	Plant-Available Water Storage (mm)				
	30 mm	60-90 mm	130 mm	30 mm	60-130 mm
March	0.2	0.4	0.5	0.5	0.8
April	0.4	1.0	1.3	1.2	2.0
May	0.6	1.6	2.0	1.6	2.8
June	0.7	1.8	2.3	1.8	3.1
July	0.8	2.1	2.6	2.0	3.4
August	1.1	2.7	3.3	2.3	4.1
September	1.3	3.7	4.6	3.2	5.4
October	1.7	4.6	5.9	5.2	7.5

6. References

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7. Appendix 1: Monthly Pasture Growth Rates

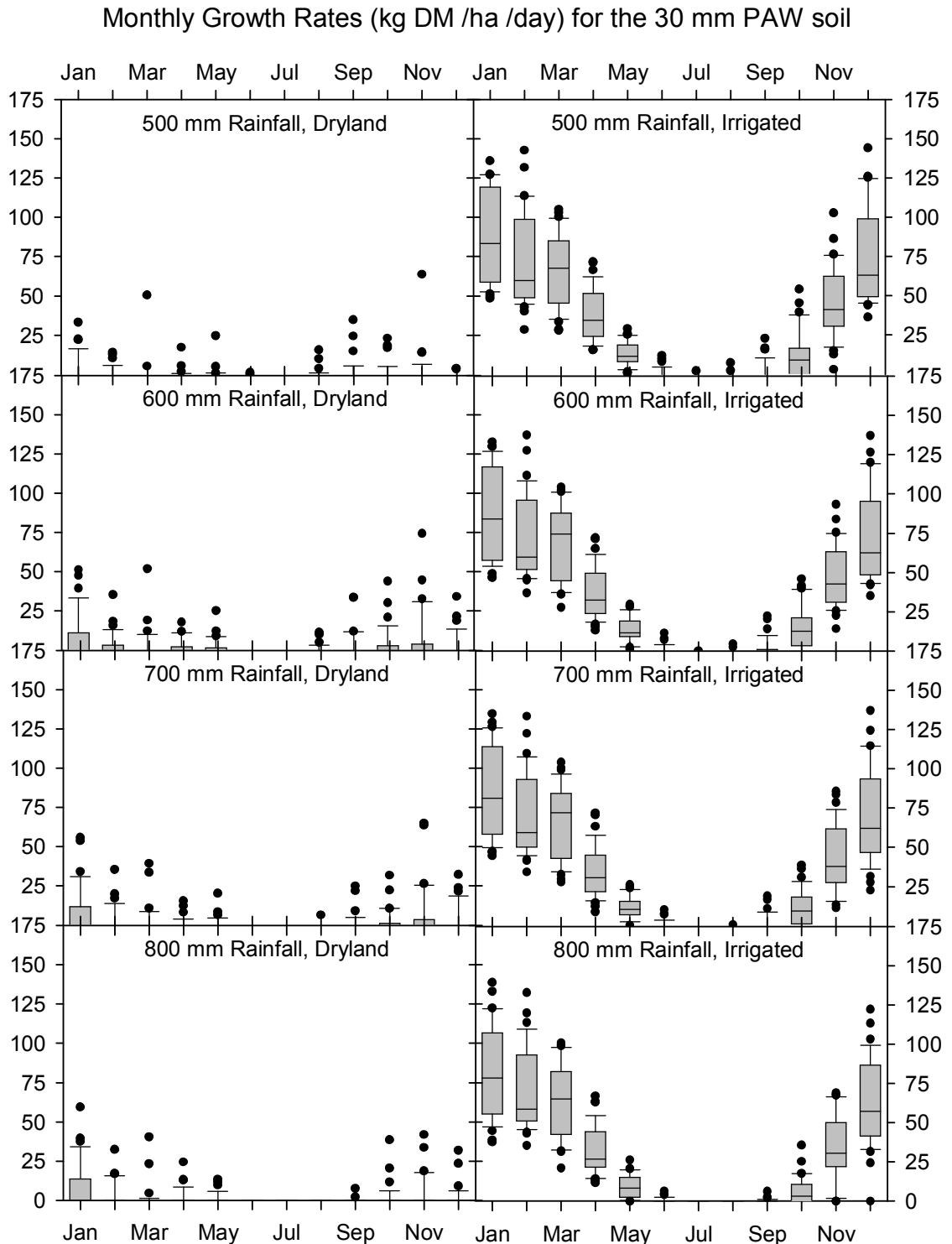


Figure A1. Monthly growth rates (kg DM /ha /day) for the 30 mm PAW soil as affected by rainfall zone and irrigation.

Monthly Growth Rates (kg DM /ha /day) for the 60 mm PAW soil

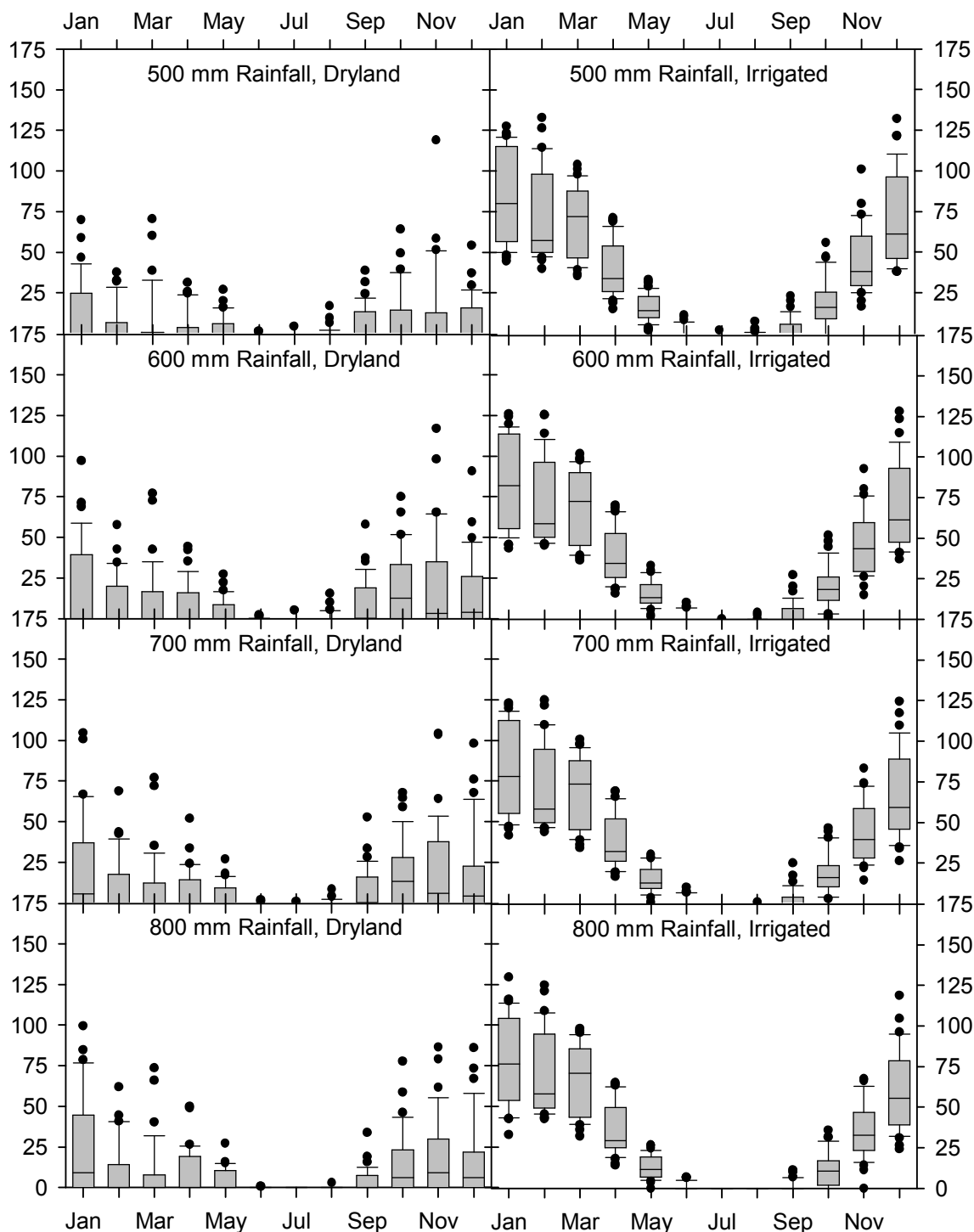


Figure A2. Monthly growth rates (kg DM /ha /day) for the 60 mm PAW soil as affected by rainfall zone and irrigation.

Monthly Growth Rates (kg DM /ha /day) for the 90 mm PAW soil

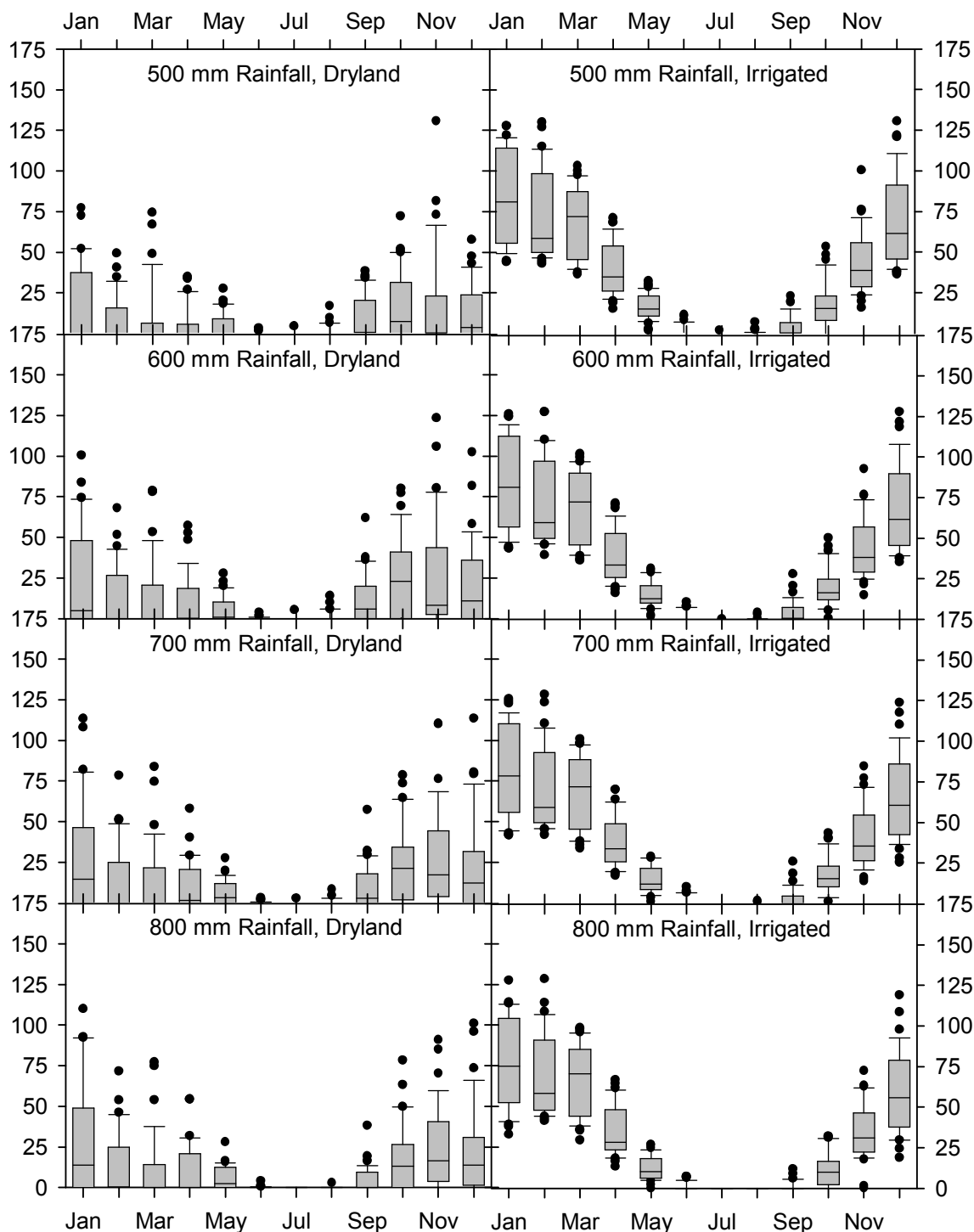


Figure A3. Monthly growth rates (kg DM /ha /day) for the 90 mm PAW soil as affected by rainfall zone and irrigation.

Monthly Growth Rates (kg DM /ha /day) for the 130 mm PAW soil

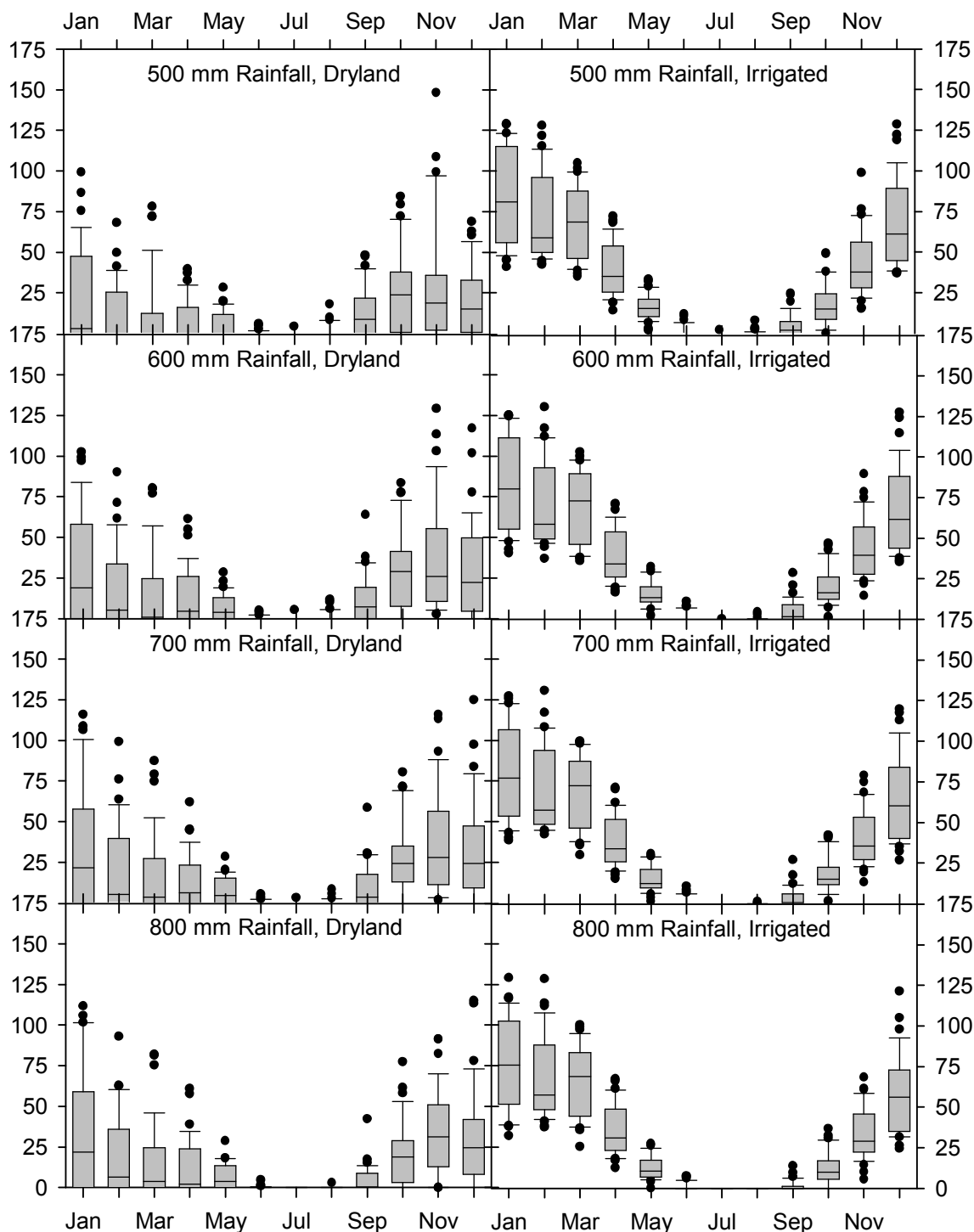


Figure A4. Monthly growth rates (kg DM /ha /day) for the 130 mm PAW soil as affected by rainfall zone and irrigation.