1 The APSIM FodderBeet Model

The model has been developed using the Plant Modelling Framework (PMF) of Brown et al., 2014. This new framework provides a library of plant organ and process submodels that can be coupled, at runtime, to construct a model in much the same way that models can be coupled to construct a simulation.This means that dynamic composition of lower level process and organ classes(e.g.photosynthesis, leaf) into larger constructions(e.g.maize, wheat, sorghum) can be achieved by the model developer without additional coding.

Khaembah E.N., Brown H.E., Zyskowski R., Chakwizira E., de Ruiter J.M., Teixeira E.I.

The New Zealand Institute for Plant & Food Research Limited Private Bag 4704, Christchurch, New Zealand

The APSIM Fodder Beet Model has been developed using the Plant Modelling Framework (PMF) of Brown et al., 2014. This framework provides a library of plant organ and process submodels that can be coupled, at runtime, to construct a model in much the same way that models can be coupled to construct a simulation. This means that dynamic composition of lower level process and organ classes (e.g. photosynthesis, leaf) into larger constructions (e.g. maize, barley, sorghum) can be achieved by the model developer without additional coding.

The model consists of:

* A phenology model to simulate development between growth phases
* A structure model to simulate plant morphology
* A collection of organs to simulate the various plant parts
* An arbitrator to allocate resources (N, biomass) to various plant organs.

The model is constructed from the following list of software components. Details of the implementation and model parameterisation are provided in the following sections.

1.1 Plant Model Components

Component Name	Component Type
Arbitrator	Models.PMF.OrganArbitrator
Phenology	Models.PMF.Phen.Phenology
Structure	Models.PMF.Struct.Structure
StorageRoot	Models.PMF.Organs.GenericOrgan
Leaf	Models.PMF.Organs.Leaf
Petiole	Models.PMF.Organs.GenericOrgan
Root	Models.PMF.Organs.Root
MortalityRate	Models.Functions.LinearInterpolationFunction
SCS	Models.Functions.AddFunction
SeedMortalityRate	Models.Functions.Constant

1.2 Composite Biomass

Component Name	Component Type
AboveGround	Models.PMF.CompositeBiomass
BelowGround	Models.PMF.CompositeBiomass

Component Name	Component Type
Total	Models.PMF.CompositeBiomass
TotalLive	Models.PMF.CompositeBiomass
TotalDead	Models.PMF.CompositeBiomass

1.3 Cultivars

Cultivar Name	Alternative Name(s)
Brigadier	Brigadier
Rivage	Rivage
Jamon	Jamon

1.4 Child Components

1.4.1 Arbitrator

The Arbitrator class determines the allocation of dry matter (DM) and Nitrogen between each of the organs in the crop model. Each organ can have up to three different pools of biomass:

* **Structural biomass** which is essential for growth and remains within the organ once it is allocated there.
* **Metabolic biomass** which generally remains within an organ but is able to be re allocated when the organ senesces and may be retranslocated when demand is high relative to supply.
* **Storage biomass** which is partitioned to organs when supply is high relative to demand and is available for retranslocation to other organs whenever supply from uptake, fixation, or re allocation is lower than demand.

The process followed for biomass arbitration is shown in the figure below. Arbitration calculations are triggered by a series of events (shown below) that are raised every day. For these calculations, at each step the Arbitrator exchange information with each organ, so the basic computations of demand and supply are done at the organ level, using their specific parameters.

1. **doPotentialPlantGrowth**. When this event occurs, each organ class executes code to determine their potential growth, biomass supplies and demands. In addition to demands for structural, non structural and metabolic biomass (DM and N) each organ may have the following biomass supplies:

* **Fixation supply**. From photosynthesis (DM) or symbiotic fixation (N)
* **Uptake supply**. Typically uptake of N from the soil by the roots but could also be uptake by other organs (eg foliage application of N).
* **Retranslocation supply**. Storage biomass that may be moved from organs to meet demands of other organs.
* **Reallocation supply**. Biomass that can be moved from senescing organs to meet the demands of other organs.

1. **doPotentialPlantPartitioning.** On this event the Arbitrator first executes the DoDMSetup() method to gather the DM supplies and demands from each organ, these values are computed at the organ level. It then executes the DoPotentialDMAllocation() method which works out how much biomass each organ would be allocated assuming N supply is not limiting and sends these allocations to the organs. Each organ then uses their potential DM allocation to determine their N demand (how much N is needed to produce that much DM) and the arbitrator calls DoNSetup() to gather the N supplies and demands from each organ and begin N arbitration. Firstly DoNReallocation() is called to redistribute N that the plant has available from senescing organs. After this step any unmet N demand is considered as plant demand for N uptake from the soil (N Uptake Demand).
2. **doNutrientArbitration.** When this event occurs, the soil arbitrator gets the N uptake demands from each plant (where multiple plants are growing in competition) and their potential uptake from the soil and determines how much of their demand that the soil is able to provide. This value is then passed back to each plant instance as their Nuptake and doNUptakeAllocation() is called to distribute this N between organs.
3. **doActualPlantPartitioning.** On this event the arbitrator call DoNRetranslocation() and DoNFixation() to satisfy any unmet N demands from these sources. Finally, DoActualDMAllocation is called where DM allocations to each organ are reduced if the N allocation is insufficient to achieve the organs minimum N concentration and final allocations are sent to organs.

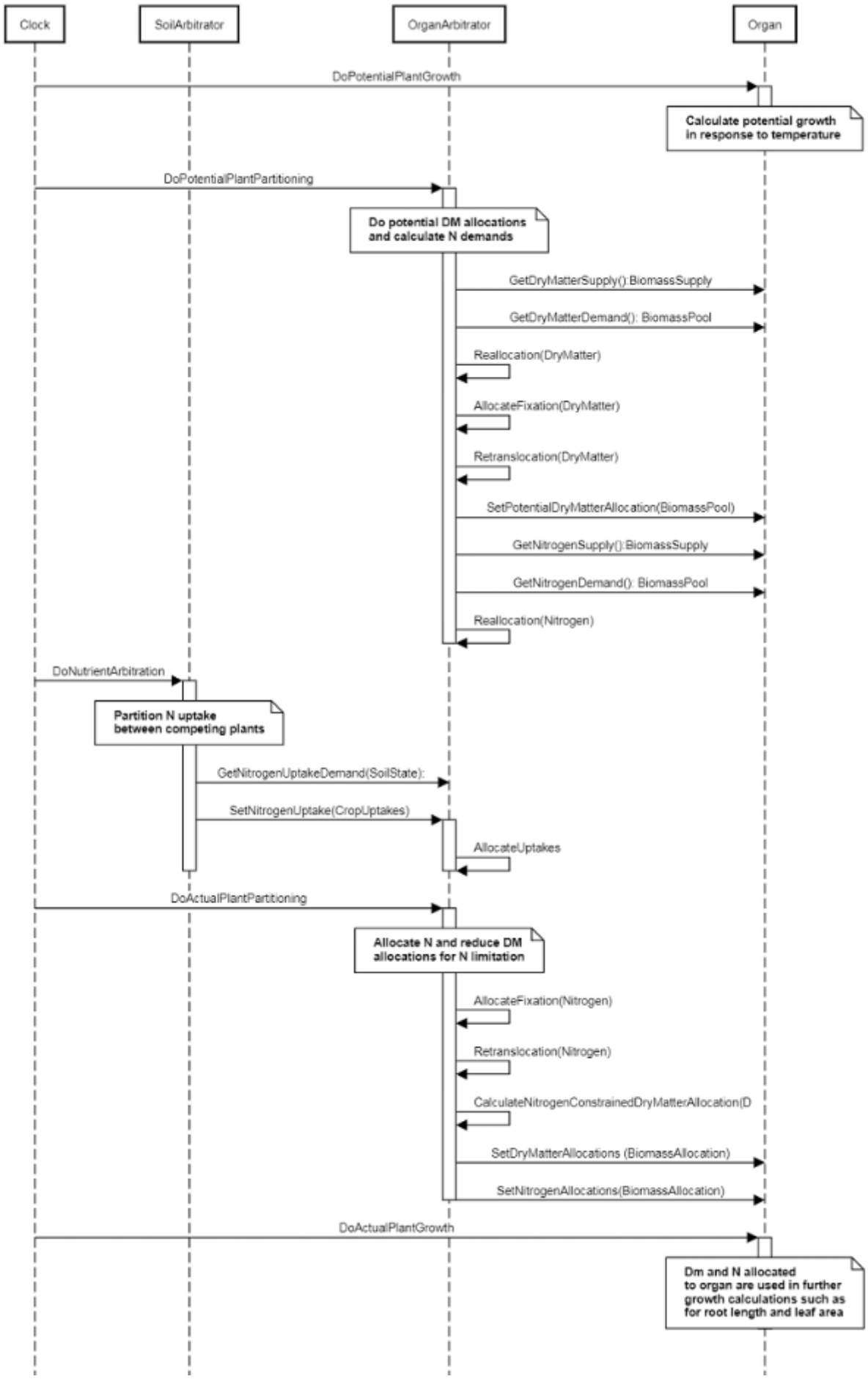


Figure 1: Schematic showing the procedure for arbitration of biomass partitioning. Pink boxes represent events that occur every day and their numbering shows the order of calculations. Blue boxes represent the methods that are called when these events occur. Orange boxes contain properties that make up the organ/arbitrator interface. Green boxes are organ specific properties.

The partitioning of biomass to fodder beet organs follows a "Relative Allocation" routine (see Arbitrator module documentation) guided by coefficients derived from the October sowing date data of the test dataset

1.4.2 Phenology

The phenological development is simulated as the progression through a series of developmental phases, each bound by distinct growth stage.

The fodder beet model is described for growth and dry matter production using solar radiation and temperature as driving functions. The effect of temperature is quantified using a thermal-time accumulation function. Thermal-time is calculated in degree days for ambient temperature above a base temperature (Tbase). Tbase is assumed to be 0°C (Chakwizira et al., 2016).

1.4.3 Structure

The structure model simulates morphological development of the plant to inform the Leaf class when and how many leaves and branches appear and provides an estimate of height.

1.4.4 StorageRoot

This organ is simulated using a GenericOrgan type. It is parameterised to calculate the growth, senescence, and detachment of any organ that does not have specific functions.

1.4.5 Leaf

The leaves are modelled as a set of leaf cohorts and the properties of each of these cohorts are summed to give overall values for the leaf organ.
A cohort represents all the leaves of a given main stem node position including all of the branch leaves appearing at the same time as the given main stem leaf (Lawless et al., 2005).
The number of leaves in each cohort is the product of the number of plants per m^2 and the number of branches per plant.
The *Structure* class models the appearance of main stem leaves and branches. Once cohorts are initiated the *Leaf* class models the area and biomass dynamics of each.
It is assumed all the leaves in each cohort have the same size and biomass properties. The modelling of the status and function of individual cohorts is delegated to *LeafCohort* classes.

1.4.6 Petiole

This organ is simulated using a GenericOrgan type. It is parameterised to calculate the growth, senescence, and detachment of any organ that does not have specific functions.

1.4.7 Root

The root model calculates root growth in terms of rooting depth, biomass accumulation and subsequent root length density in each soil layer.

1.4.8 MortalityRate

A linear interpolation model, where an

1.4.9 SCS

A class that returns the sum of its child functions.

Non structural carbohydrates and sugars

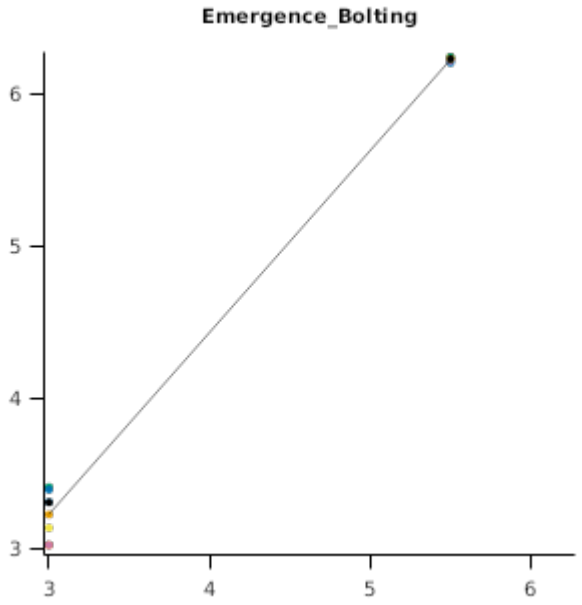
1.4.10 SeedMortalityRate

A constant function (name=value)

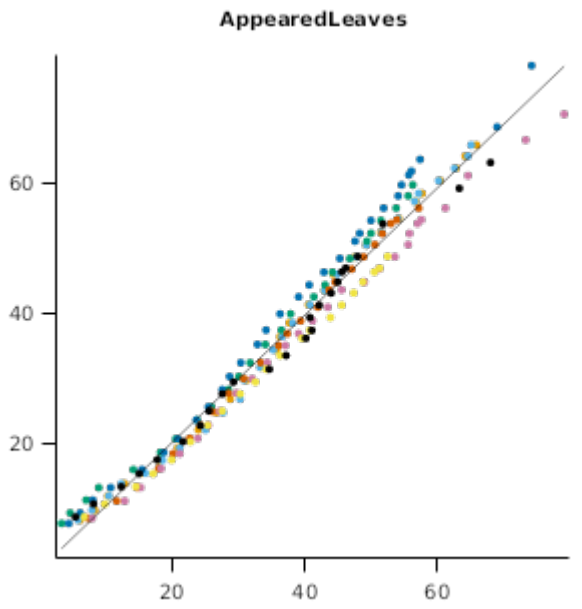
2 FodderBeetValidation

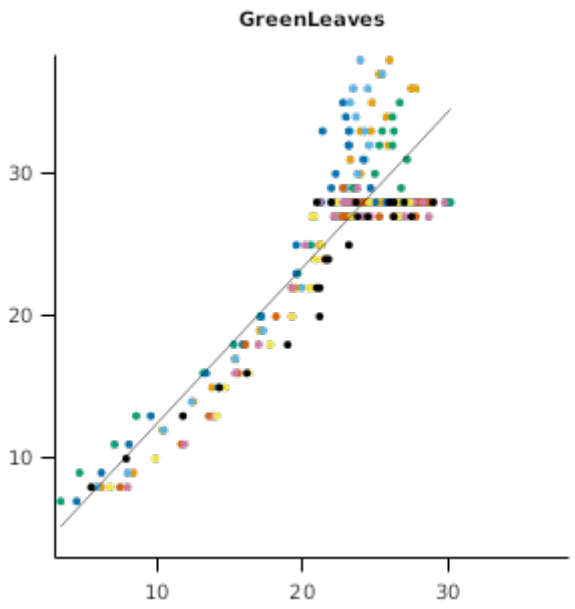
2.1 CombinedStatistics

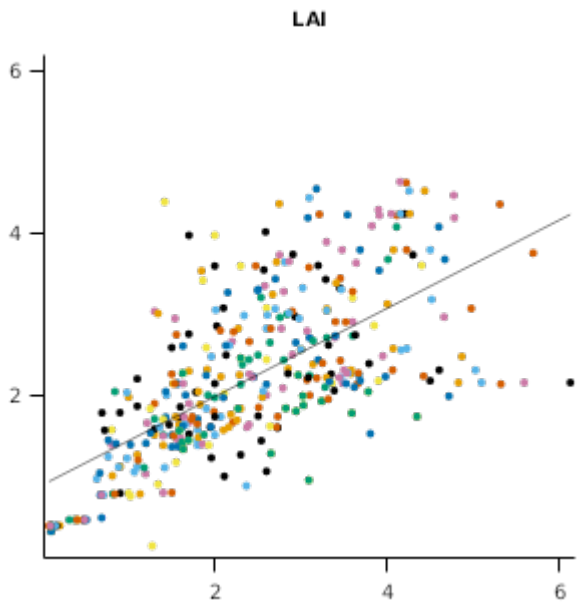
2.1.1 PhenologyStatistics

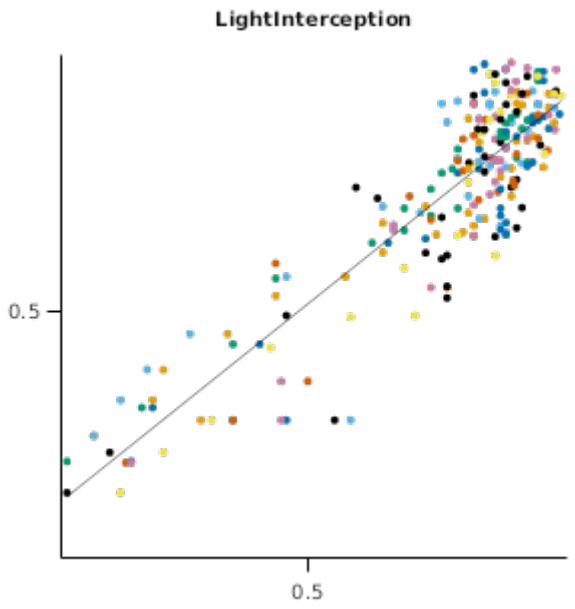


2.1.2 CanopyStatistics

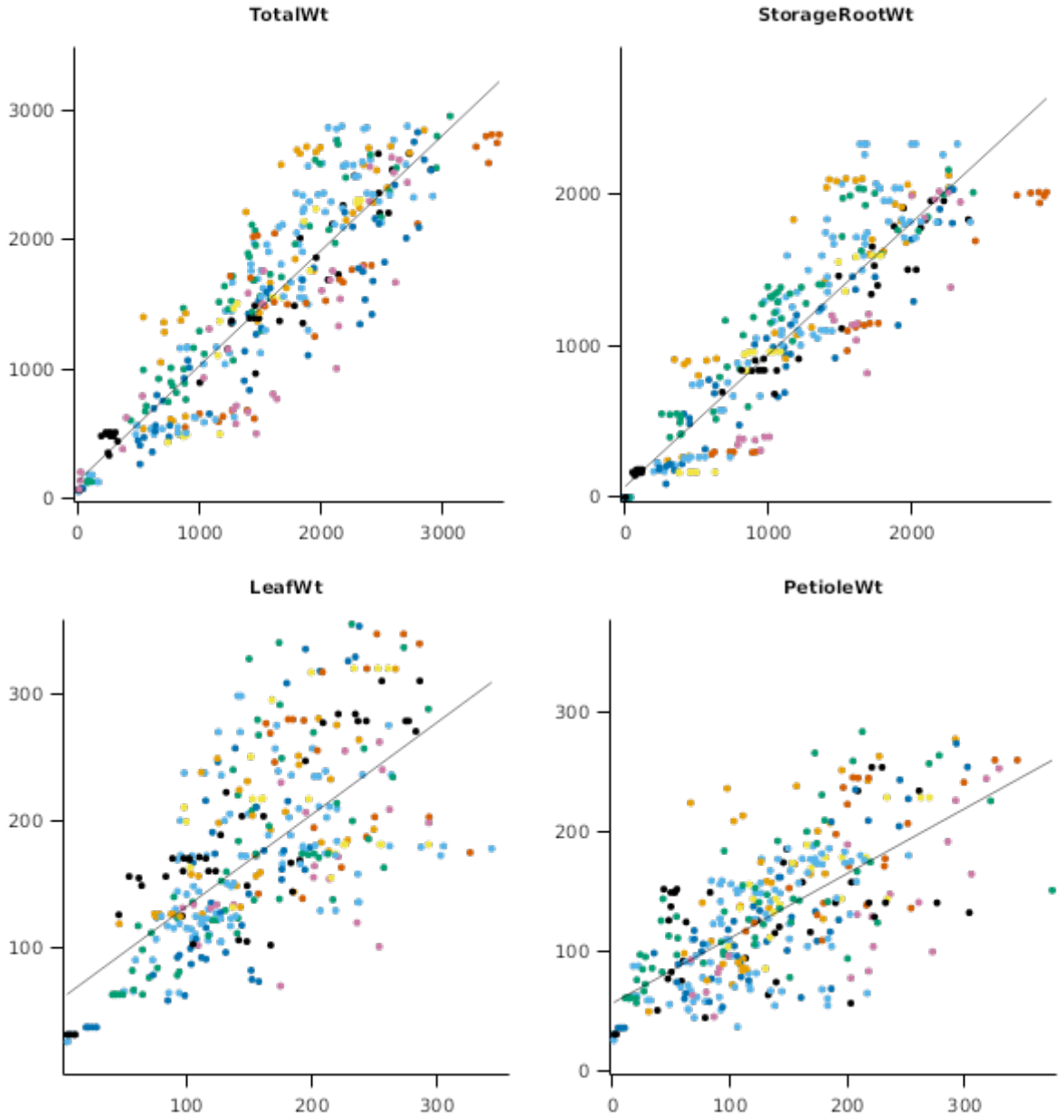




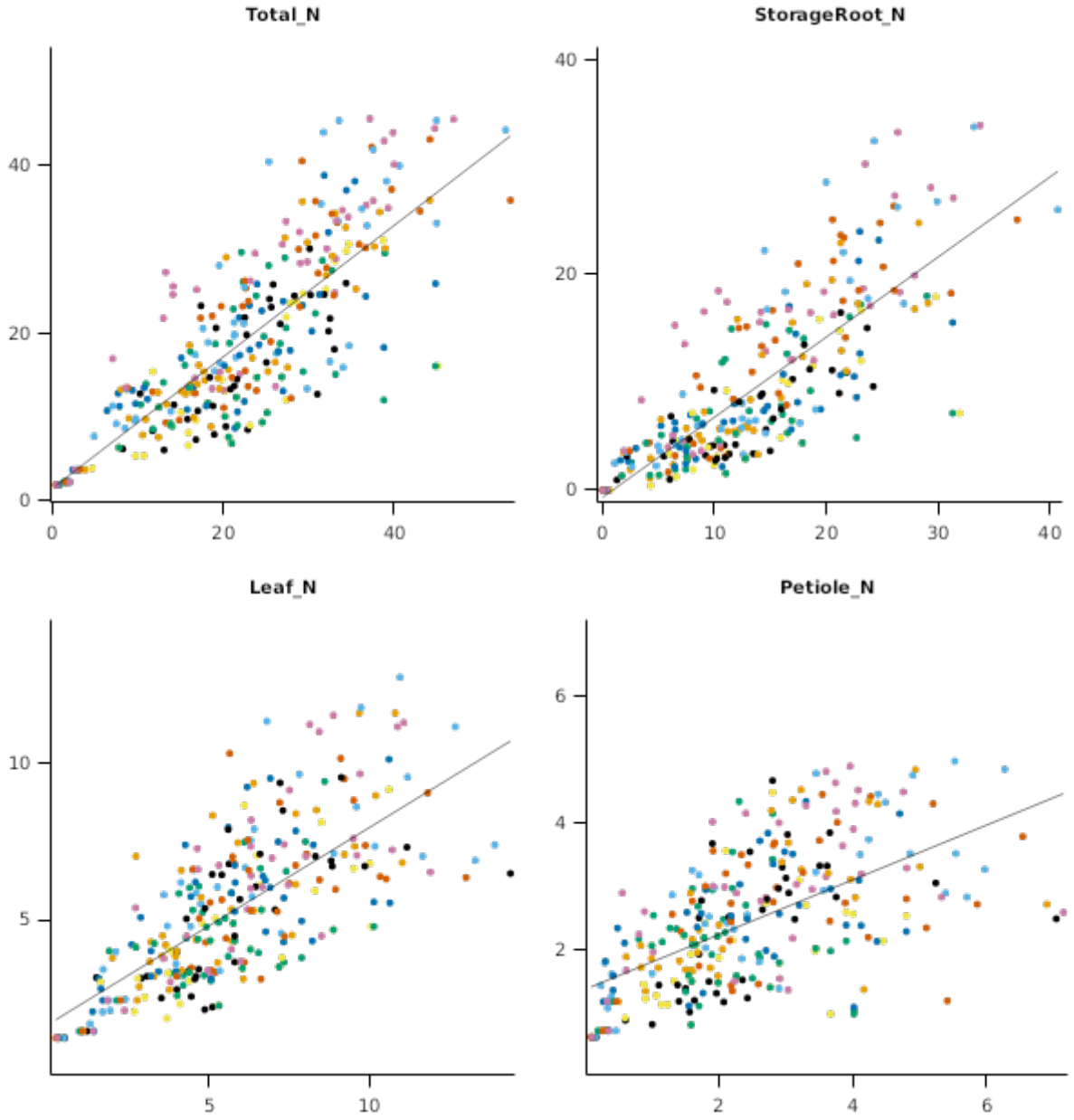




2.1.3 BiomassStatistics



2.1.4 N_uptakeStatistics



2.2 NewZealand

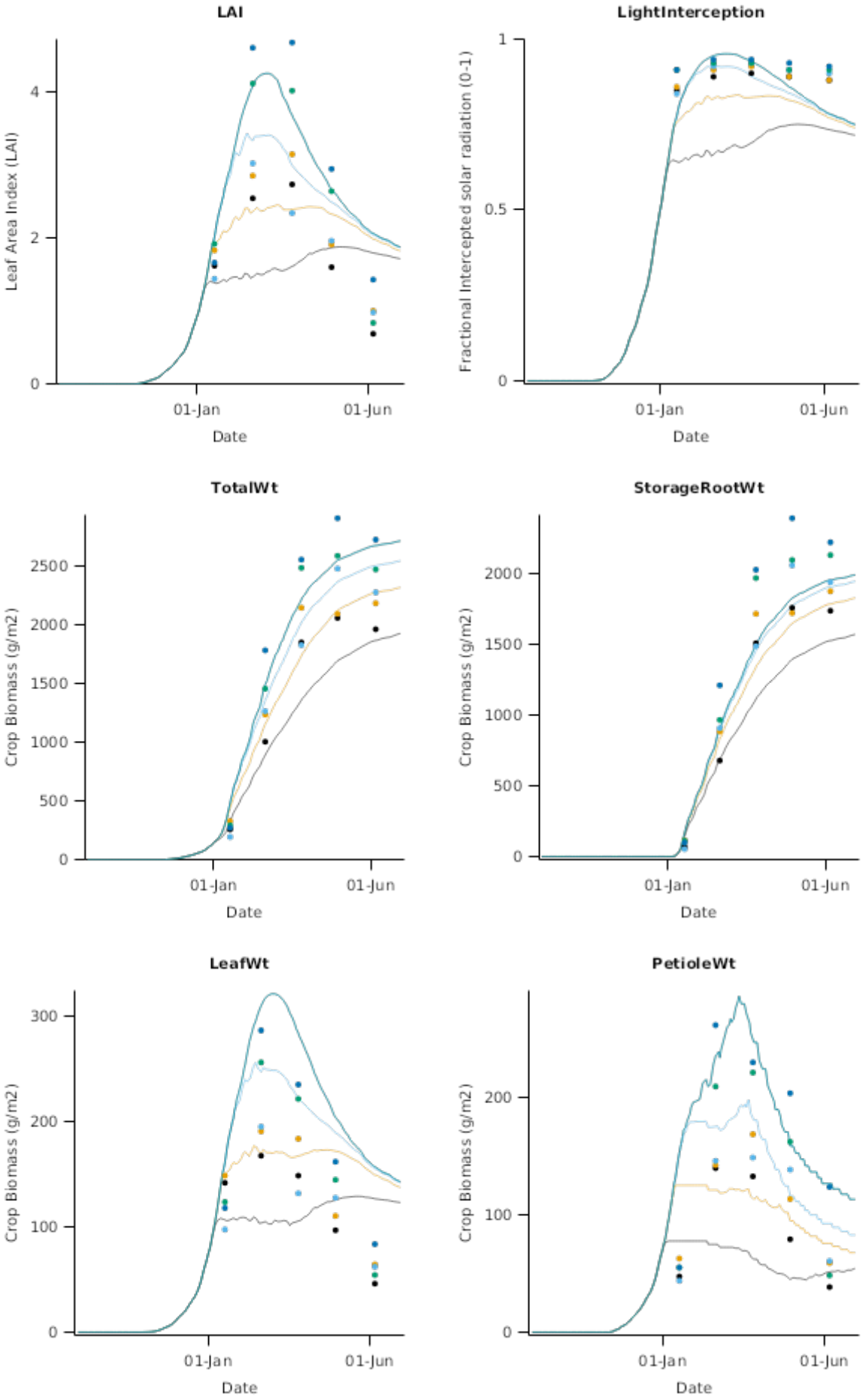
2.2.1 Lincoln

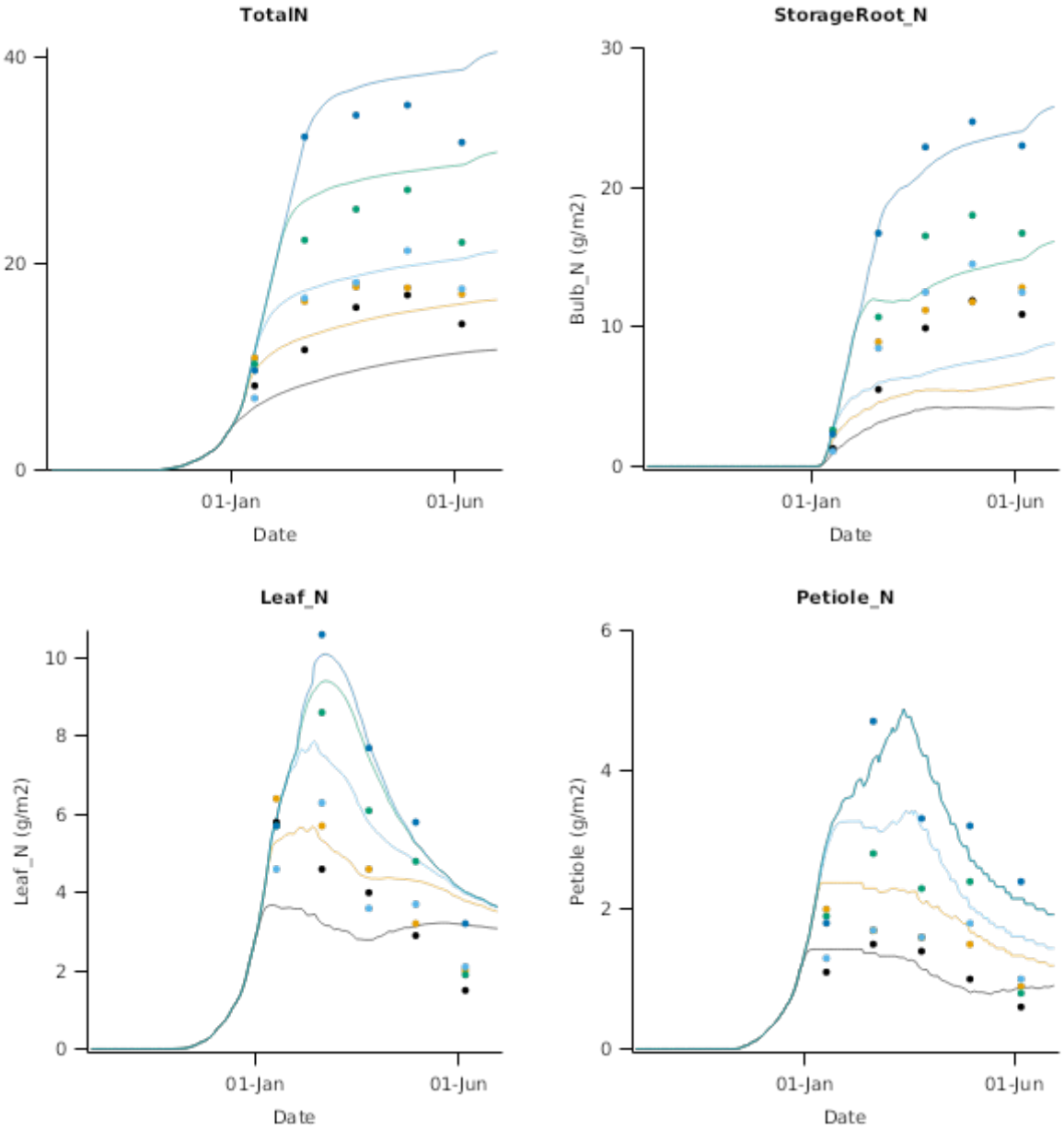
2.2.1.1 List of experiments

Experiment Name	Design (Number of Treatments)
Lincoln2011	Nit (5)
Lincoln2012	Irr (4)
Lincoln2014	Cv x SD (8)
LincolnRS2016	Irr x Nit (6)

2.2.1.2 Lincoln2011

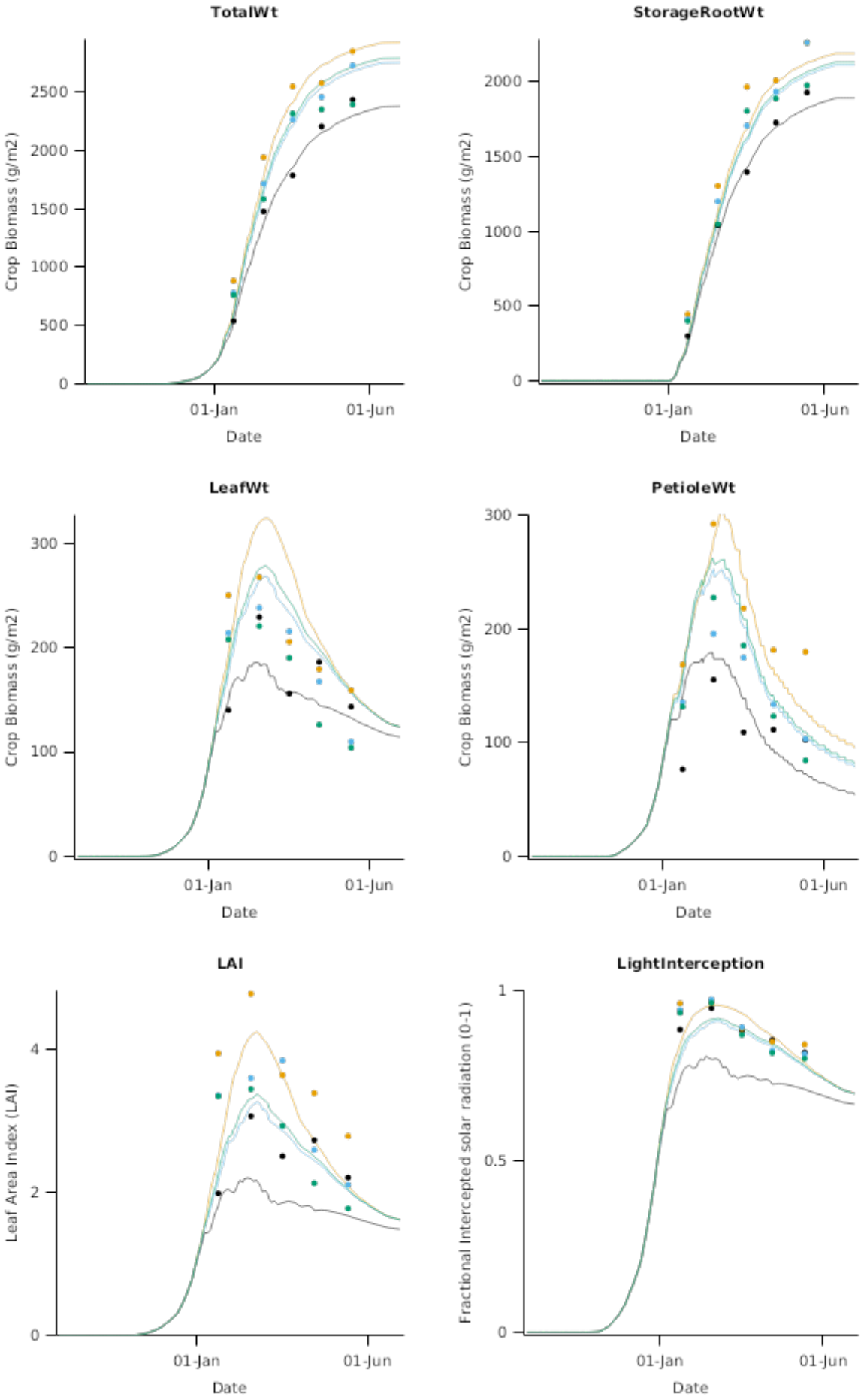
This was a nitrogen fertiliser treatment trial conducted at Lincoln in 2011 (Chakwizira et al., 2014).

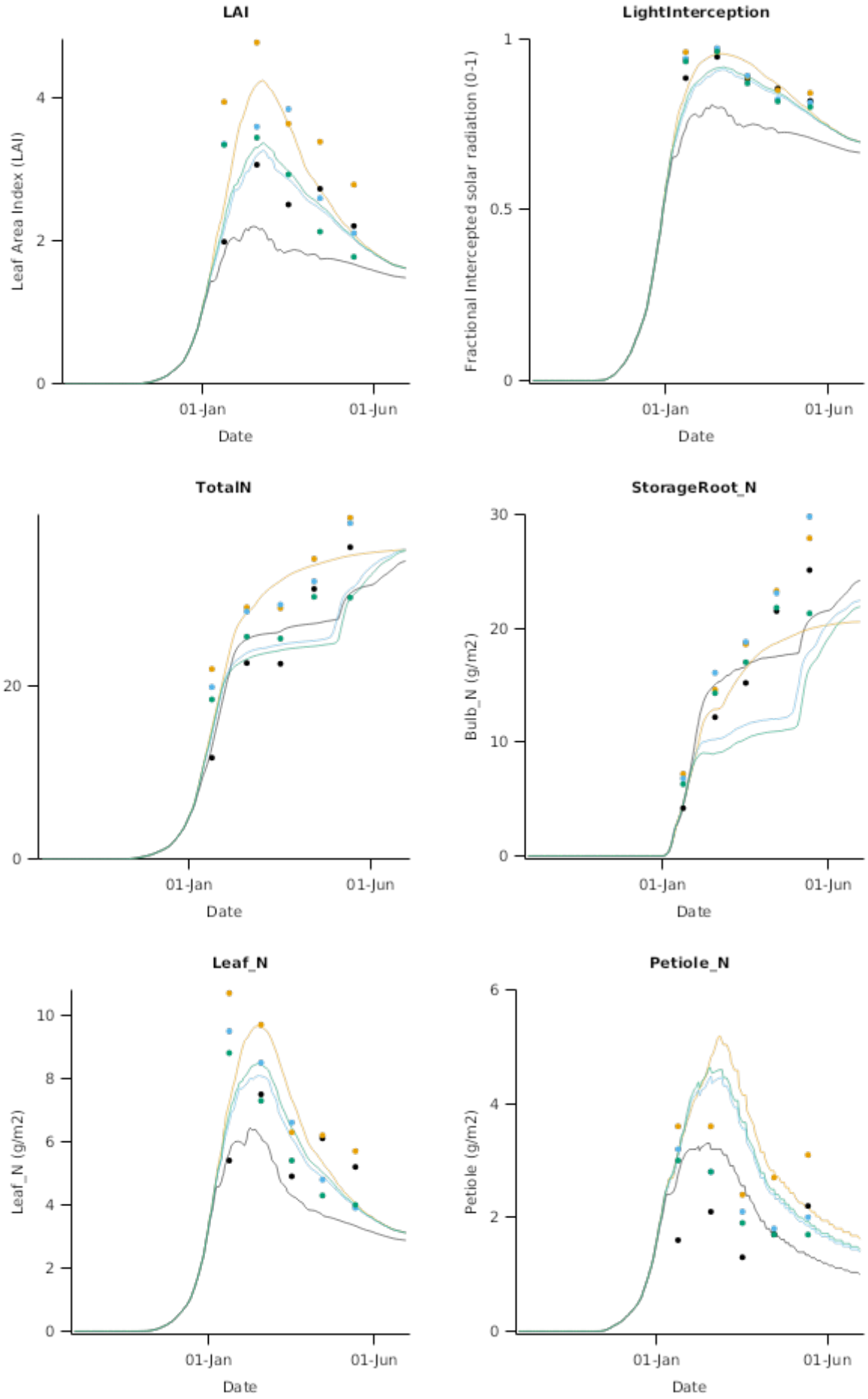

LAI
Leaf Area Index (LAI)
0
2
4
01-Jan
01-Jun
Date
LightInterception
Fractional Intercepted solar radiation (0-1)
0
0.5
1
01-Jan
01-Jun
Date
TotalWt
Crop Biomass (g/m2)
0
500
1000
1500
2000
2500
01-Jan
01-Jun
Date
StorageRootWt
Crop Biomass (g/m2)
0
500
1000
1500
2000
01-Jan
01-Jun
Date
LeafWt
Crop Biomass (g/m2)
0
100
200
300
01-Jan
01-Jun
Date
PetioleWt
Crop Biomass (g/m2)
0
100
200
01-Jan
01-Jun
Date



2.2.1.3 Lincoln2012

This was an irrigation treatment trial conducted at Lincoln in 2012 (Chakwizira et al., 2014).

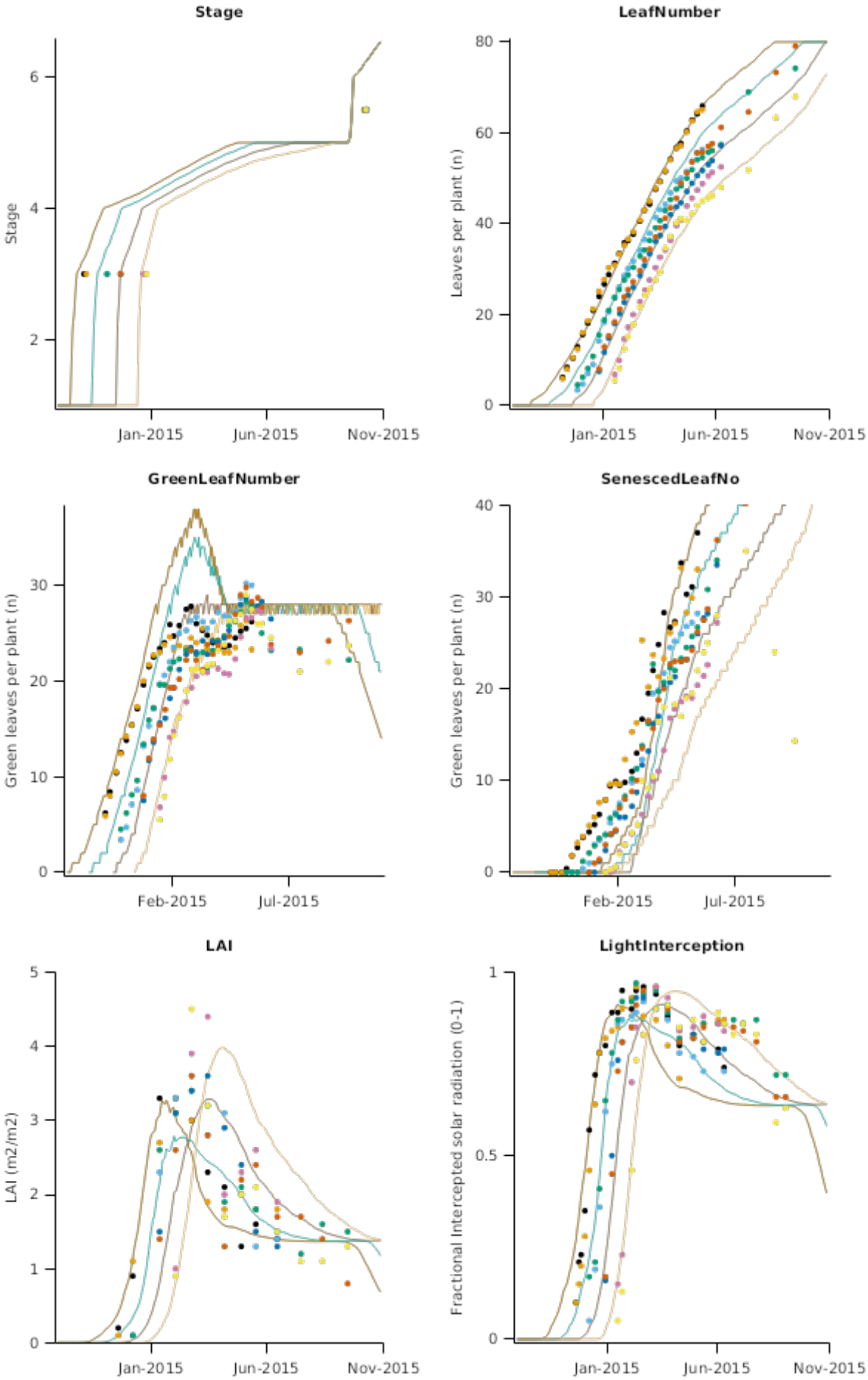

TotalWt
Crop Biomass (g/m2)
0
500
1000
1500
2000
2500
01-Jan
01-Jun
Date
StorageRootWt
Crop Biomass (g/m2)
0
500
1000
1500
2000
01-Jan
01-Jun
Date
LeafWt
Crop Biomass (g/m2)
0
100
200
300
01-Jan
01-Jun
Date
PetioleWt
Crop Biomass (g/m2)
0
100
200
300
01-Jan
01-Jun
Date
LAI
Leaf Area Index (LAI)
0
2
4
01-Jan
01-Jun
Date
LightInterception
Fractional Intercepted solar radiation (0-1)
0
0.5
1
01-Jan
01-Jun
Date

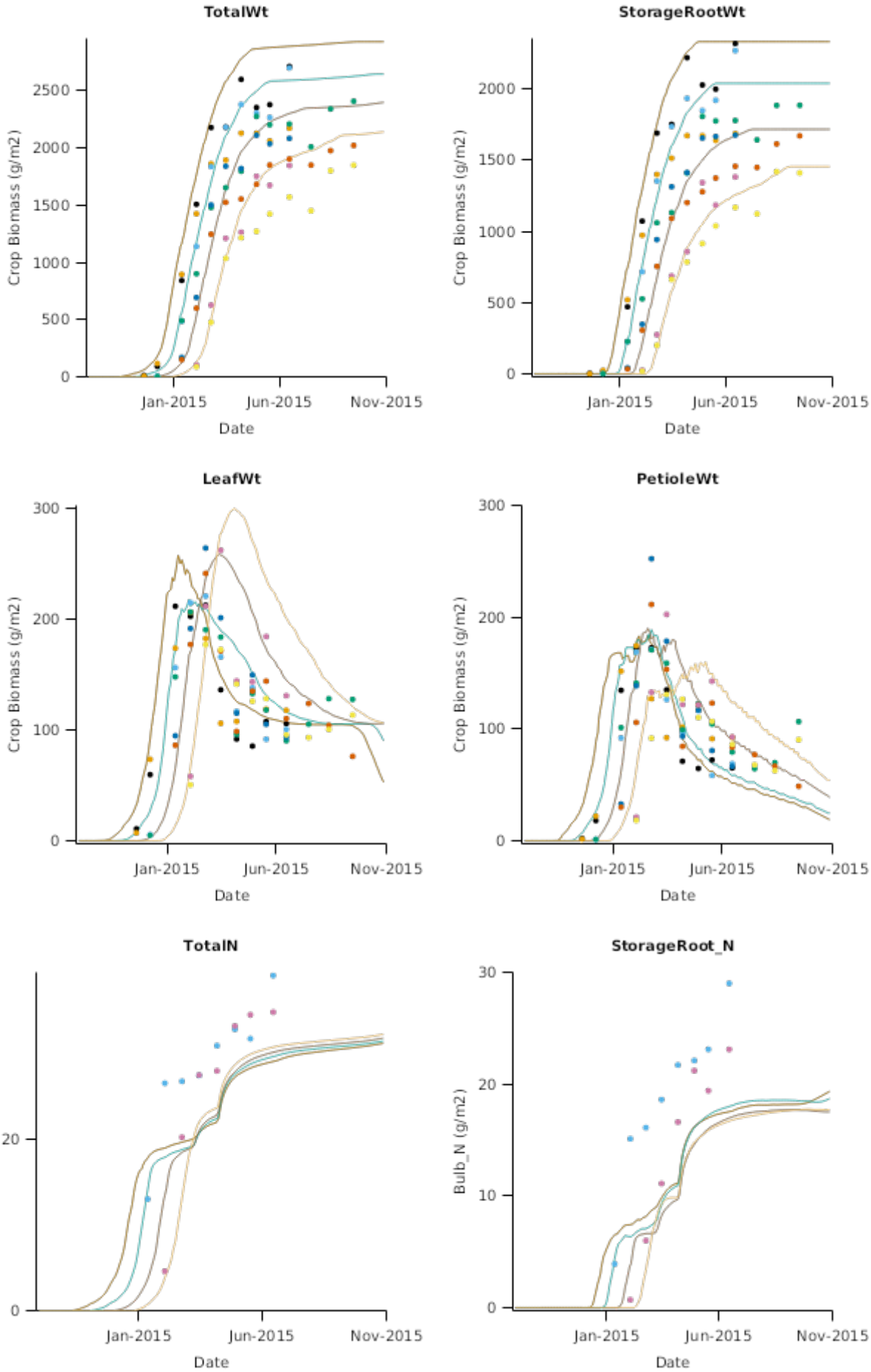


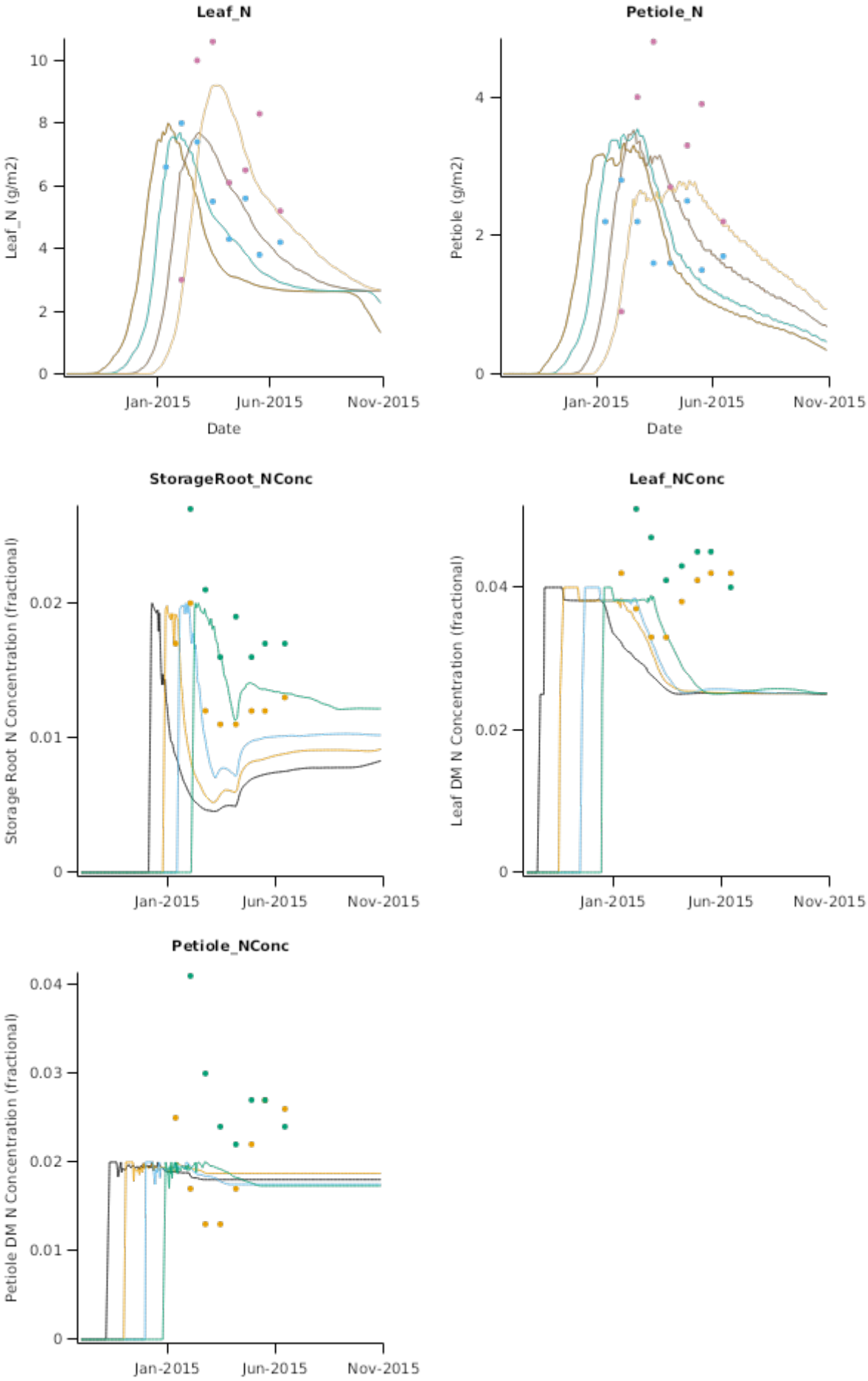
2.2.1.4 Lincoln2014

The data used here is from a sowing date experiment conducted at Lincoln, Canterbury, New Zealand. The experiment was established in the field as a Randomised Complete Block Design with four replicates. Two culivars ("Rivage" and "Brigadier") were evaluated over four sowing dates (19 September, 17 October, 17 November and 15 December in 2014).

The first phase i.e. calibration/parameterisation of a potential yield model was completed using cultivar "Rivage" data from the October sowing date (Khaembah et al., 2017).




TotalWt
Crop Biomass (g/m2)
0
500
1000
1500
2000
2500
Jan-2015
Jun-2015
Nov-2015
Date
StorageRootWt
Crop Biomass (g/m2)
0
500
1000
1500
2000
Jan-2015
Jun-2015
Nov-2015
Date
LeafWt
Crop Biomass (g/m2)
0
100
200
300
Jan-2015
Jun-2015
Nov-2015
Date
PetioleWt
Crop Biomass (g/m2)
0
100
200
300
Jan-2015
Jun-2015
Nov-2015
Date
TotalN
0
20
Jan-2015
Jun-2015
Nov-2015
Date
StorageRoot_N
Bulb_N (g/m2)
0
10
20
30
Jan-2015
Jun-2015
Nov-2015
Date

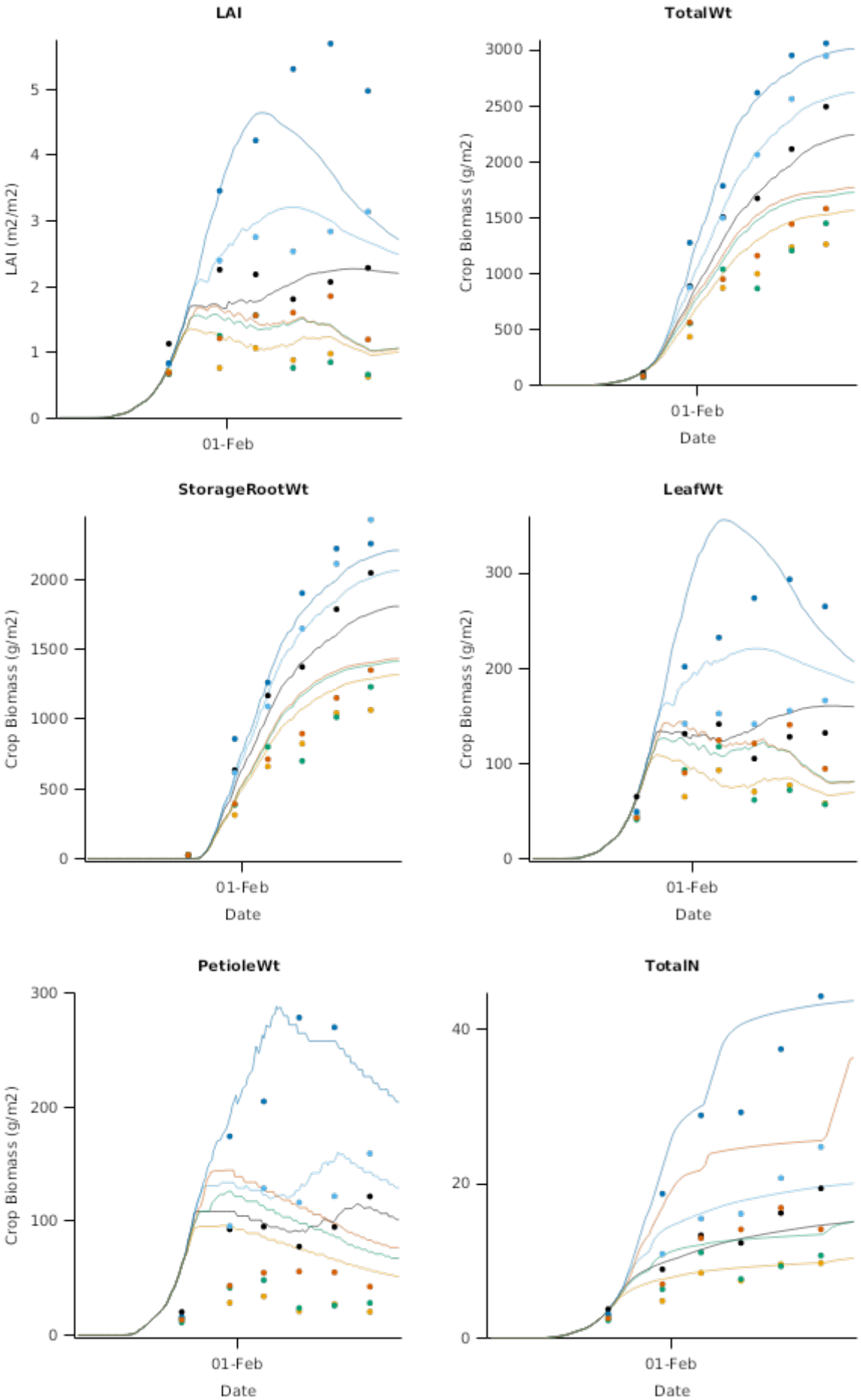


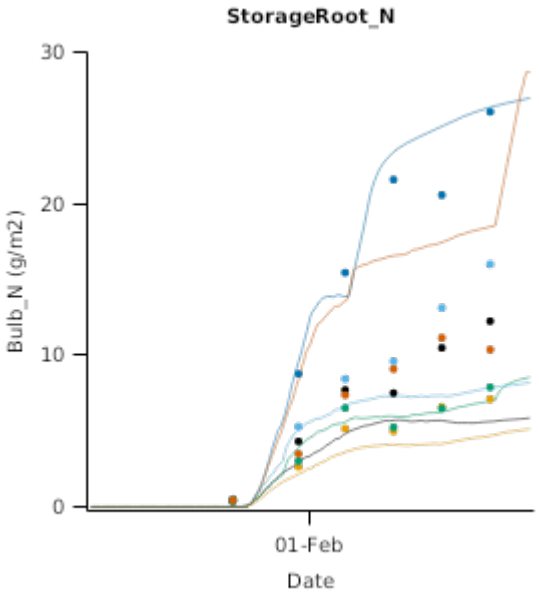
2.2.1.5 LincolnRS2016

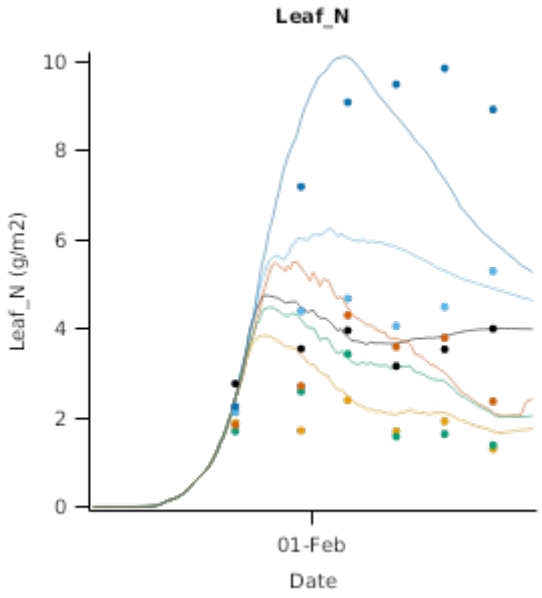
This trial was conducted in the rainshelter at Plant and Food Research in Lincoln, New Zealand in 2016. The objective was to evaluate the effect of nitrogen and irrigation on the development and growth of fodder beet crops.
Details:

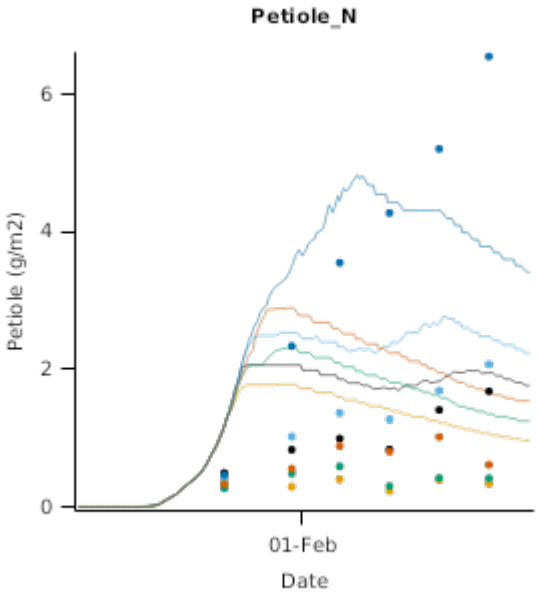
â€¢ Three nitrogen treatments: 0 kg N/ha, 50 kg N/ha & 300 kg N/ha applied as dissolved urea with fertigation
â€¢ Two irrigation treatments: Nil and full irrigation

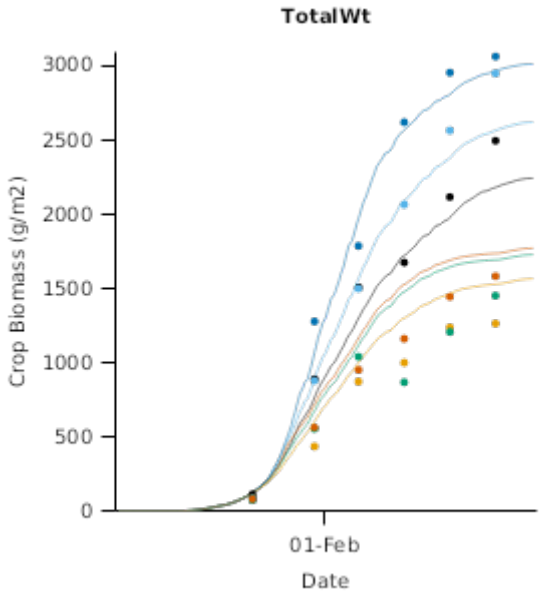
Fodder beet (cultiva "Rivage") was precision drilled on 18 October 2016. Sowing density was 11 plants/m2 and row spacing was 0.45m.

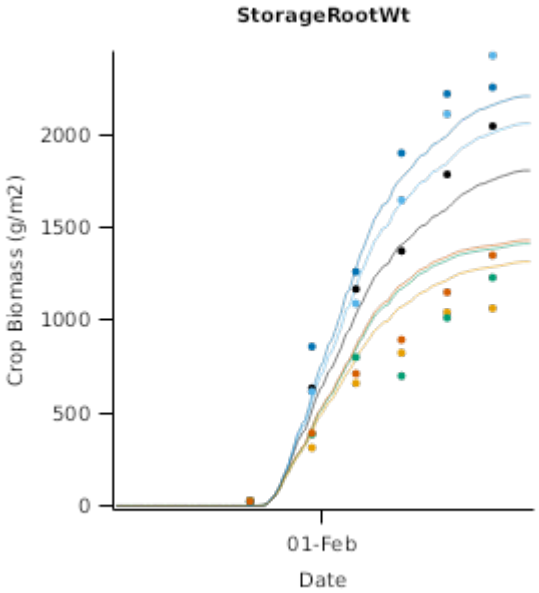


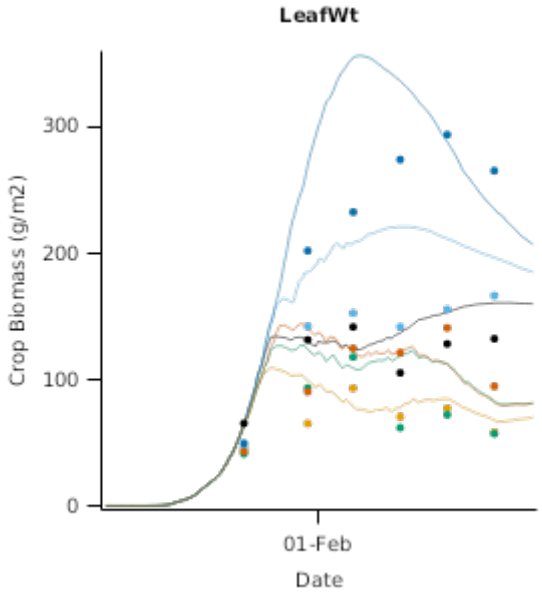

StorageRoot_N
Bulb_N (g/m2)
30
20
10
0
01-Feb
Date

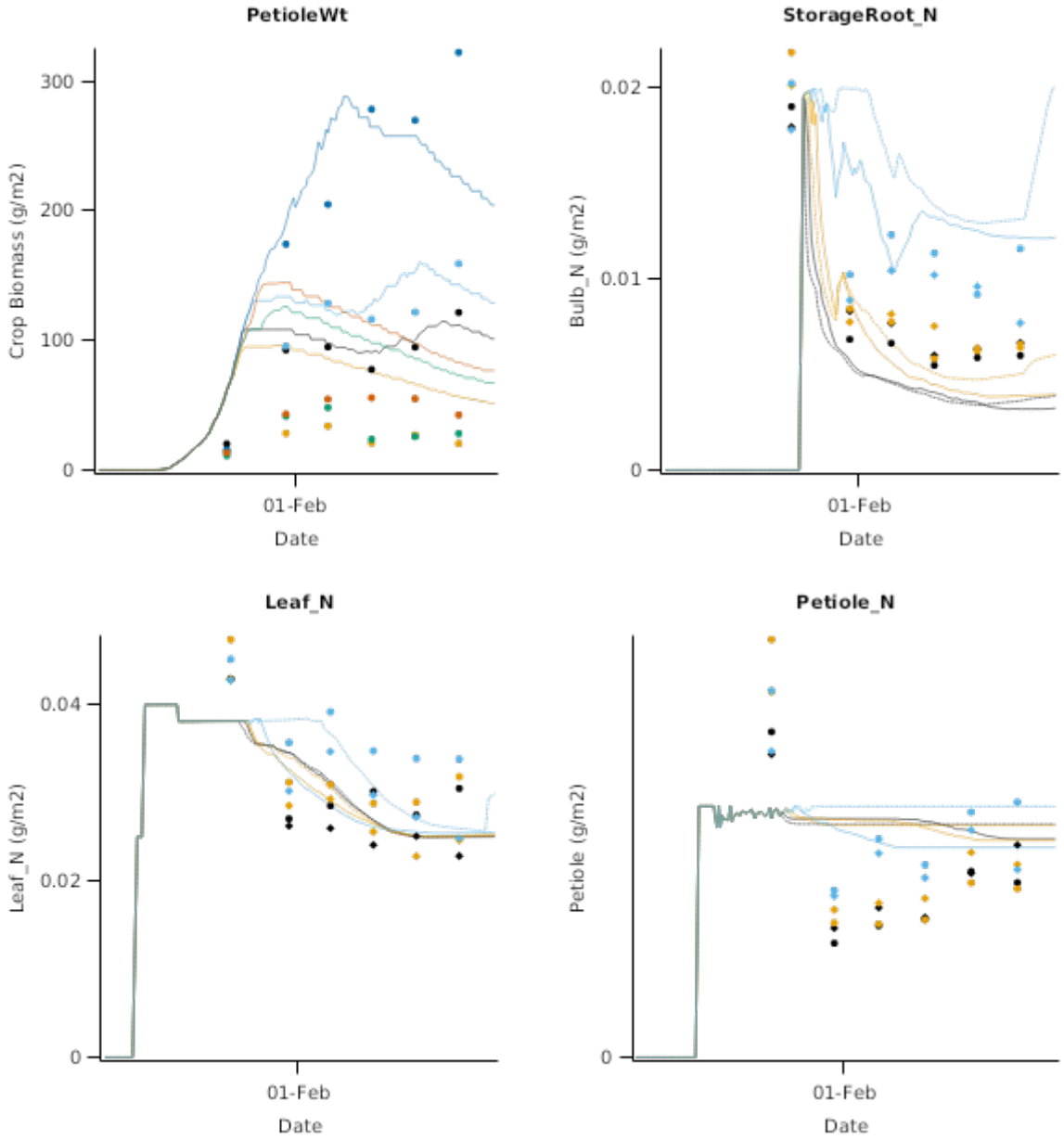

Leaf_N
Leaf_N (g/m2)
10
8
6
4
2
0
01-Feb
Date


Petiole_N
Petiole (g/m2)
6
4
2
0
01-Feb
Date


TotalWt
Crop Biomass (g/m2)
3000
2500
2000
1500
1000
500
0
01-Feb
Date


StorageRootWt
Crop Biomass (g/m2)
2000
1500
1000
500
0
01-Feb
Date


LeafWt
Crop Biomass (g/m2)
300
200
100
0
01-Feb
Date



2.2.2 AshleyDene

This is a nitrogen fertiliser by irrigation trial conducted at Ashley Dene in 2013 (Chakwizira et al., 2016).

2.2.2.1 List of experiments

Experiment Name	Design (Number of Treatments)
Ashley2013	Irr x Nit (8)

2.2.2.2 Ashley2013

LAI

LightInterception

AboveGround_N

StorageRoot_N

Leaf_N

Petiole_N

LAI

LightInterception

TotalWt

StorageRootWt

LeafWt

PetioleWt

Total_N

Leaf_N

Petiole_N

StorageRoot_N

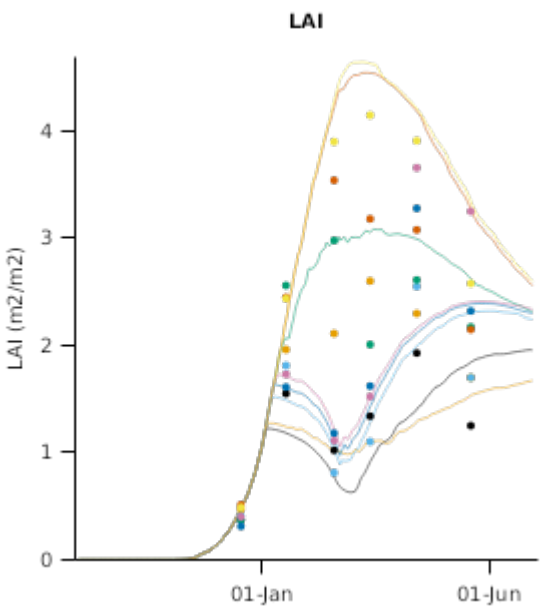
TotalWt

StorageRootWt

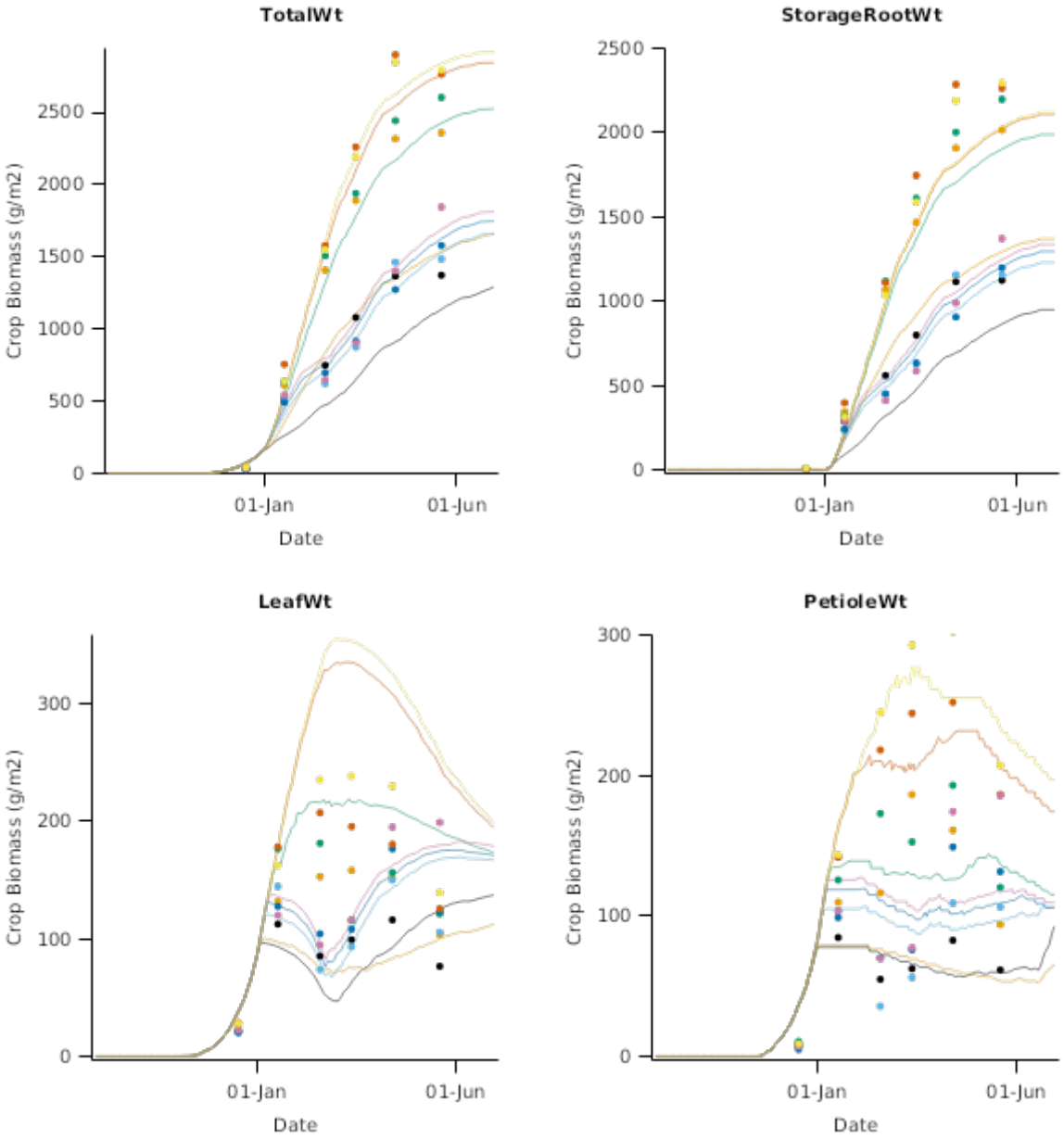
LeafWt

PetioleWt

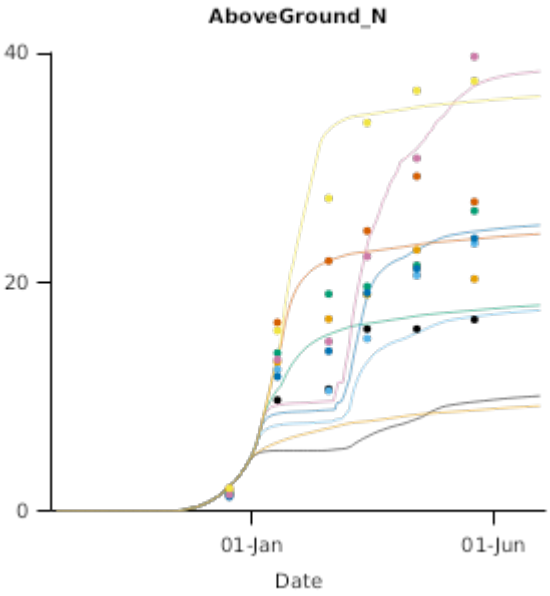
2.2.2.3 LeafGraphs

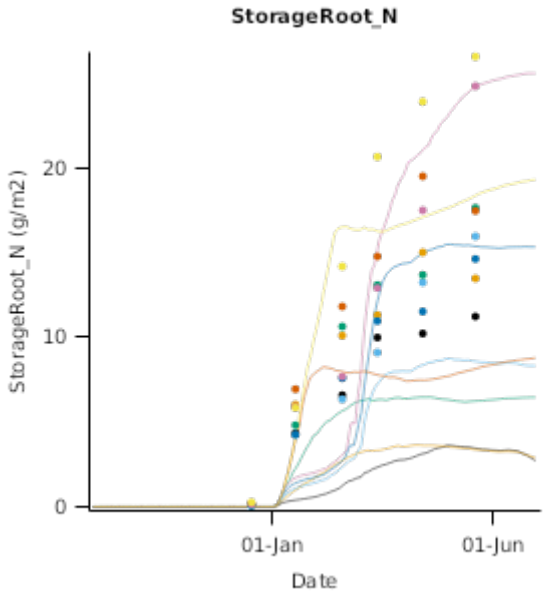


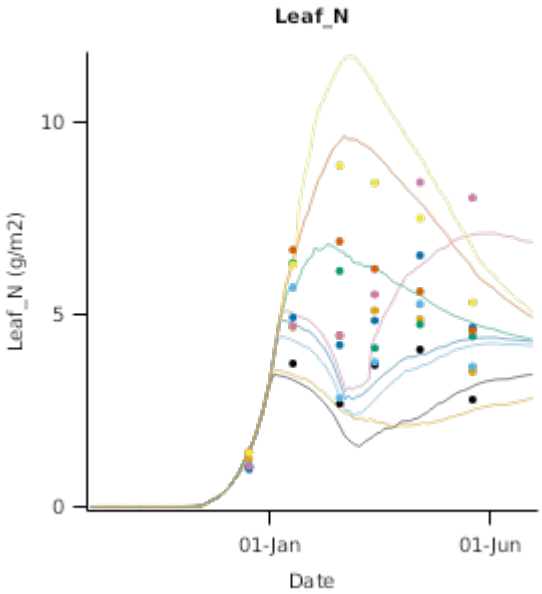
2.2.2.4 BiomassGraphs

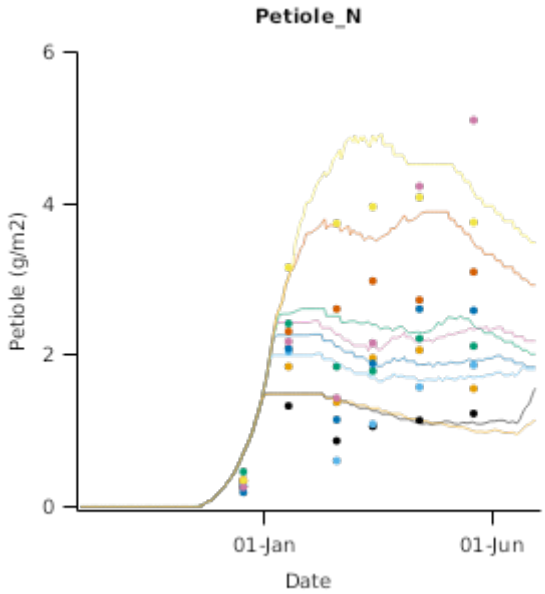


2.2.2.5 N_Uptake









2.2.3 SFF

The data (unpublished)used here is from a SFF experiment managed by de Ruiter et al.

2.2.3.1 Canterbury

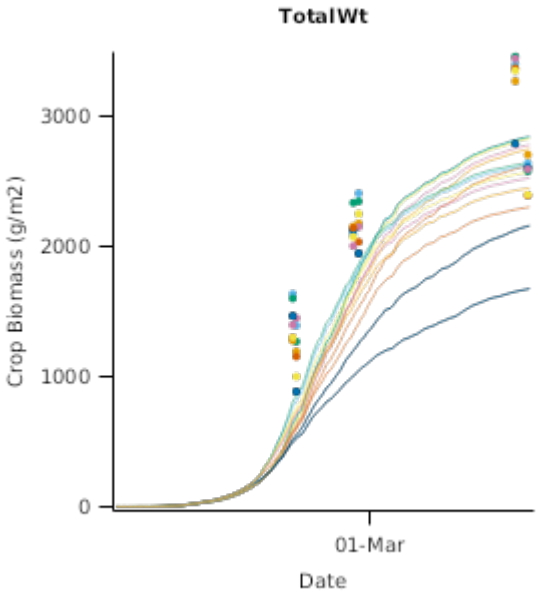
2.2.3.1.1 List of experiments

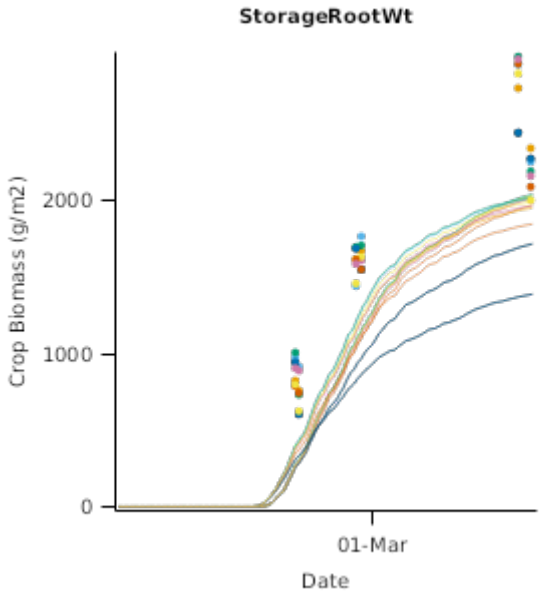
Experiment Name	Design (Number of Treatments)
Orari	Nit x Splits (8)
Rakaia	Nit x Splits (8)

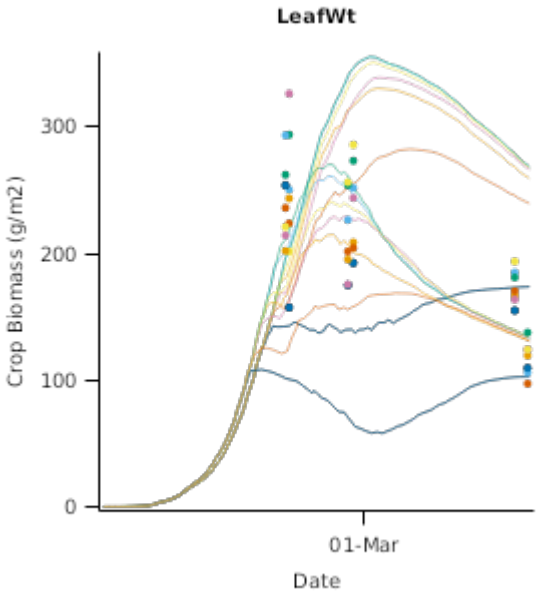
2.2.3.1.2 Orari

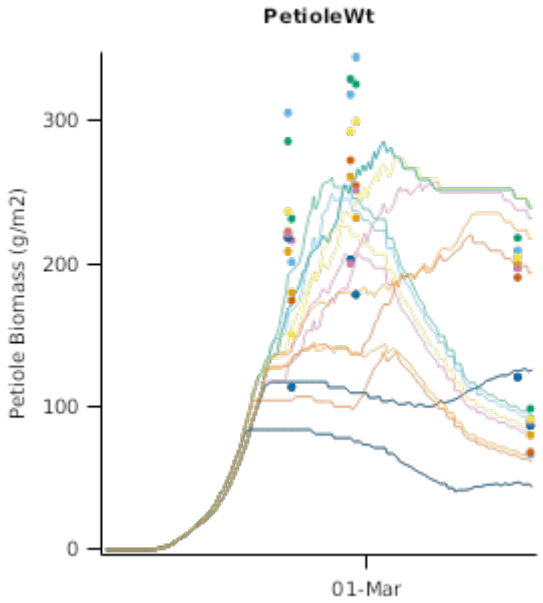
The data used here is from a SFF experiment (Batty; Winchester)managed by de Ruiter et al.

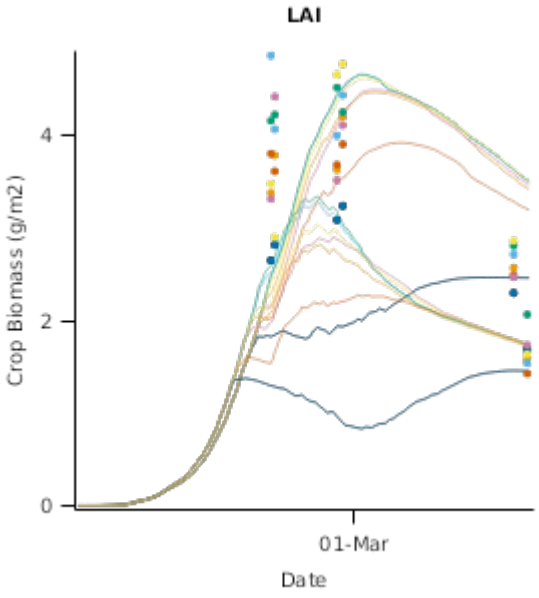
2.2.3.1.3 Graphs

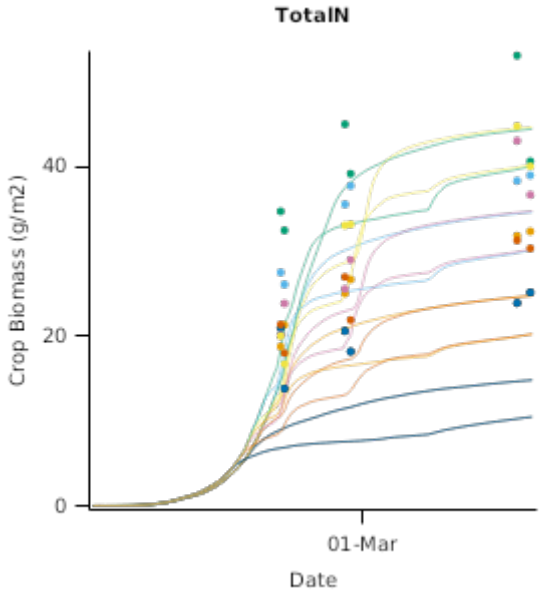










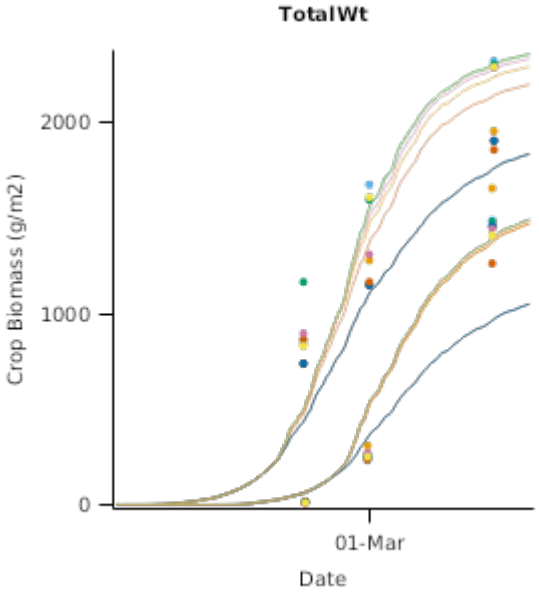


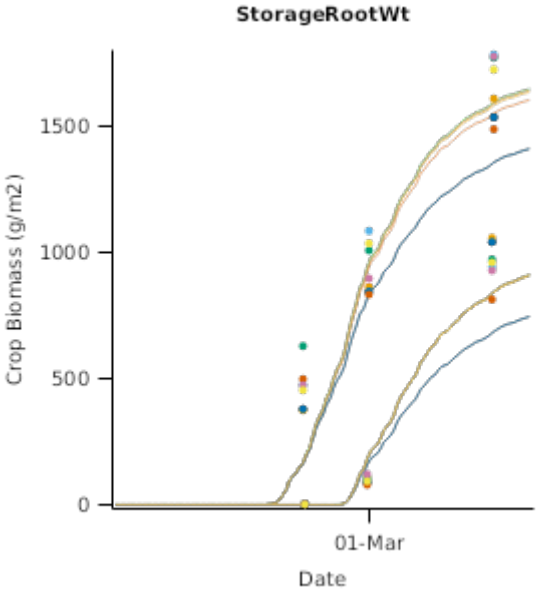
2.2.3.2 Southland

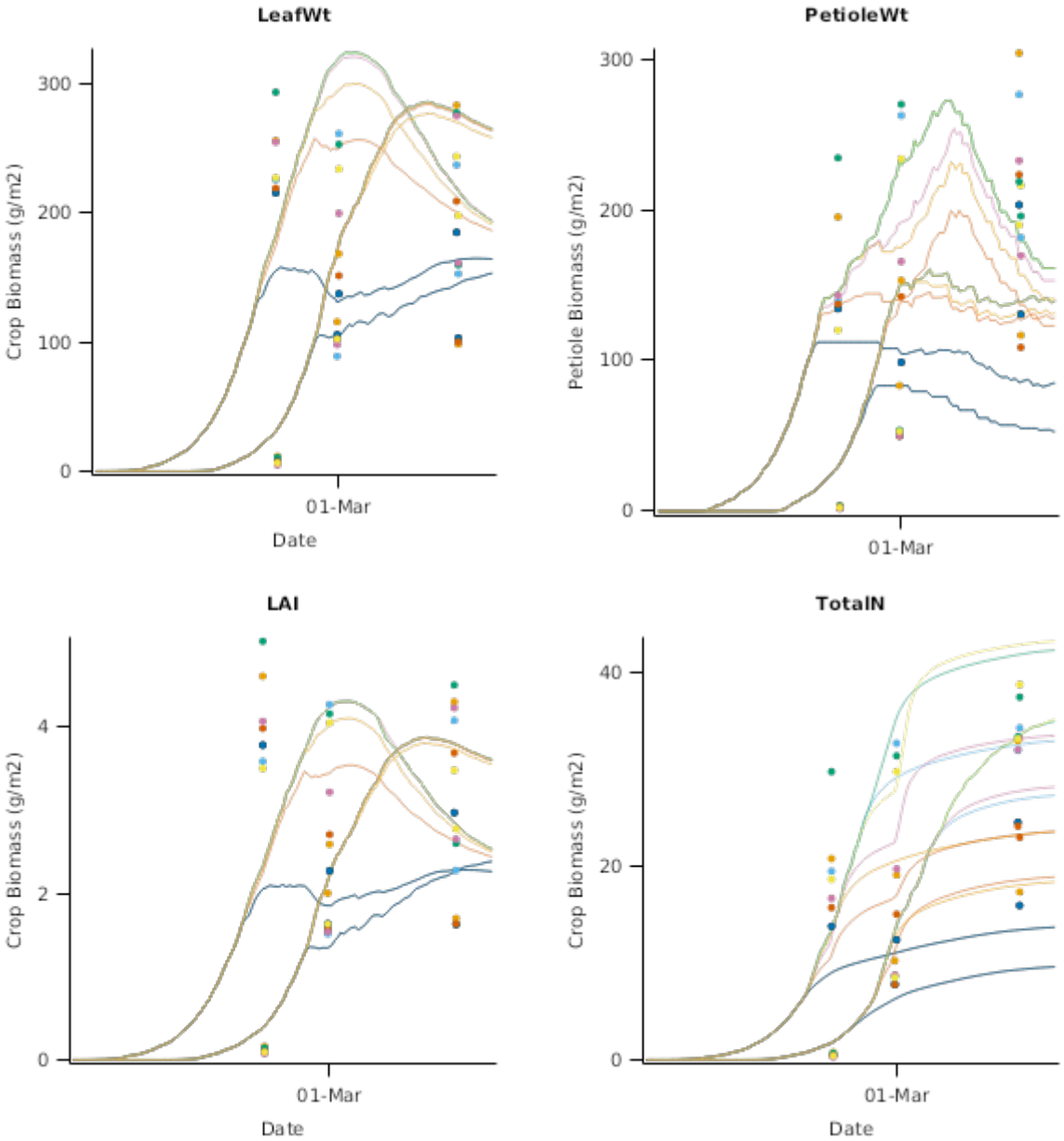
2.2.3.2.1 List of experiments

Experiment Name	Design (Number of Treatments)
Gore	Nit x Splits (8)
Riverton	Nit x Splits (8)

2.2.3.2.2 Graphs





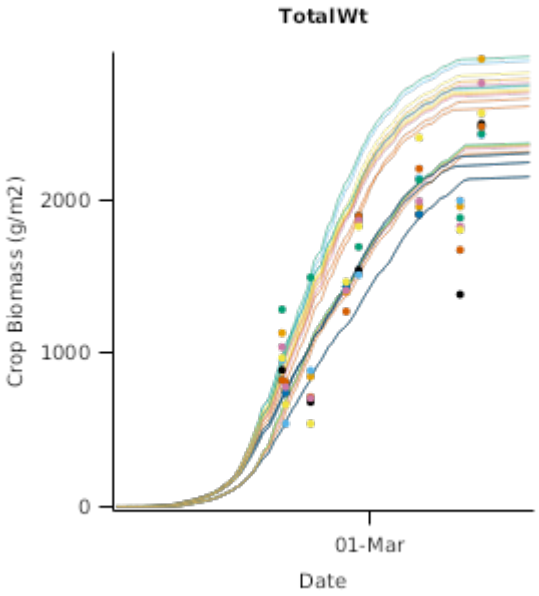


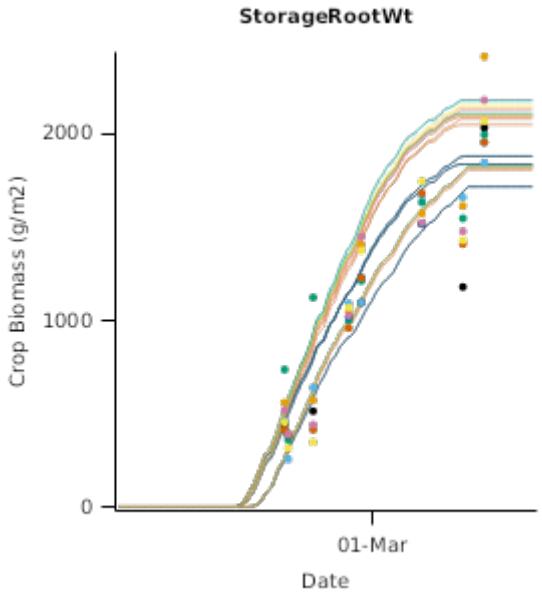
2.2.3.3 NorthIsland

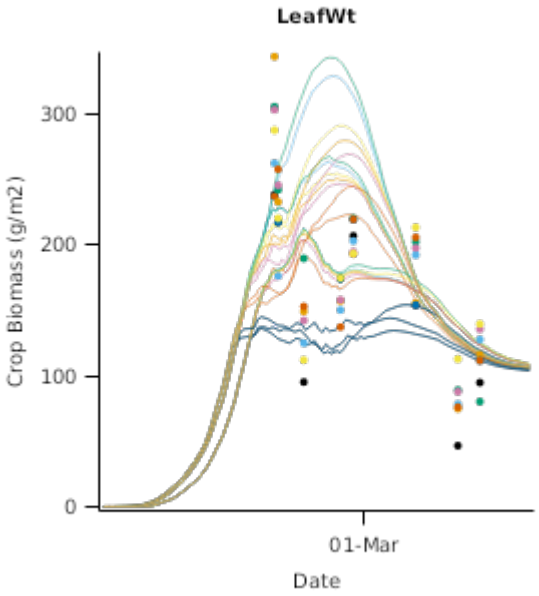
2.2.3.3.1 List of experiments

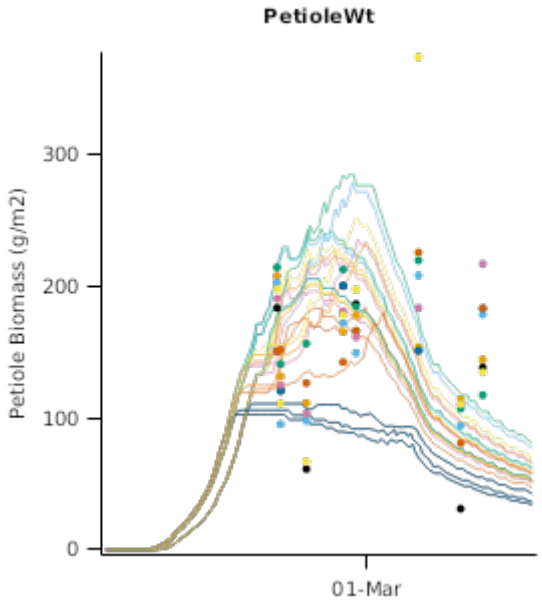
Experiment Name	Design (Number of Treatments)
Taranaki	Nit x Splits (8)
Waikato	Nit x Splits (8)
Whanganui	Nit x Splits (8)

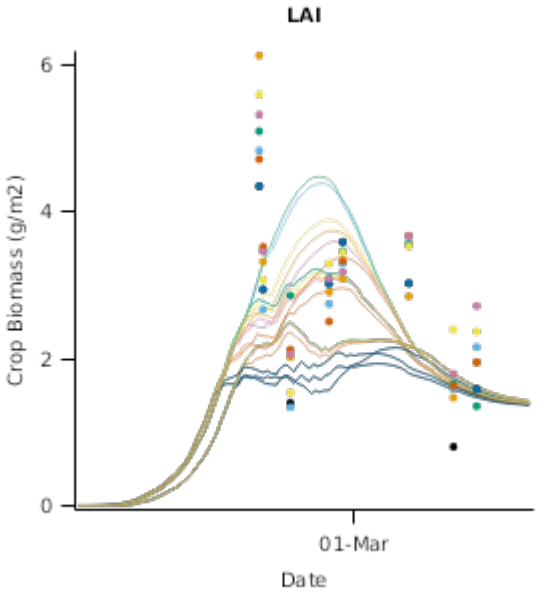
2.2.3.3.2 Graphs

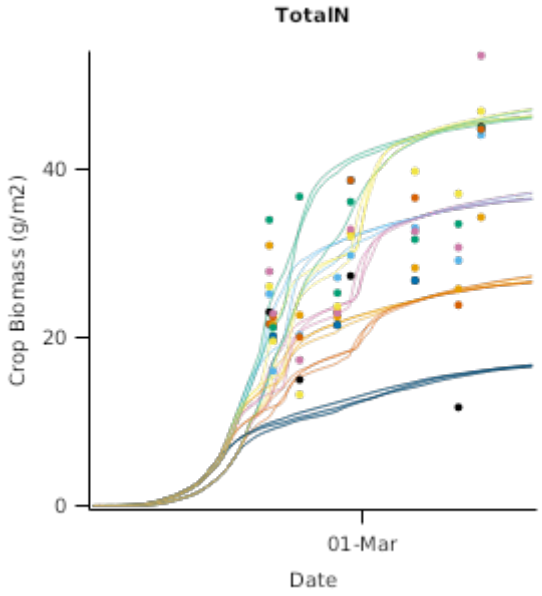










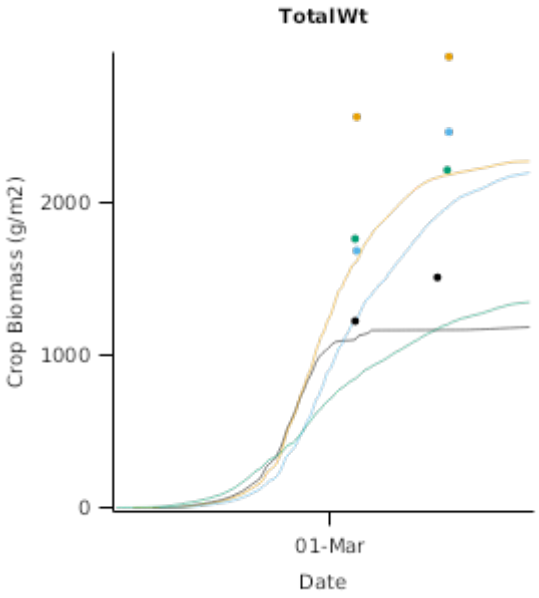


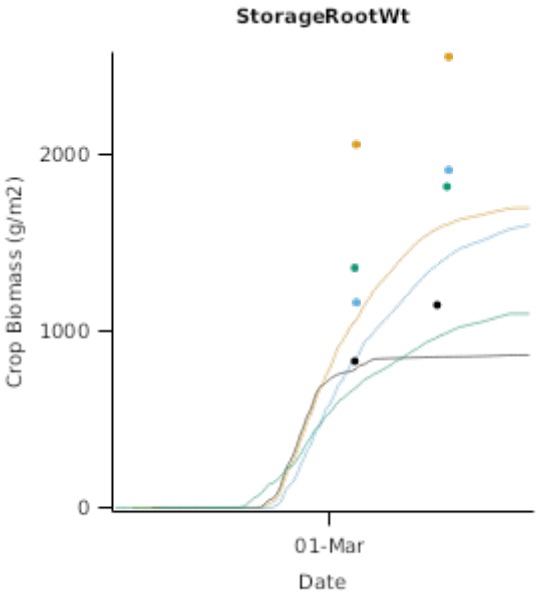
2.2.4 P21EXT

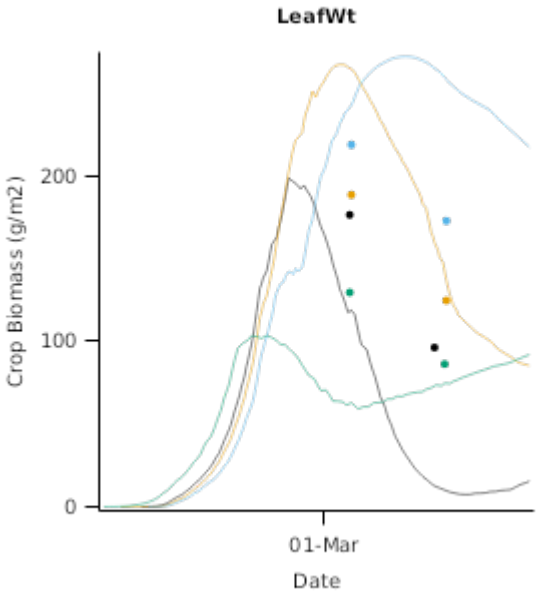
This was an extension of the P21 project

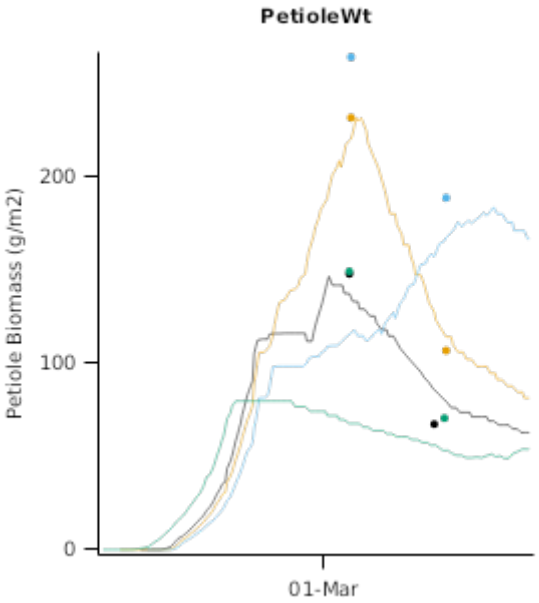
2.2.4.1 Canterbury

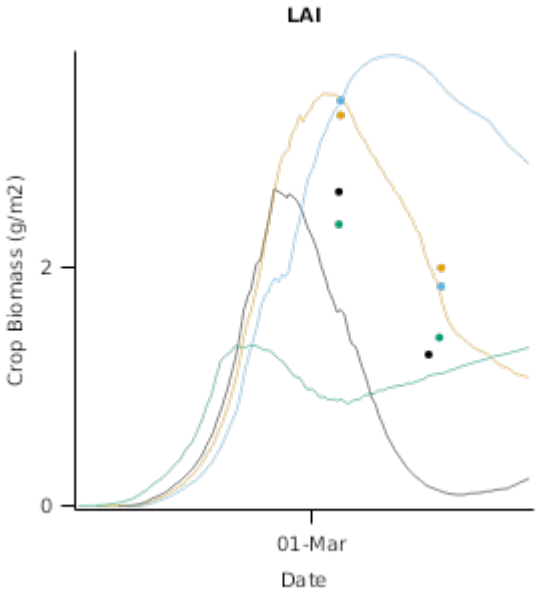
2.2.4.1.1 Graphs





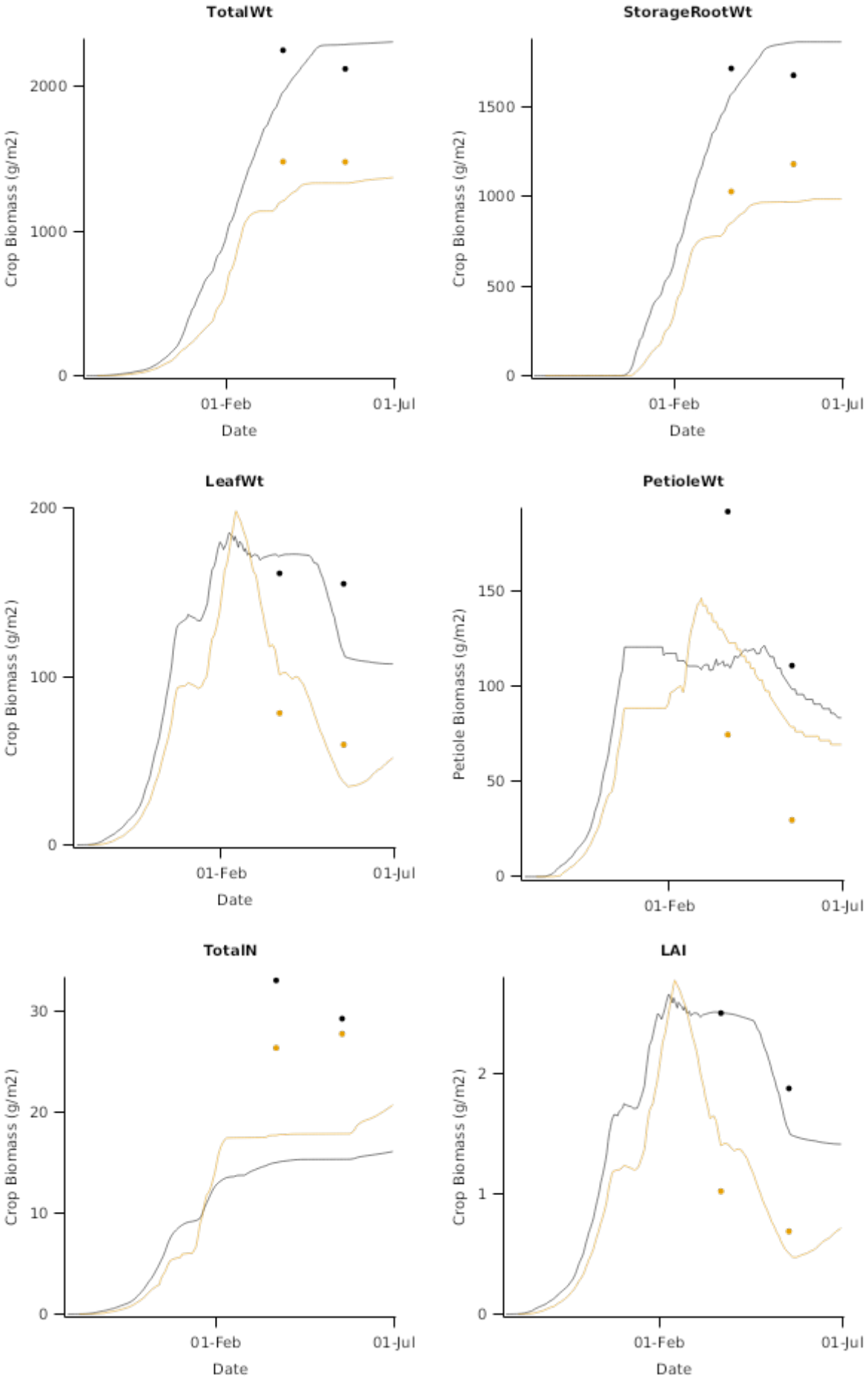






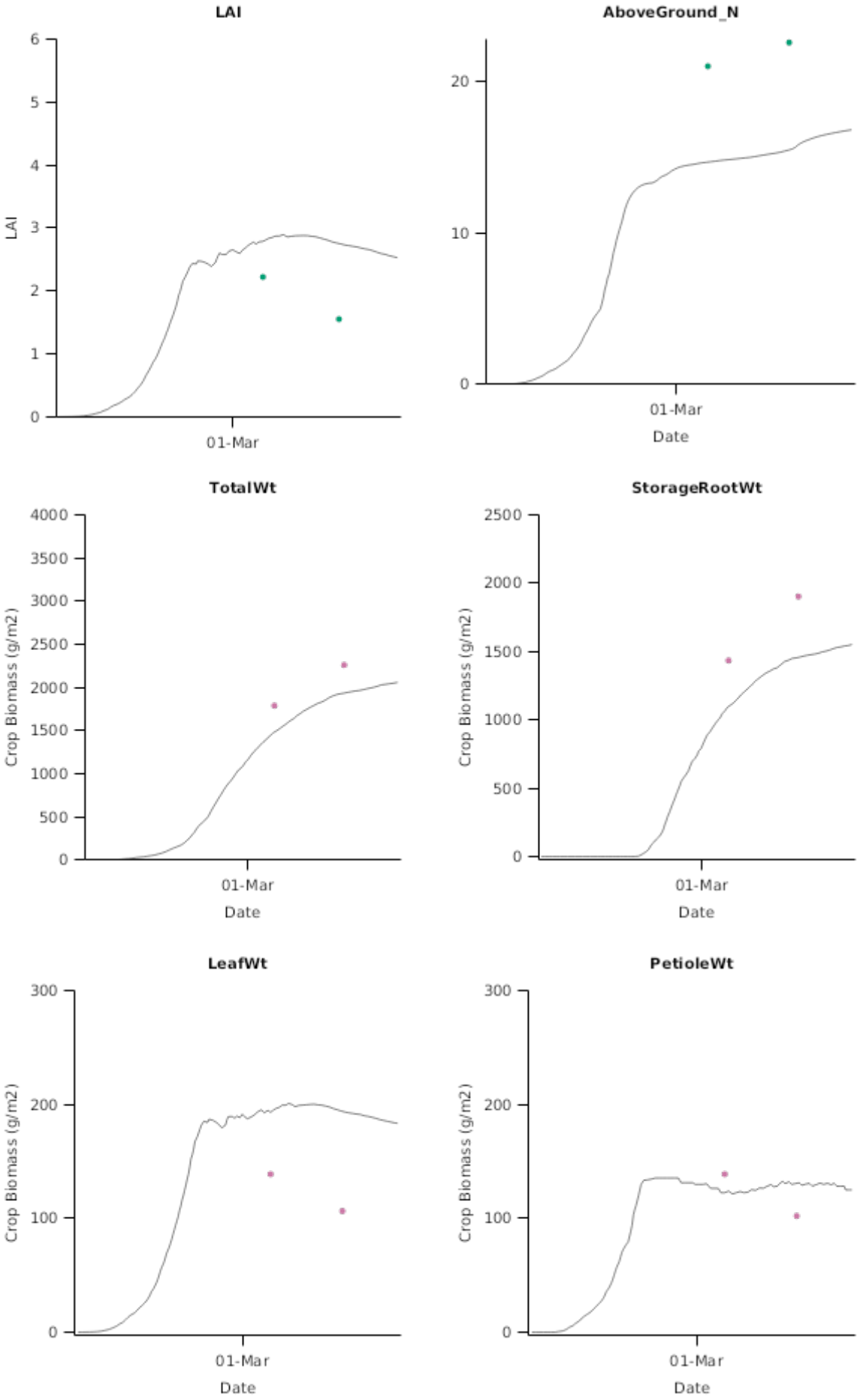
2.2.4.2 NorthOtago

2.2.4.2.1 Graphs

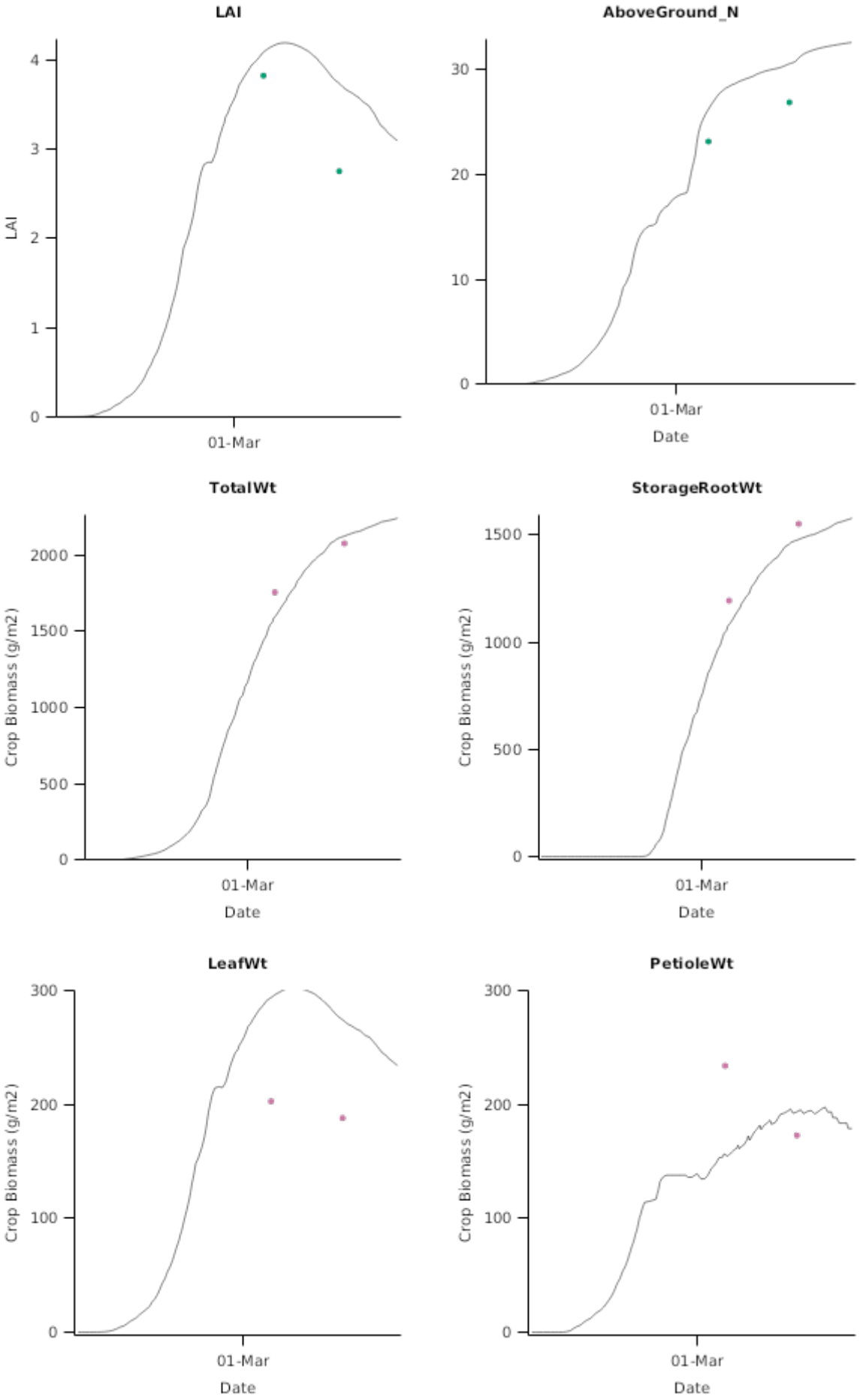


2.2.4.3 Southland

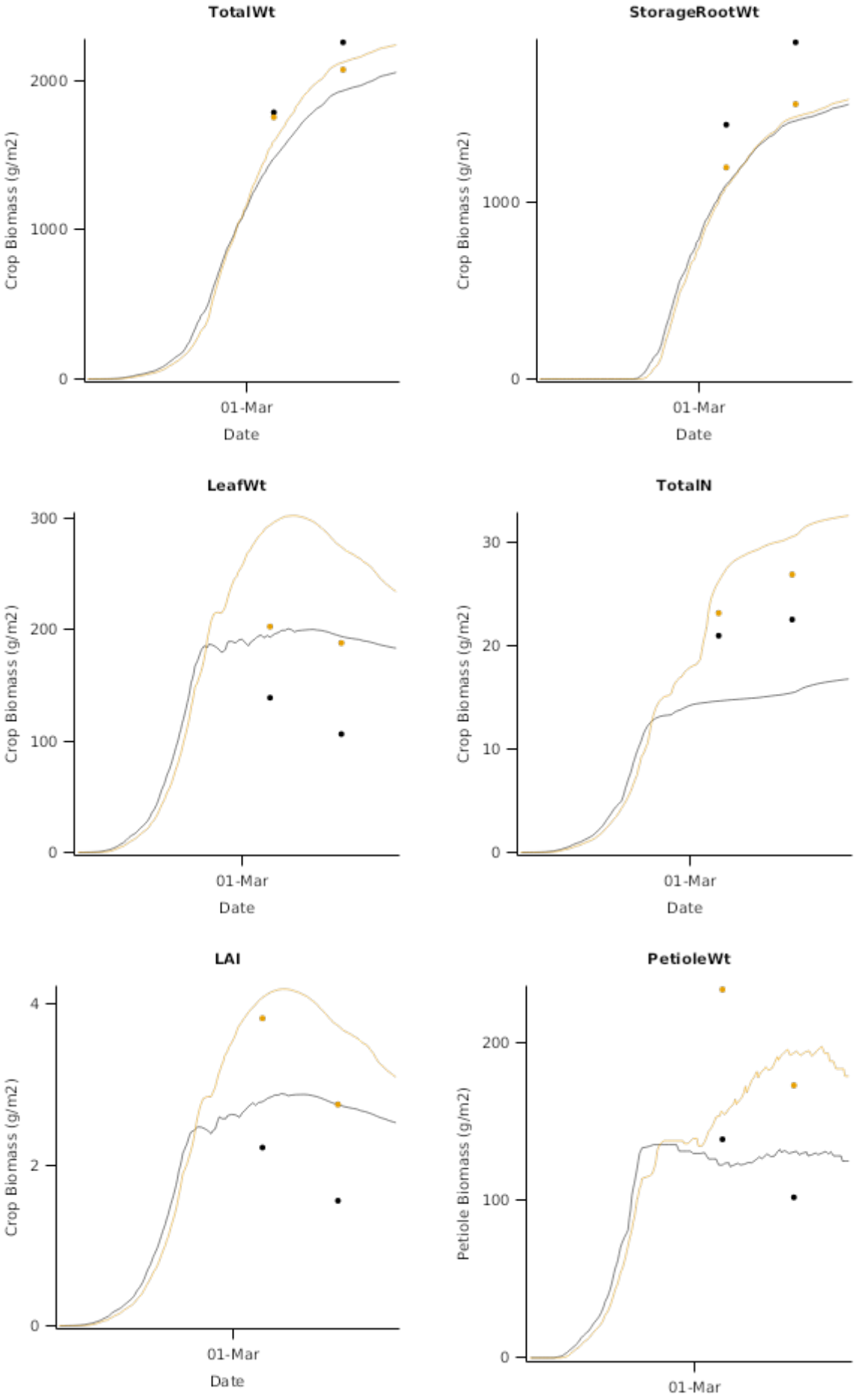
2.2.4.3.1 Balfour_P21ext



2.2.4.3.2 Gore_P21ext

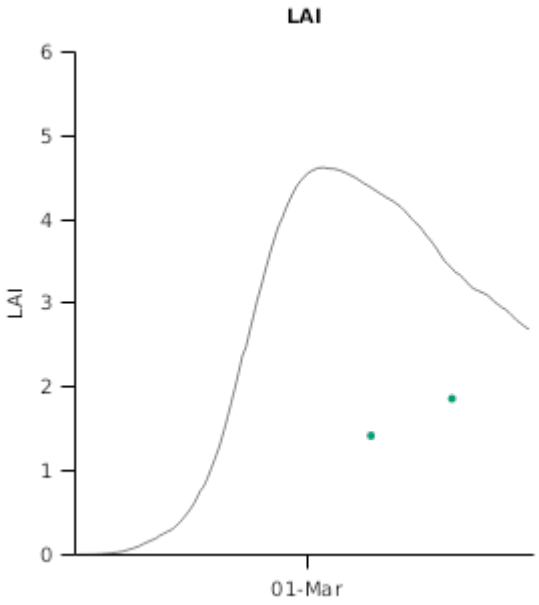


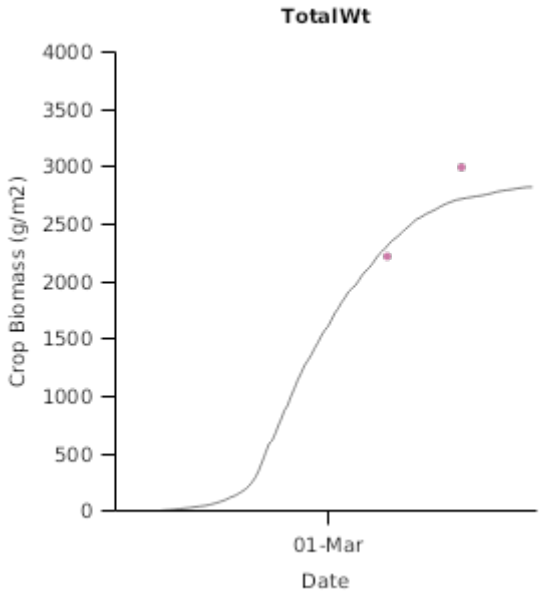
2.2.4.3.3 Graphs

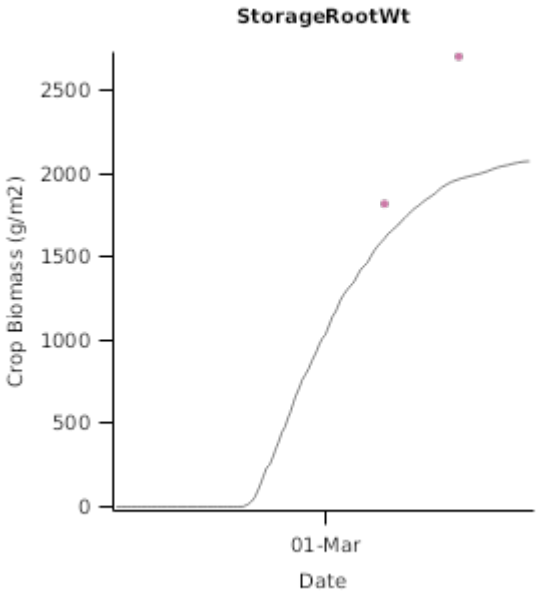


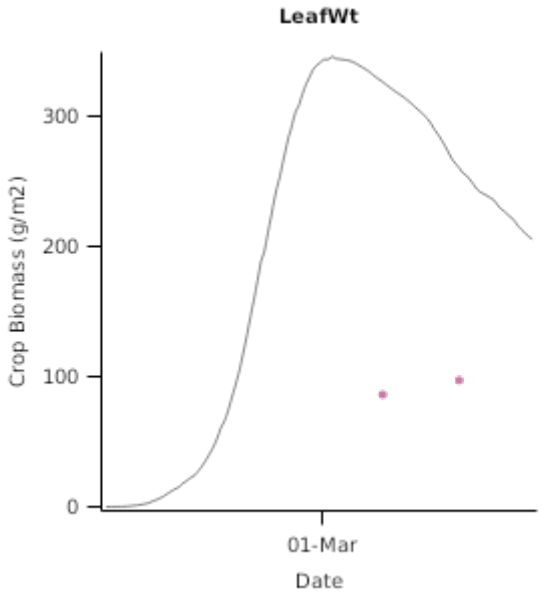
2.2.4.4 NorthIsland

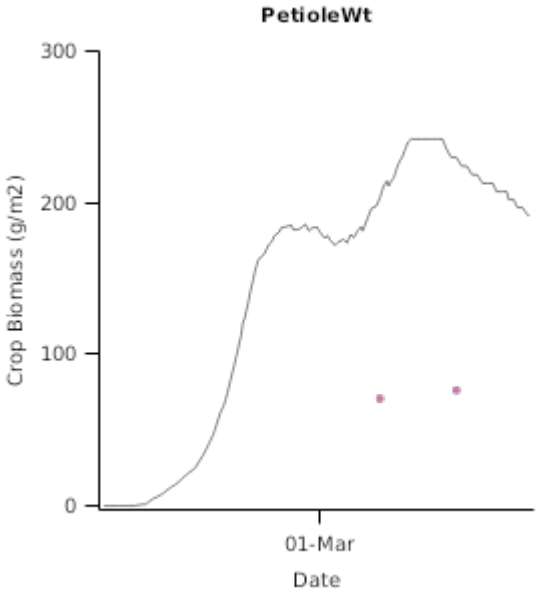
2.2.4.4.1 Manawatu_P21ext



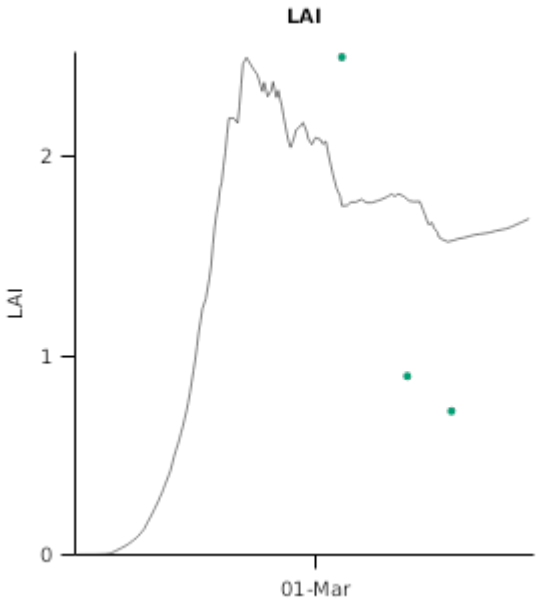


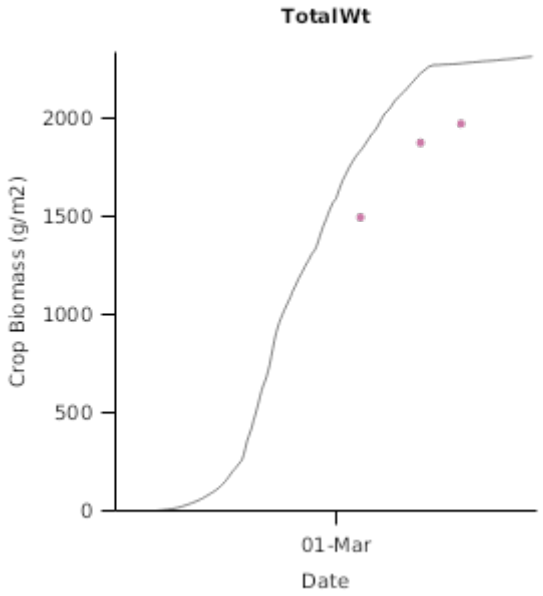


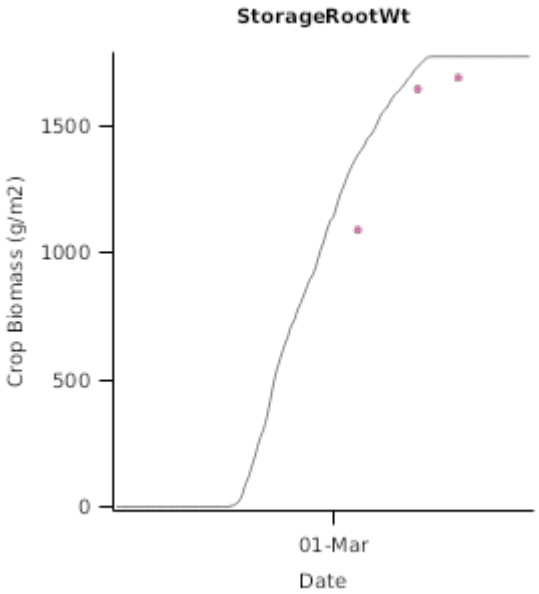


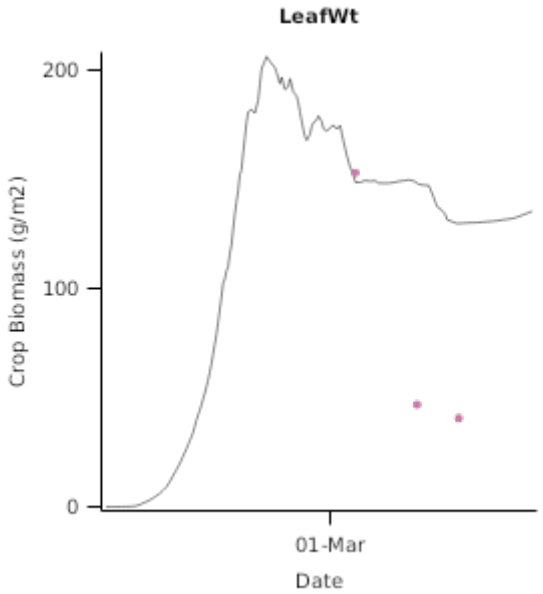


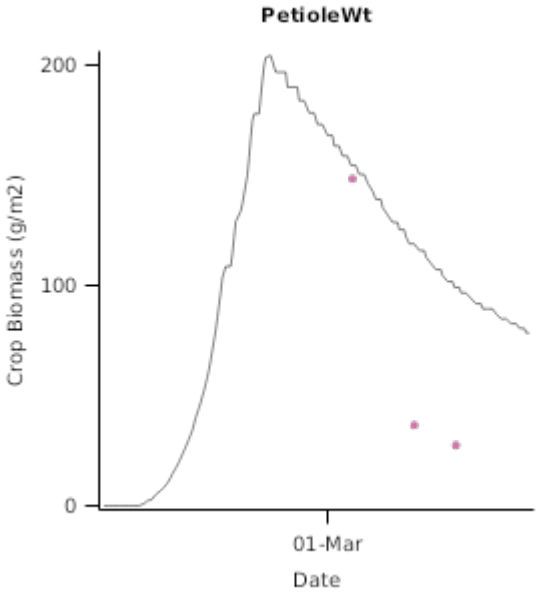
2.2.4.4.2 Waikato_P21ext



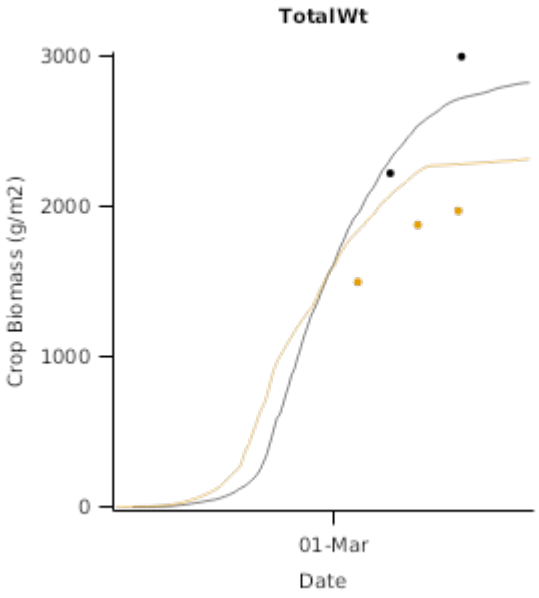


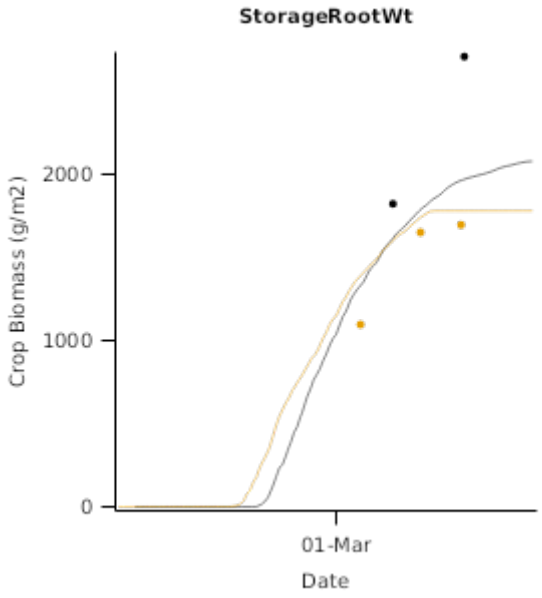


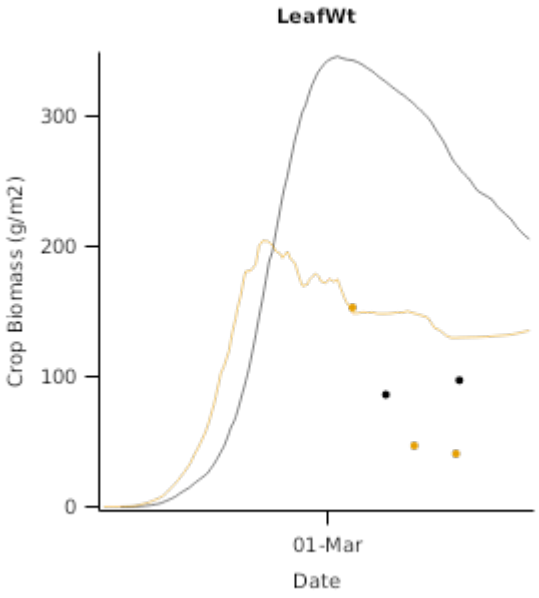


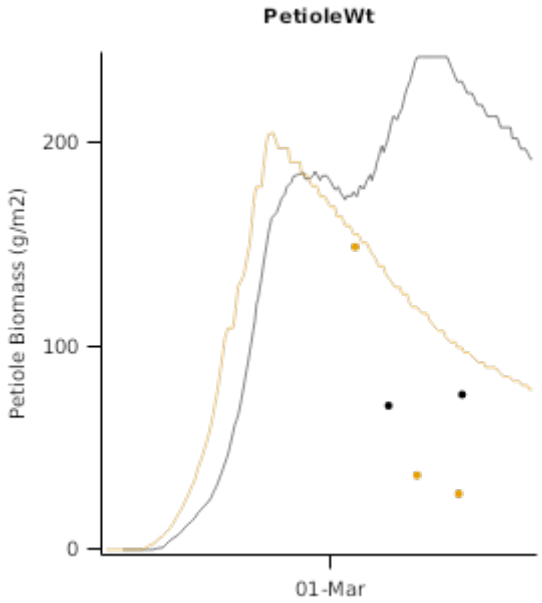


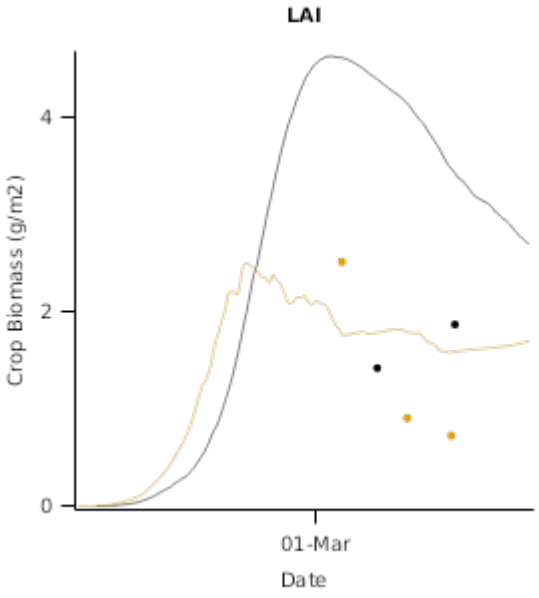
2.2.4.4.3 Graphs











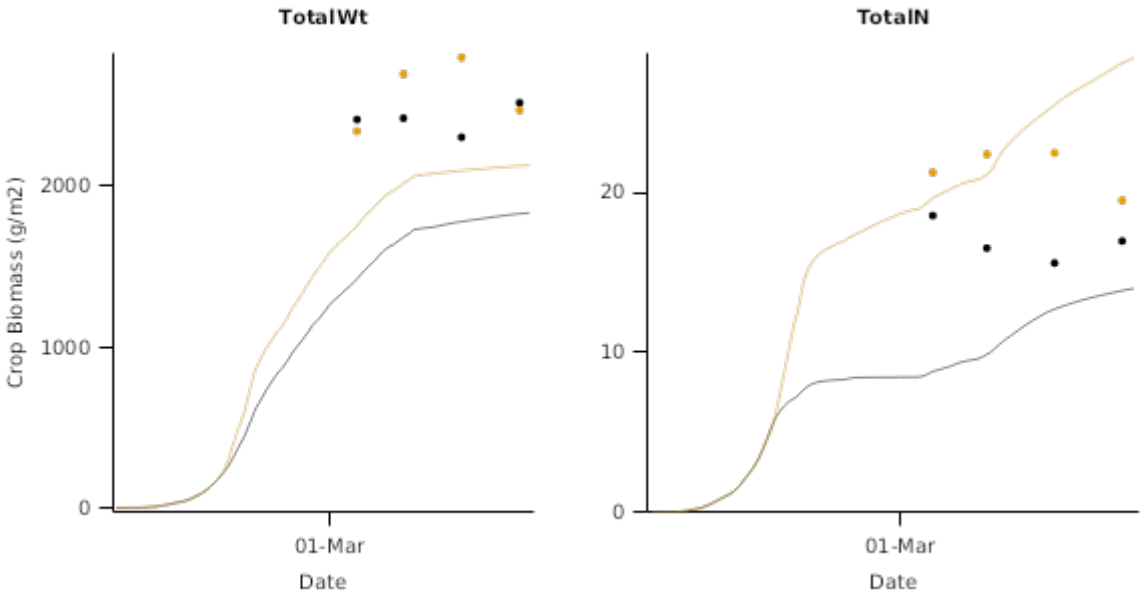
2.2.5 FRNL_NCRS

The data used here is from the FRNL trials managed by de Ruiter et al.

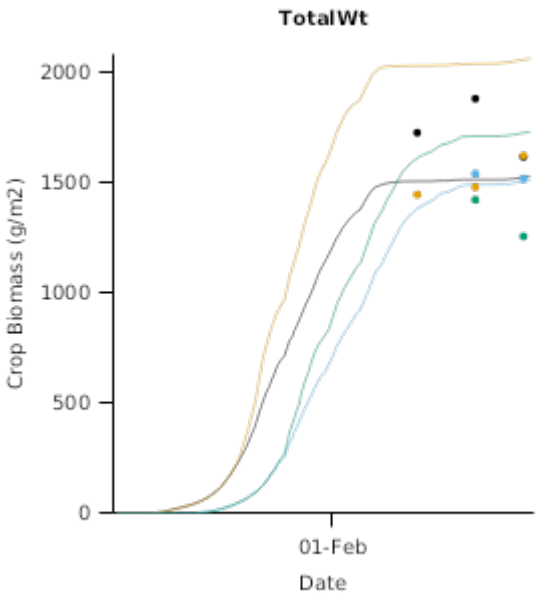
2.2.5.1 List of experiments

Experiment Name	Design (Number of Treatments)
FRNL_NCRS2014	Nit (2)
FRNL_NCRS2015	SD (4)

2.2.5.2 FRNL_NCRS2014



2.2.5.3 FRNL_NCRS2015



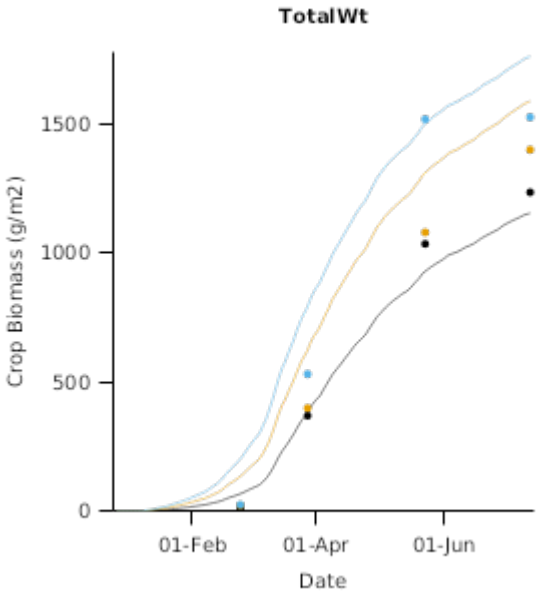
2.3 Australia

Fodder beet population experiment based on Pembleton & Rawnsley (2011) report. Three sowing (precision)rates (4, 8, 12 plants/m^2) were evaluated.

2.3.1 List of experiments

Experiment Name	Design (Number of Treatments)
Irishtown	Pop (3)

2.3.2 BiomassGraphs



2.4 NewZealand_Sensitivity

2.4.1 LincolnSens

2.4.1.1 List of experiments

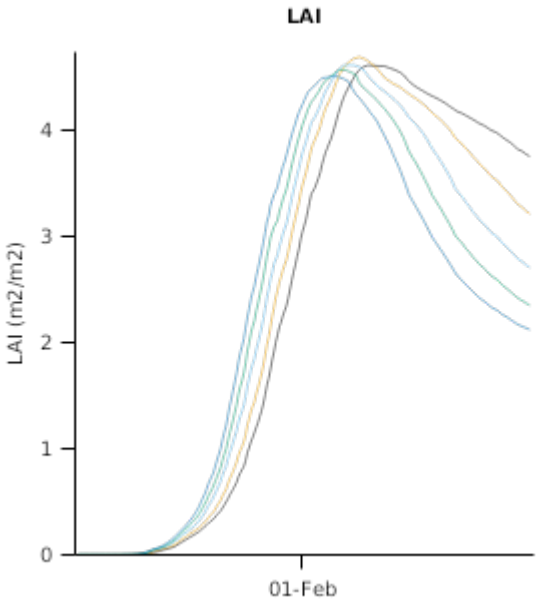
Experiment Name	Design (Number of Treatments)
Lincoln2016Temp	Temperature (5)
Lincoln2016Extinc	KCoefficent (8)

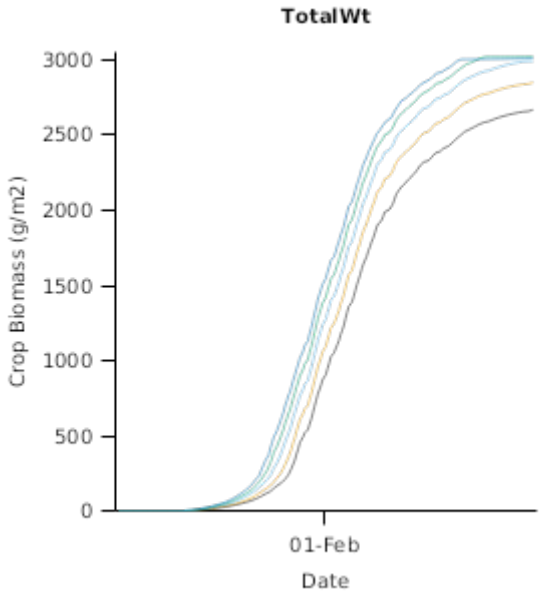
2.4.1.2 Lincoln2016Temp

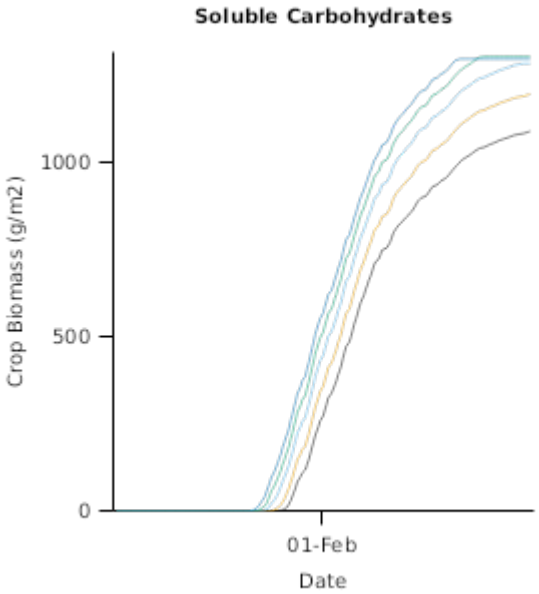
This trial was conducted in the rainshelter at Plant and Food Research in Lincoln, New Zealand in 2016. The objective was to evaluate the effect of nitrogen and irrigation on the development and growth of fodder beet crops.
Details:

â€¢ Three nitrogen treatments: 0 kg N/ha, 50 kg N/ha & 300 kg N/ha applied as dissolved urea with fertigation
â€¢ Two irrigation treatments: Nil and full irrigation

Fodder beet (cultiva "Rivage") was precision drilled on 18 October 2016. Sowing density was 11 plants/m2 and row spacing was 0.45m.





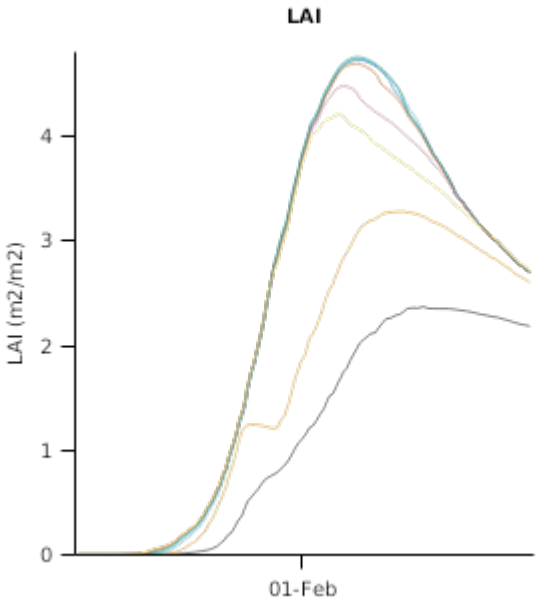


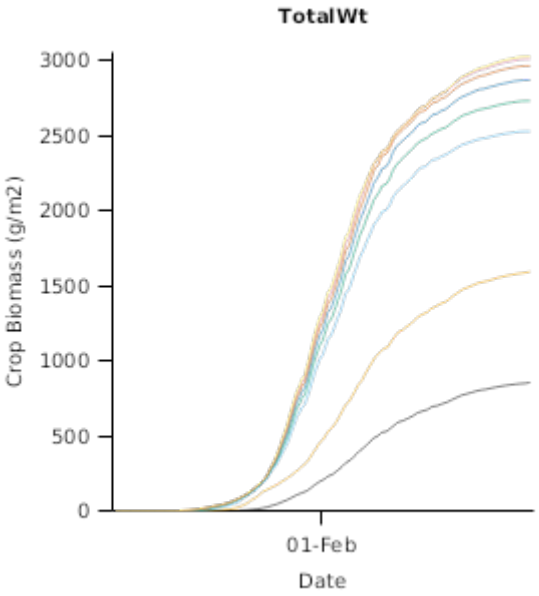
2.4.1.3 Lincoln2016Extinc

This trial was conducted in the rainshelter at Plant and Food Research in Lincoln, New Zealand in 2016. The objective was to evaluate the effect of nitrogen and irrigation on the development and growth of fodder beet crops.
Details:

â€¢ Three nitrogen treatments: 0 kg N/ha, 50 kg N/ha & 300 kg N/ha applied as dissolved urea with fertigation
â€¢ Two irrigation treatments: Nil and full irrigation

Fodder beet (cultiva "Rivage") was precision drilled on 18 October 2016. Sowing density was 11 plants/m2 and row spacing was 0.45m.



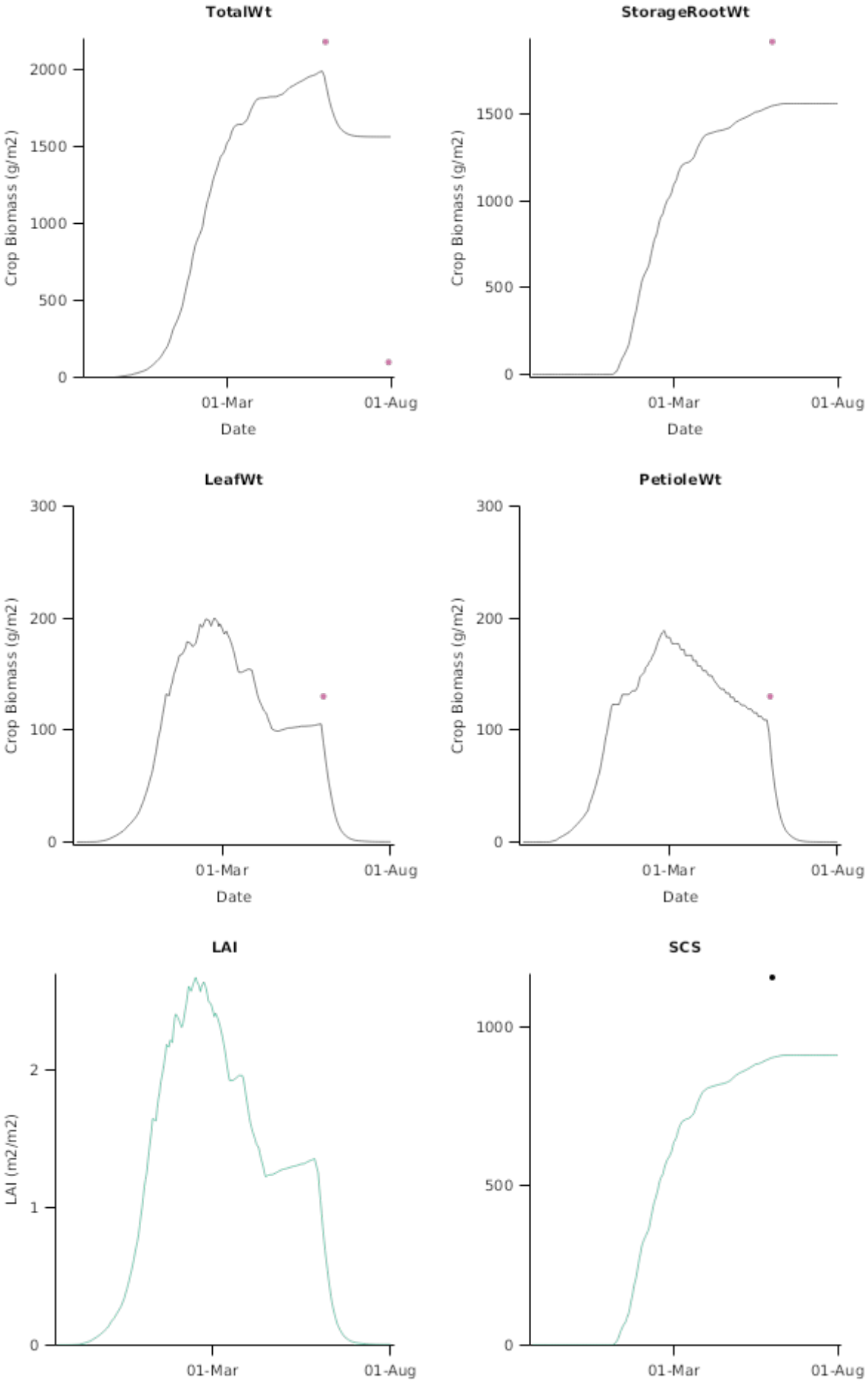


2.5 GrazingExample

2.5.1 AshleyDene2013

This represents a Grazing trial at Ashley Dene, Canterbury, New Zealand

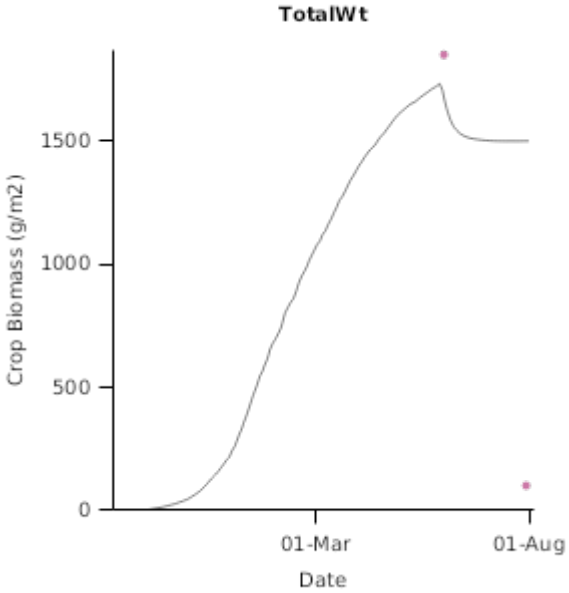
Management and Data from Edwards, G.R., J.M., d.R., Dalley, D.E., Pinxterhuis, J.B., Cameron, K.C., Bryant, R.H., Di, H.J., Malcolm, B.J.and Chapman, D.F. 2014. Dry matter intake and body condition score change of dairy cows grazing fodder beet, kale and kale-oat forage systems in winter. Proceedings of the New Zealand Grassland Association 76: 81-88.

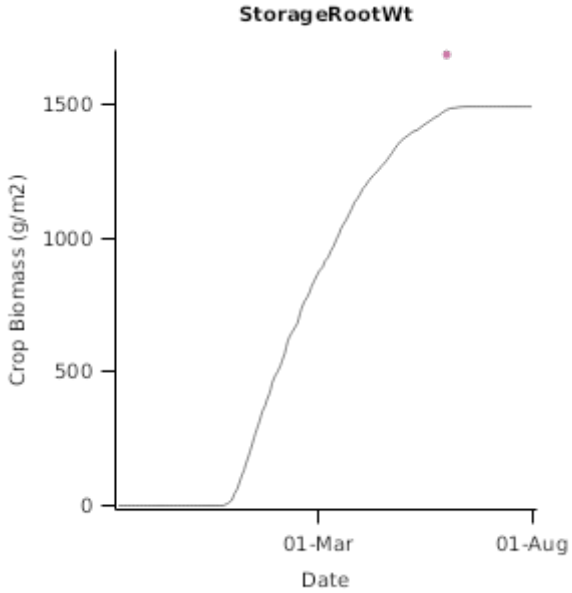


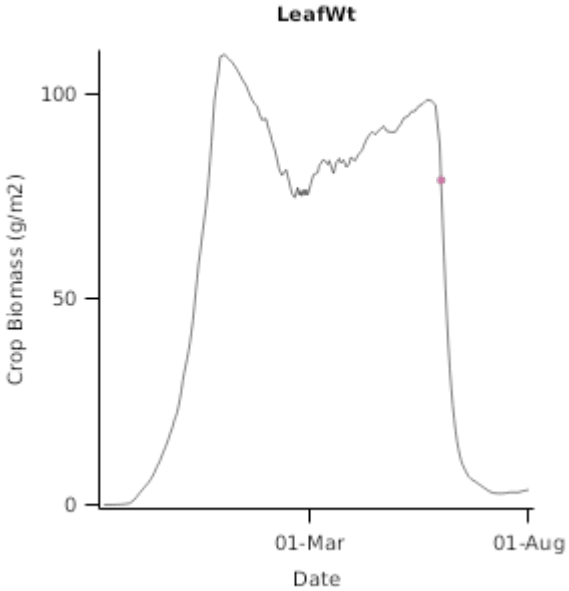
2.5.2 AshleyDene2012

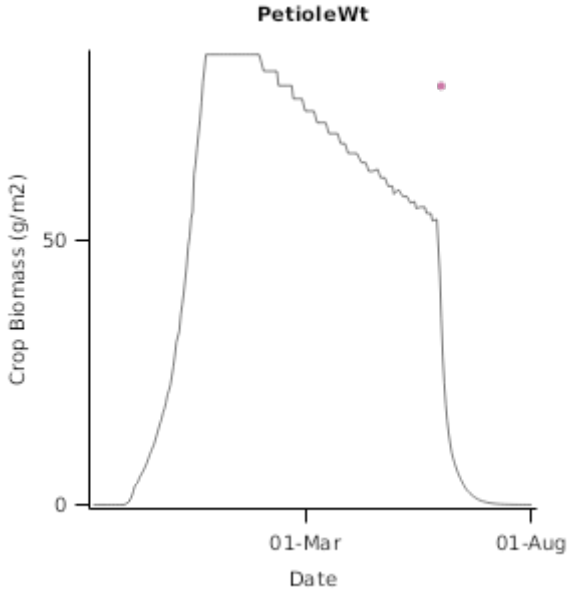
This represebts a Grazing trial at Ashley Dene, Canterbury, New Zealand

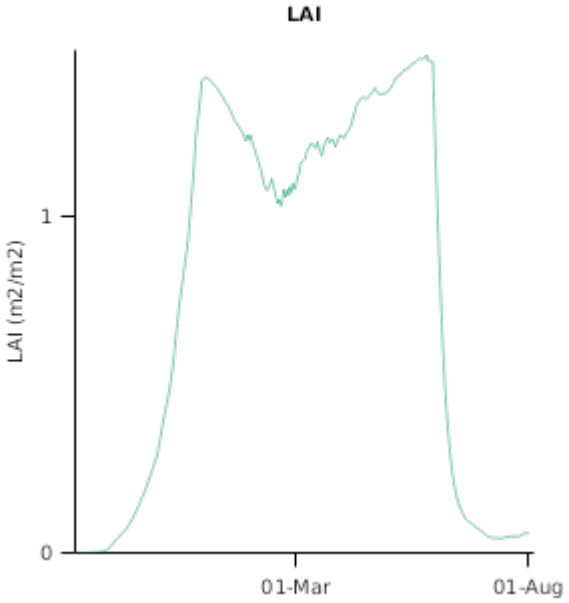
Management and Data from Edwards, G.R., J.M., d.R., Dalley, D.E., Pinxterhuis, J.B., Cameron, K.C., Bryant, R.H., Di, H.J., Malcolm, B.J.and Chapman, D.F. 2014. Dry matter intake and body condition score change of dairy cows grazing fodder beet, kale and kale-oat forage systems in winter. Proceedings of the New Zealand Grassland Association 76: 81-88.

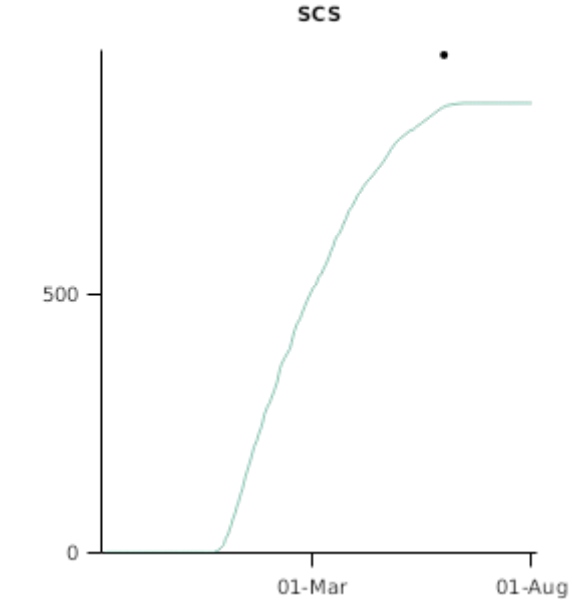












3 References

Brown, Hamish E., Huth, Neil I., Holzworth, Dean P., Teixeira, Edmar I., Zyskowski, Rob F., Hargreaves, John N. G., Moot, Derrick J., 2014. Plant Modelling Framework: Software for building and running crop models on the APSIM platform. Environmental Modelling and Software 62, 385-398.

Chakwizira, E. de Ruiter, J. M. Maley, S. Dellow, S. J. George, M.J., Michel, A.J., 2014. Water use efficiency of fodder beet crops. Proceedings of New Zealand Grassland Association 76, 125-134.

Chakwizira, E. de Ruiter, J. M., Maley, S., 2014. Growth, nitrogen partitioning and nutritive value of fodder beet crops grown under different application rates of nitrogen fertiliser. New Zealand Journal of Agricultural Research 57, 75-89.

Chakwizira, E., Dellow, S. J., Teixeira, E. I., 2016. Quantifying canopy formation processes in fodder beet (Beta vulgaris subsp. vulgaris var. alba L.) crops. European Journal of Agronomy 74, 144-154.

Khaembah, E. N. Brown, H. E. Zyskowski, R. Chakwizira, E. de Ruiter, J. M., Teixeira, E. I., 2017. Development of a fodder beet potential yield model in the next generation APSIM. Agricultural Systems 158, 23-38.

Lawless, Conor, Semenov, MA, Jamieson, PD, 2005. A wheat canopy model linking leaf area and phenology. European Journal of Agronomy 22 (1), 19-32.