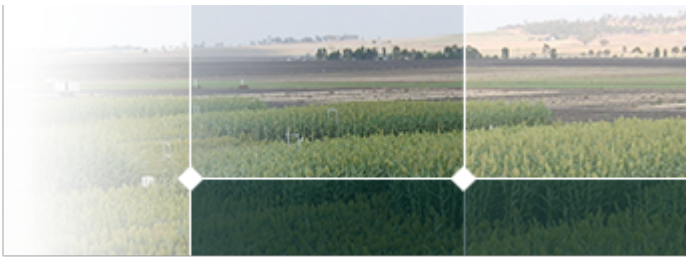


1 The APSIM Barley Model

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.

Brown, H.E., Huth, N.I., Khaembah E.N., Zyskowski, R., and Holzworth, D.P.

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
Grain	Models.PMF.Organs.ReproductiveOrgan
Root	Models.PMF.Organs.Root
Leaf	Models.PMF.Organs.Leaf
Spike	Models.PMF.Organs.GenericOrgan
Stem	Models.PMF.Organs.GenericOrgan
MortalityRate	Models.Functions.Constant
SeedMortalityRate	Models.Functions.Constant

1.2 Composite Biomass

Component Name	Component Type
AboveGround	Models.PMF.CompositeBiomass
AboveGroundLive	Models.PMF.CompositeBiomass
AboveGroundDead	Models.PMF.CompositeBiomass
BelowGround	Models.PMF.CompositeBiomass
Total	Models.PMF.CompositeBiomass
TotalLive	Models.PMF.CompositeBiomass
TotalDead	Models.PMF.CompositeBiomass
Ear	Models.PMF.CompositeBiomass
StemPlusSpike	Models.PMF.CompositeBiomass

1.3 Cultivars

Cultivar Name	Alternative Name(s)
Booma	Booma
Bumpa	Bumpa
Boss	Boss
Cellar	Cellar
County	County
Dash	Dash
Doyen	Doyen
Hooded	Hooded
Omaka	Omaka
Omaka1	Omaka1
Optic	Optic
Pyramid	Pyramid
Quench	Quench
Retriever	Retriever
Sherwood	Sherwood
Tavern	Tavern
Triumph	Triumph
Valetta	Valetta
Vortex	Vortex
Alestar	Alestar
Banks	Banks
Baudin	Baudin
Bass	Bass
Biere	Biere
Buloke	Buloke
Cassiopee	Cassiopee
Capstan	Capstan
Commander	Commander
Compass	Compass
CSIROB1	CSIROB1
CSIROB3	CSIROB3
Dash	Dash
Fathom	Fathom

Cultivar Name	Alternative Name(s)
Fleet	Fleet
Flinders	Flinders
Franklin	Franklin
Gairdner	Gairdner
Granger	Granger
Grimmett	Grimmett
Grout	Grout
Hindmarsh	Hindmarsh
Keel	Keel
Lockyer	Lockyer
Mundah	Mundah
Navigator	Navigator
Oxford	Oxford
RGT_Planet	RGT_Planet,Planet
Rosalind	Rosalind
Schooner	Schooner
Scope	Scope
Shepherd	Shepherd
Spartacus_CL	Spartacus_CL,Spartacus
Stirling	Stirling
Unicorn	Unicorn
Urambie	Urambie
Westminster	Westminster
Yagan	Yagan

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.

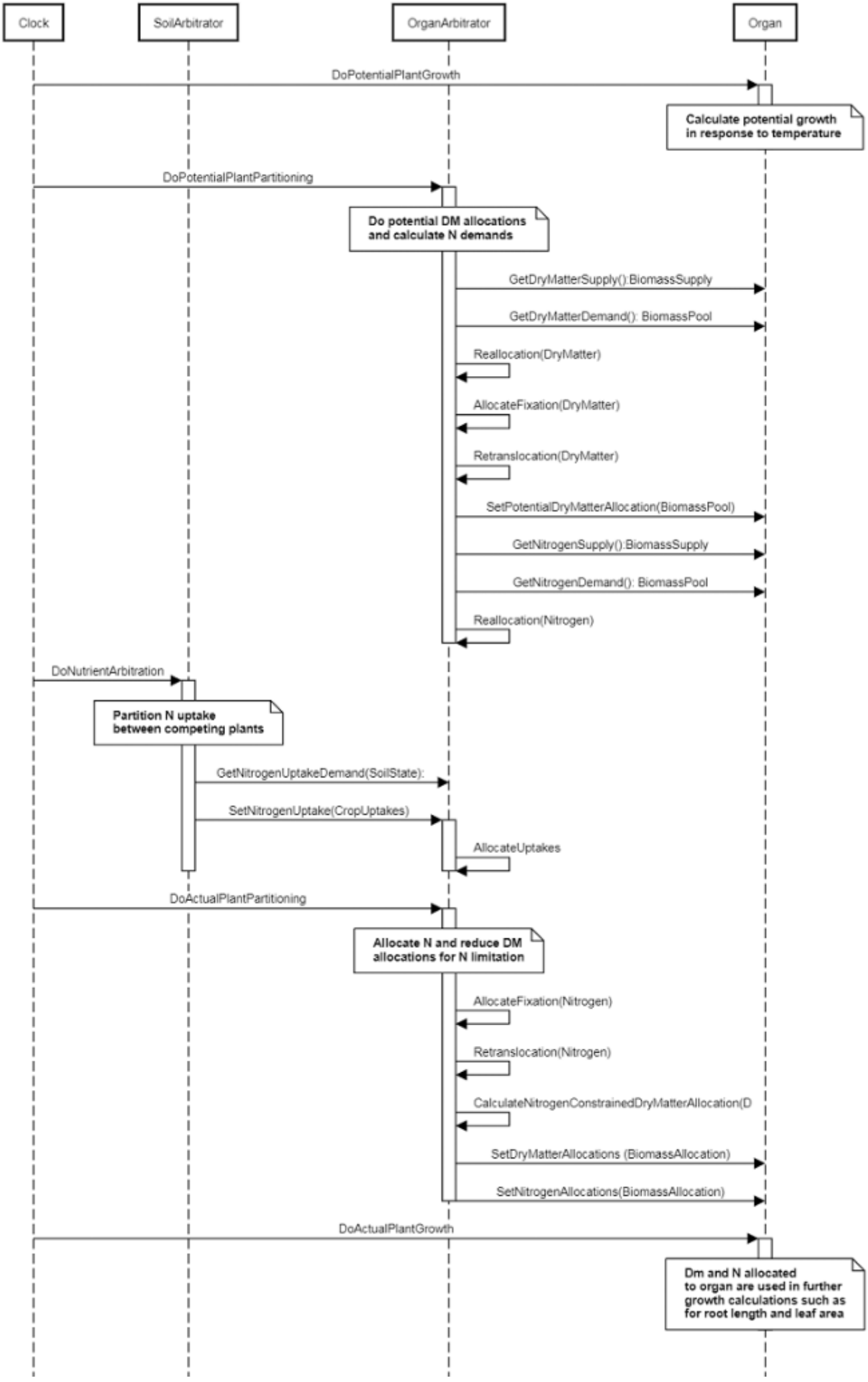

Clock
SoilArbitrator
OrganArbitrator
Organ
DoPotentialPlantGrowth
Calculate potential growth in response to temperature
DoPotentialPlantPartitioning
Do potential DM allocations and calculate N demands
GetDryMatterSupply():BiomassSupply
GetDryMatterDemand(): BiomassPool
Reallocation(DryMatter)
AllocateFixation(DryMatter)
Retranslocation(DryMatter)
SetPotentialDryMatterAllocation(BiomassPool)
GetNitrogenSupply():BiomassSupply
GetNitrogenDemand(): BiomassPool
Reallocation(Nitrogen)
DoNutrientArbitration
Partition N uptake between competing plants
GetNitrogenUptakeDemand(SoilState):
SetNitrogenUptake(CropUptakes)
AllocateUptakes
DoActualPlantPartitioning
Allocate N and reduce DM allocations for N limitation
AllocateFixation(Nitrogen)
Retranslocation(Nitrogen)
CalculateNitrogenConstrainedDryMatterAllocation(D
SetDryMatterAllocations (BiomassAllocation)
SetNitrogenAllocations(BiomassAllocation)
DoActualPlantGrowth
Dm and N allocated to organ are used in further growth calculations such as for root length and leaf area

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.

1.4.2 Phenology

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

Barley exhibits a range of developmental responses to environment and these are strongly influences by genotype characteristics. Temperature effects development increasing development rates and decreasing phase durations as temperatures increase. Theset affects are captured by thermal time, . However, Barley also exhibits vernalisation and photoperiod sensitivities in its Vegetative phase and further photoperiod sensitivity in the EarlyReproducivePhase. Photoperiod responses are seen as a reduction in the length of a phase for a photoperiod sensitive genotype in response to a longer photoperiod. For vernalisation sensitive varieties (Winter types) exposure to cool temperatures or short photoperiods during the Vegetative phase will reduce the thermal time duration of the vegetative phase.

This model draws on the Kirby Framework to capture these vernalisation and photoperiod responses. This framework assumes that the timing of anthesis is a result of the timing of flag leaf and an additional thermal time passage from there to anthesis. It also assumes the timing of flag leaf is a result of the Final Leaf Number which sets a target, and leaf appearance rate, which sets the rate of progress toward this target. Leaf appearance rate is a function of Thermal time and a genotype specific Phyllochron which changes with Haun stage (Jamieson et al., 1995).

Final Leaf Number (FLN) is modeled as the sum of three numbers:

FLN = MinLeafNumber + VernalLeaves + PhotoLeaves

Where MinLeafNumber is the number of leaves that a barley crop will produce when vernalisation is satisified early in the crops duration (before 2nd true leaf) and it is grown in a long photoperiod. VernalLeaves are the number of leaves that are added due to vernalisation effects. For insensitive varieties this will always be zero but this is potentially a larger number for sensitivie varieties and the number progresively decreases as the crop encounters more vernalisation. PhotoLeaves are the number of leaves that are added to the minimum leaf number as a result of short day exposure. For insensitive varieties this will be zero but is potential larger for more sensitivie varieties and decreases as day length increases. More detailed explinations of the components of phenology are provided below.

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.

Barley exhibits a range of developmental responses to environment and these are influences by genotype characteristics. Temperature effects development increasing development rates and decreasing phase durations as temperatures increase. These affects are captured by thermal time. However, barley also exhibits vernalisation and photoperiod sensitivities in its Vegetative phase and further photoperiod sensitivity in the EarlyReproducivePhase. Photoperiod responses are seen as a reduction in the length of a phase for a photoperiod sensitive genotype in response to a longer photoperiod. Vernalisation responses are more complicated as they are driven by temperature but interact with photoperiod. For vernalisation sensitive varieties (Winter types) exposure to cool temperatures or short photoperiods during the Vegetative phase will reduce the thermal time duration of the vegetative phase.

We draw on the Kirby Framework to capture these vernalisation and photoperiod responses. This framework assumes that the timing of anthesis is a result of the timing of flag leaf and an additional thermal time passage from there to anthesis. It also assumes the timing of flag leaf is a result of the Final Leaf Number which sets a target, and leaf appearance rate, which sets the rate of progress toward this target. Leaf appearance rate is a function of Thermal time and a genotype specific Phyllochron which changes with Haun stage as described by Jamieson et al., 1995.

Final Leaf Number (FLN) is modeled as the sum of three numbers:

FLN = MinLeafNumber + VernalLeaves + PhotoLeaves

Where MinLeafNumber is the number of leaves that a wheat crop will produce when vernalisation is satisified early in the crops duration (before 2nd true leaf) and it is grown in a long photoperiod.. VernalLeaves are the number of leaves that are added due to vernalisation effects. For insensitive varieties this will always be zero but this is potentially a larger number for sensitivie varieties and the number progresively decreases as the crop encounters more vernalisation. PhotoLeaves are the number of leaves that are added to the minimum leaf number as a result of short day exposure. For insensitive varieties this will be zero but is potential larger for more sensitivie varieties and decreases as day length increases. More detailed explinations of the components of phenology are provided below.

Wheat exhibits a range of developmental responses to environment and these are strongly influences by genotype characteristics. Temperature effects development increasing development rates and decreasing phase durations as

temperatures increase. Theset affects are captured by thermal time, . However, wheat also exhibits vernalisation and photoperiod sensitivities in its Vegetative phase and further photoperiod sensitivity in the EarlyReproducivePhase. Photoperiod responses are seen as a reduction in the length of a phase for a photoperiod sensitive genotype in response to a longer photoperiod. Vernalisation responses are more complicated as they are driven by temperature but interact with photoperiod. For vernalisation sensitive varieties (Winter types) exposure to cool temperatures or short photoperiods during the Vegetative phase will reduce the thermal time duration of the vegetative phase.

We draw on the Kirby Framework to capture these vernalisation and photoperiod responses. This framework assumes that the timing of anthesis is a result of the timing of flag leaf and an additional thermal time passage from there to anthesis. It also assumes the timing of flag leaf is a result of the Final Leaf Number which sets a target, and leaf appearance rate, which sets the rate of progress toward this target. Leaf appearance rate is a function of Thermal time and a genotype specific Phyllochron which changes with Haun stage as described by Jamieson et al., 1995.

Final Leaf Number (FLN) is modeled as the sum of three numbers:

FLN = MinLeafNumber + VernalLeaves + PhotoLeaves

Where MinLeafNumber is the number of leaves that a wheat crop will produce when vernalisation is satisified early in the crops duration (before 2nd true leaf) and it is grown in a long photoperiod.. VernalLeaves are the number of leaves that are added due to vernalisation effects. For insensitive varieties this will always be zero but this is potentially a larger number for sensitivie varieties and the number progresively decreases as the crop encounters more vernalisation. PhotoLeaves are the number of leaves that are added to the minimum leaf number as a result of short day exposure. For insensitive varieties this will be zero but is potential larger for more sensitivie varieties and decreases as day length increases. More detailed explinations of the components of phenology are provided below.

1.4.4 Grain

This organ uses a generic model for plant reproductive components. Yield is calculated from its components in terms of organ number and size (for example, grain number and grain size).

1.4.5 Root

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

1.4.6 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.

1.4.7 Spike

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.

1.4.8 Stem

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.

1.4.9 MortalityRate

A constant function (name=value)

1.4.10 SeedMortalityRate

A constant function (name=value)

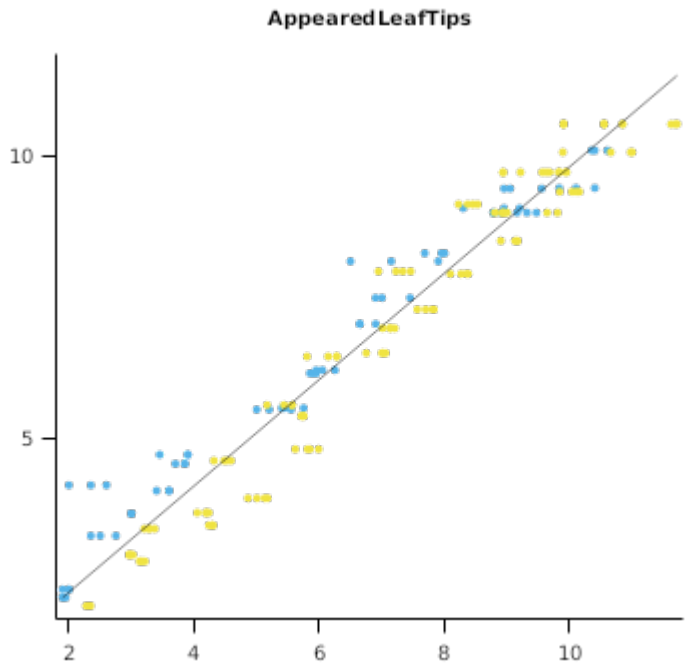
2 Validation

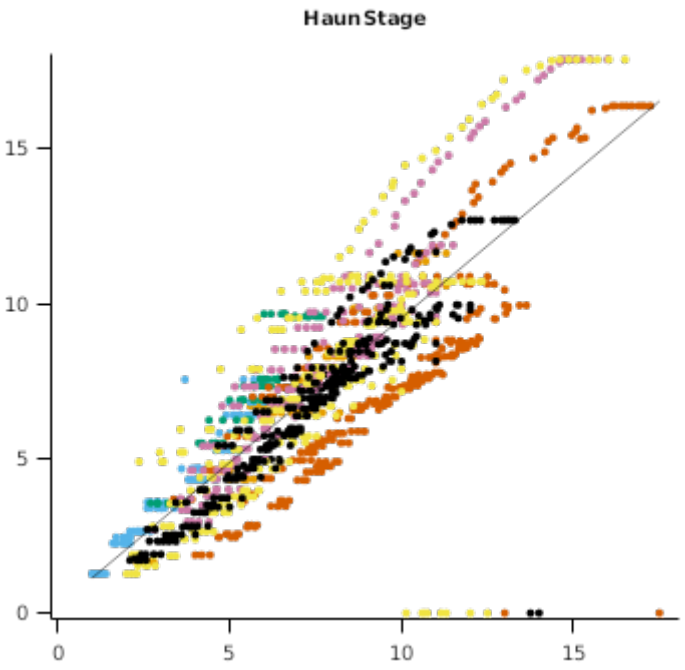
A test dataset has been developed to test the APSIM barley model for a range of environmental (soil and climate) conditions, management options (sowing dates, populations, nitrogen rates, irrigation) and genetic backgrounds (different

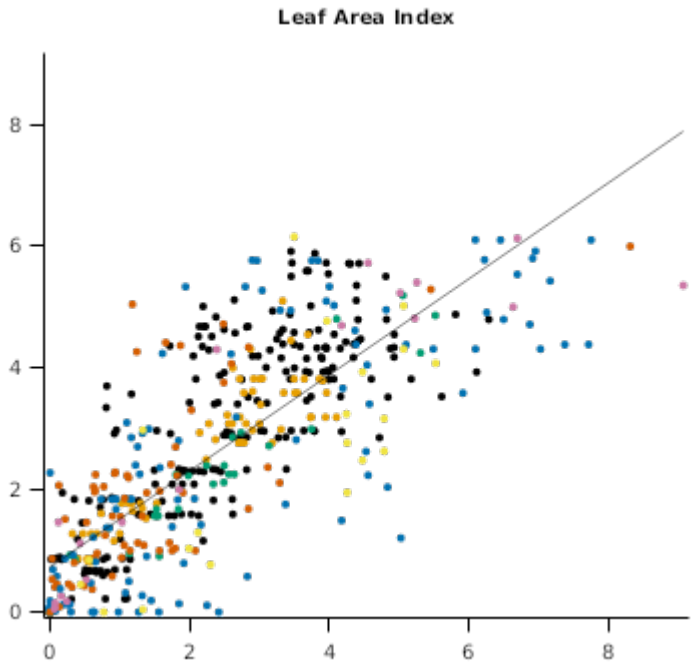
regions, cultivar types). These tests have been groups into various geographical regions to allow the user to evaluate the suitability of the model for their particular region of interest. Graphs of model performance are provided for yield, biomass production, canopy development, phenological development, water and nitrogen uptake, and grain yield components.

2.1 Map

2.2 Combined Results


AppearedLeafTips
10
5
2
4
6
8
10


HaunStage
15
10
5
0
0
5
10
15


Leaf Area Index
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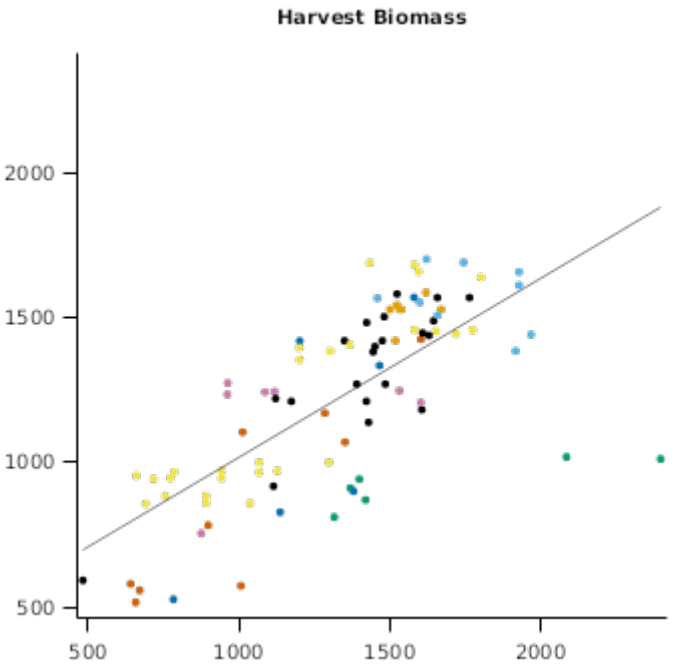
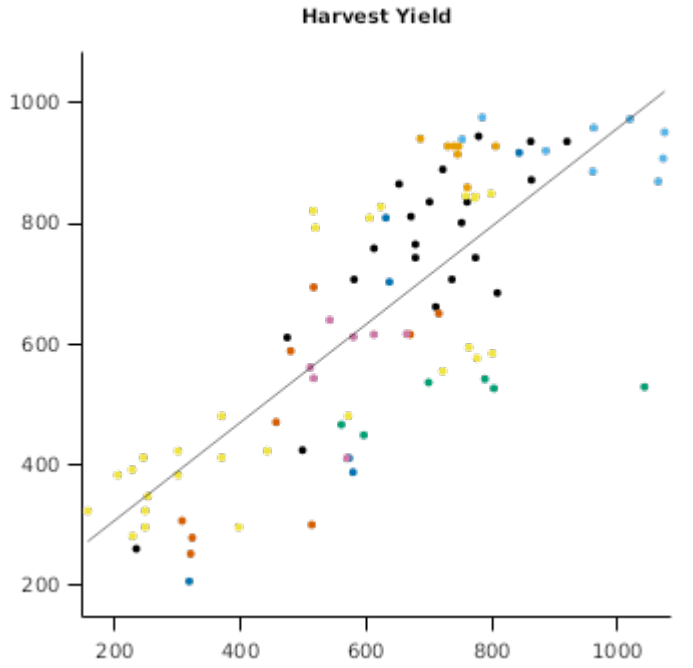
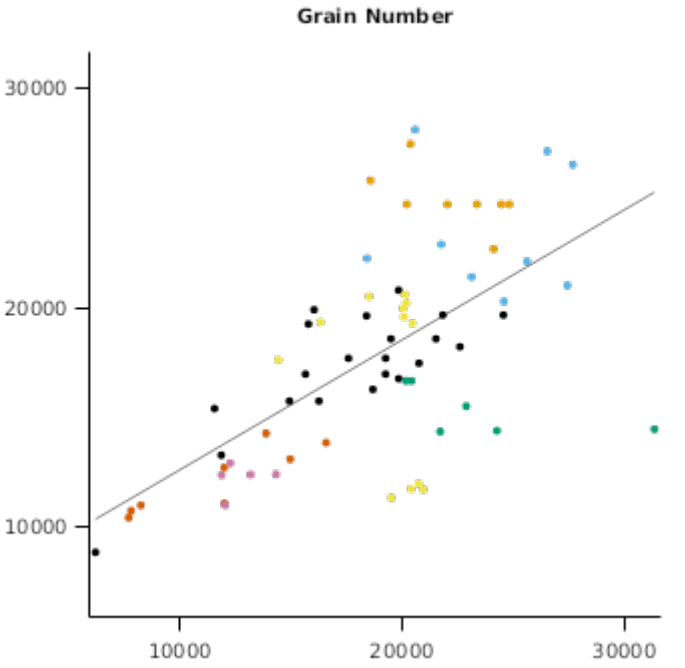
6
4
2
0
0
2
4
6
8


Harvest Biomass
2000
1500
1000
500
500
1000
1500
2000


Harvest Yield
1000
800
600
400
200
200
400
600
800
1000


Grain Number
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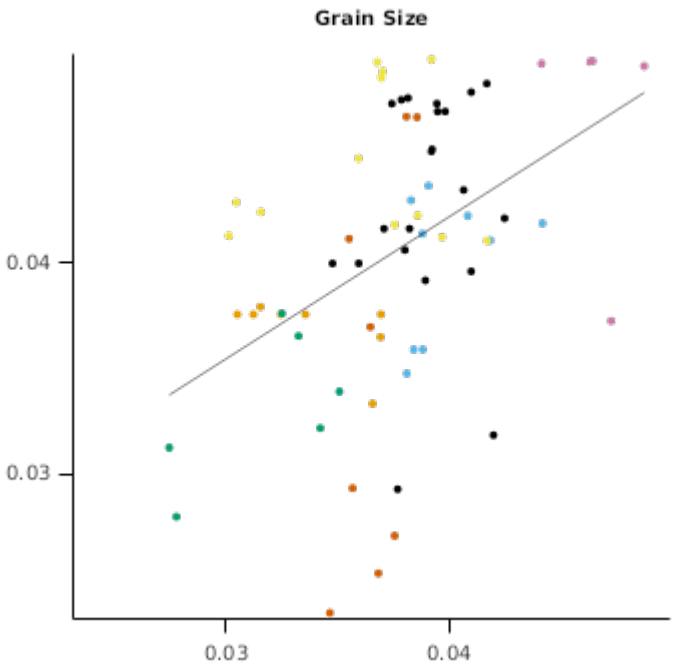
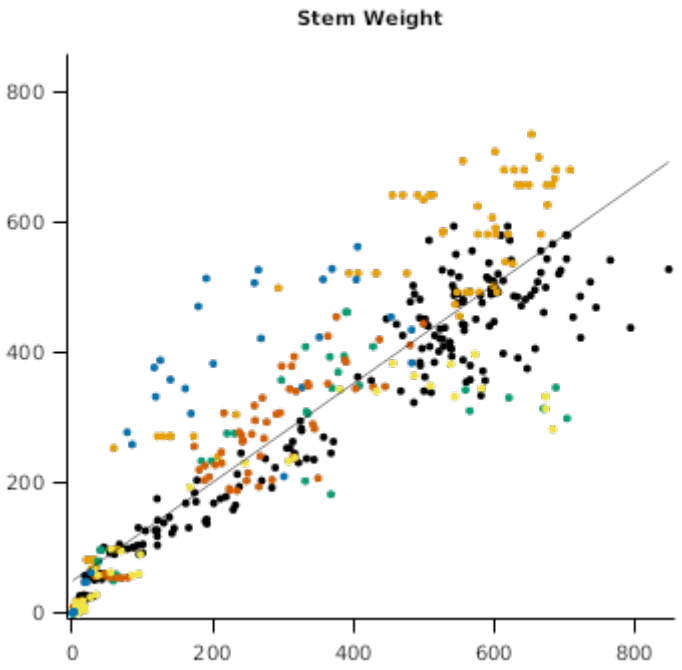
20000
10000
10000
20000
30000


Grain Size
0.04
0.03
0.03
0.04


Stem Weight
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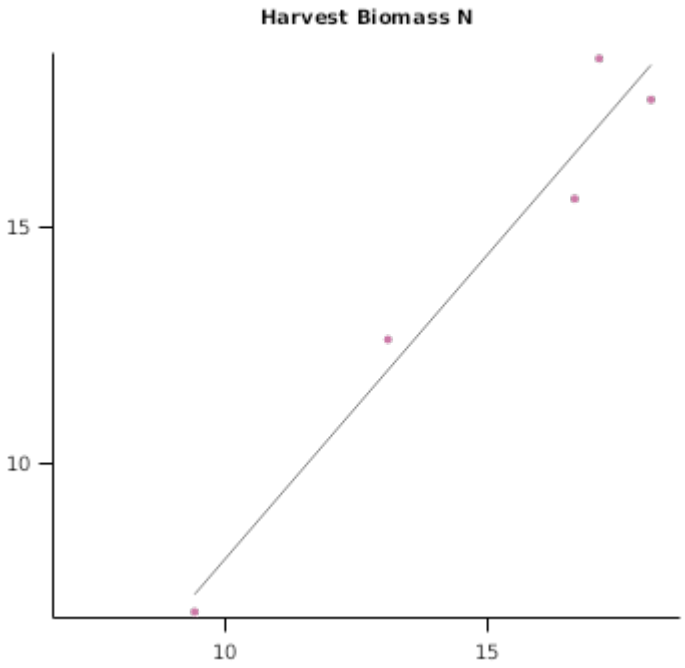
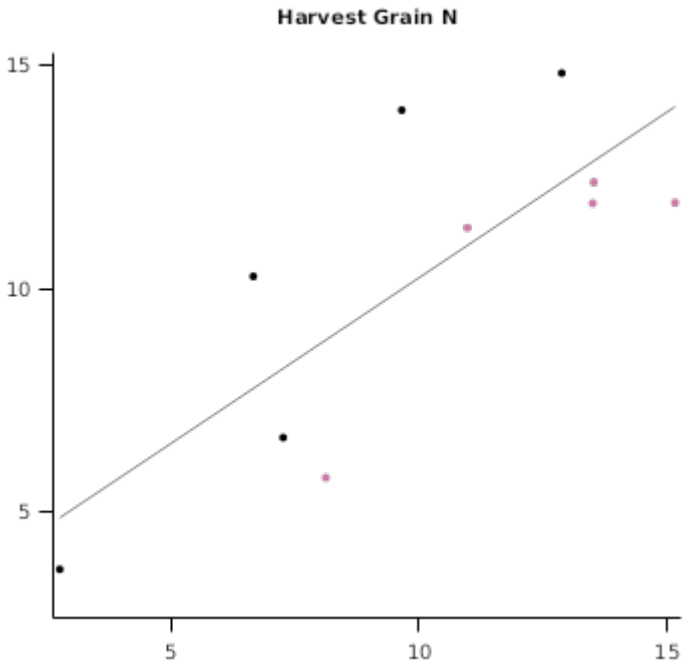
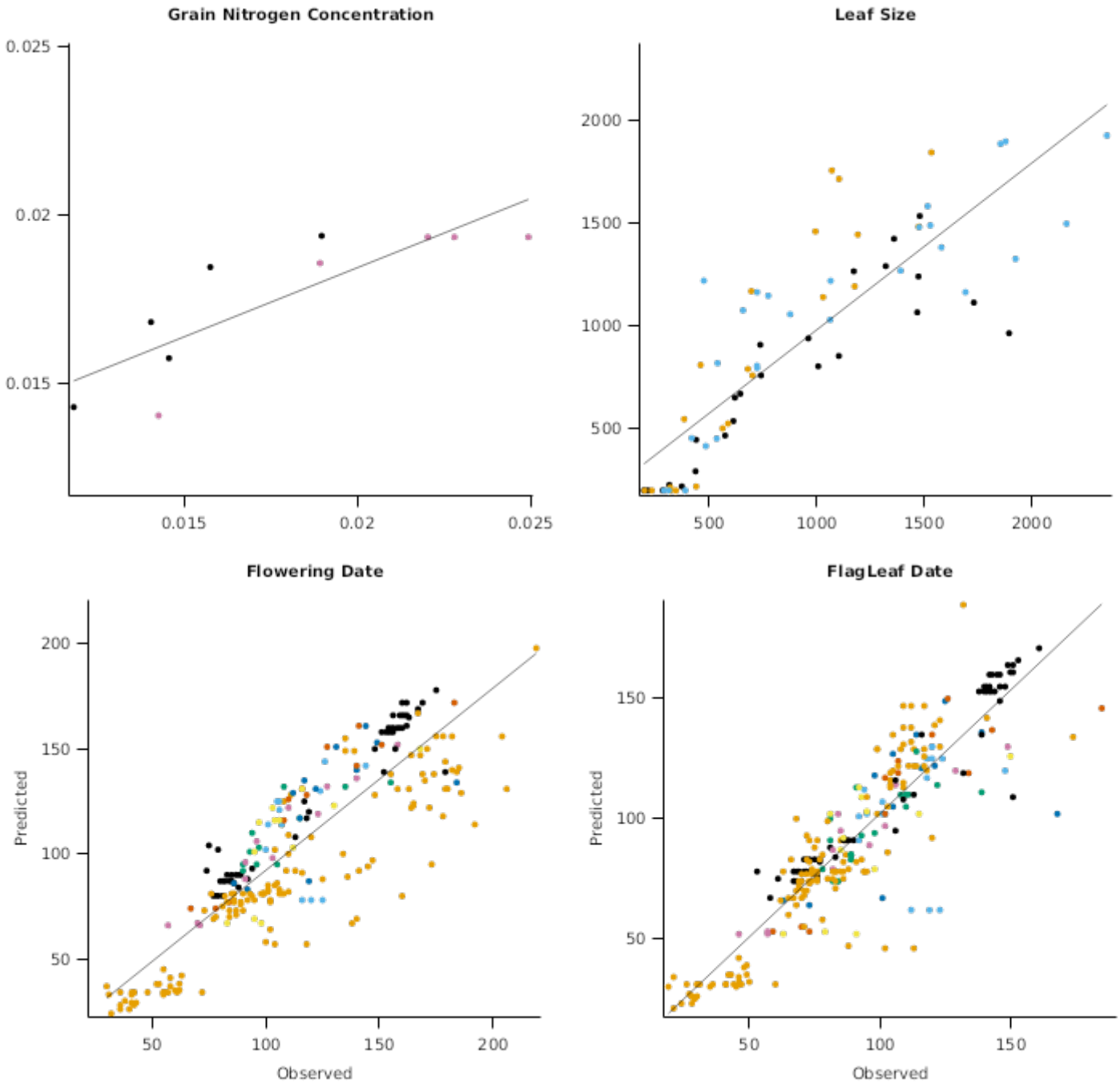
600
400
200
0
0
200
400
600
800


Harvest Biomass N
15
10
10
15

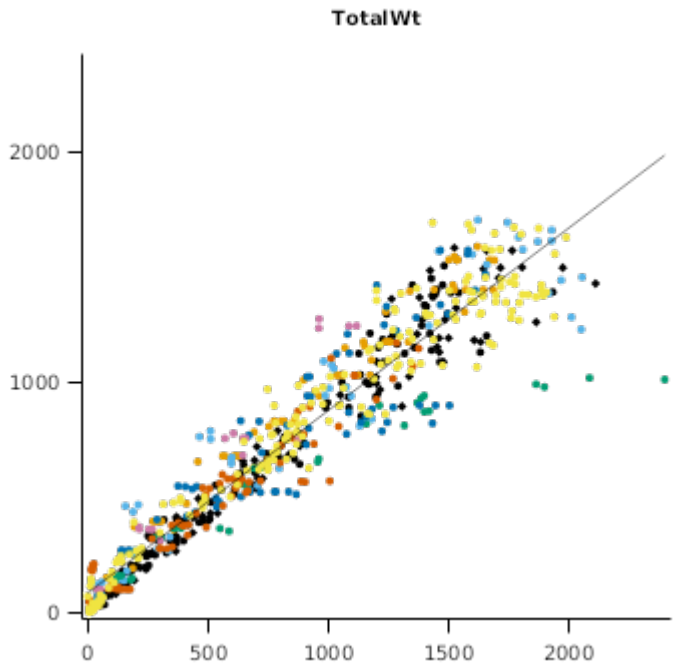

Harvest Grain N
15
10
5
5
10
15



2.3 NewZealand

2.3.1 List of experiments

Experiment Name	Design (Number of Treatments)
MCPD09_10	Cult x Nit x Irr (16)
MCPD10_11	Cult (8)
MCPD11_12	Cult x SD (9)
RS2014_15	Cult x Irr (6)
RS1988_89	Irr (6)
RS1995_96	Water x N (8)
LUDF2015_16	NProp (5)
ABlock99_00	Sow x Pop (12)


TotalWt
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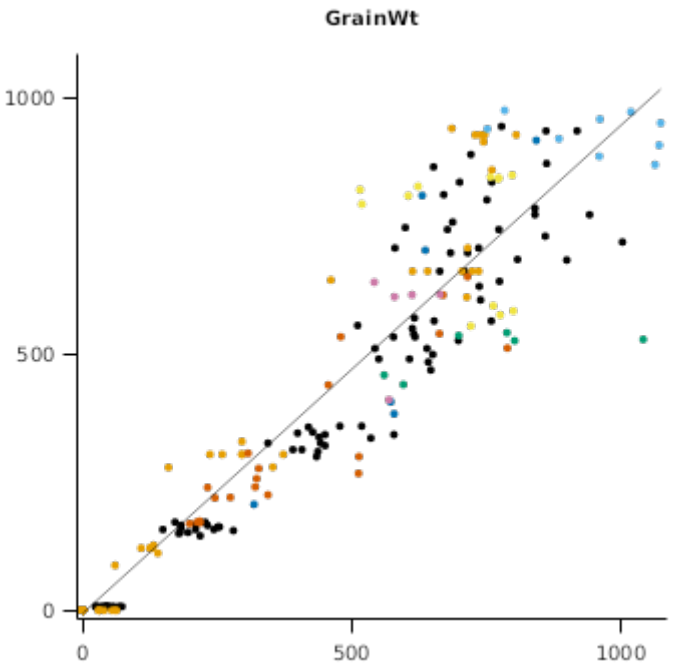
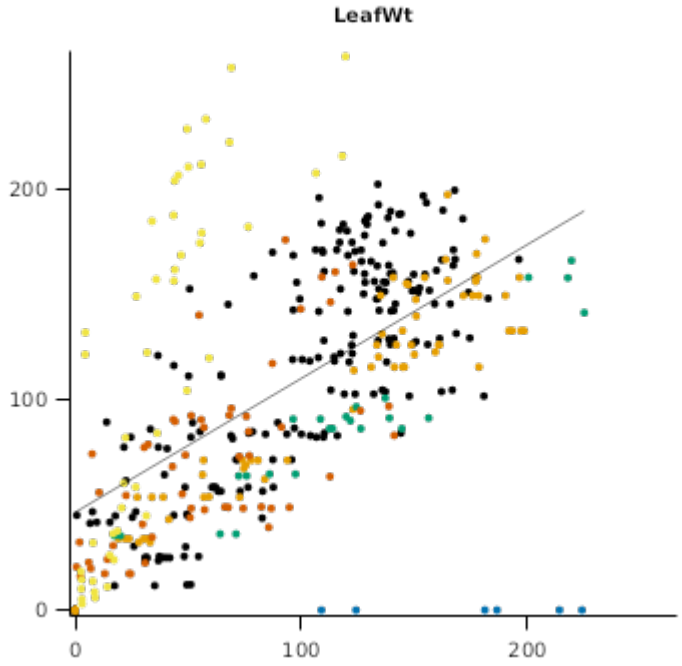
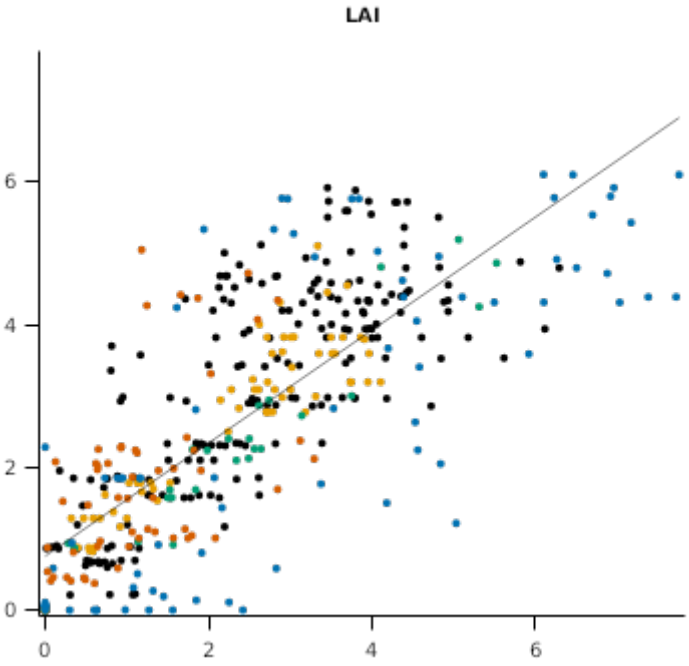
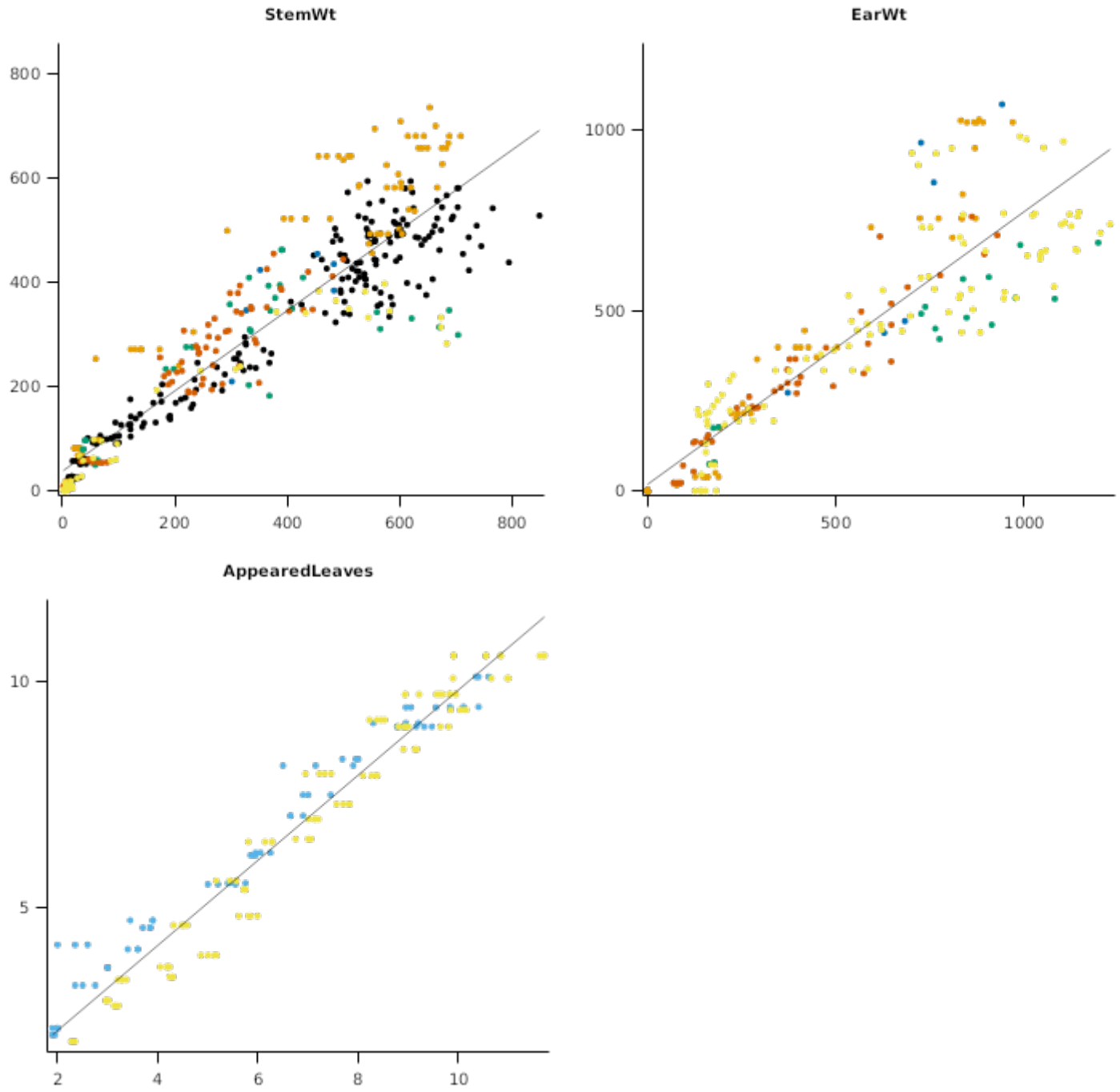
1000
0
0
500
1000
1500
2000


GrainWt
1000
500
0
0
500
1000


LeafWt
200
100
0
0
100
200

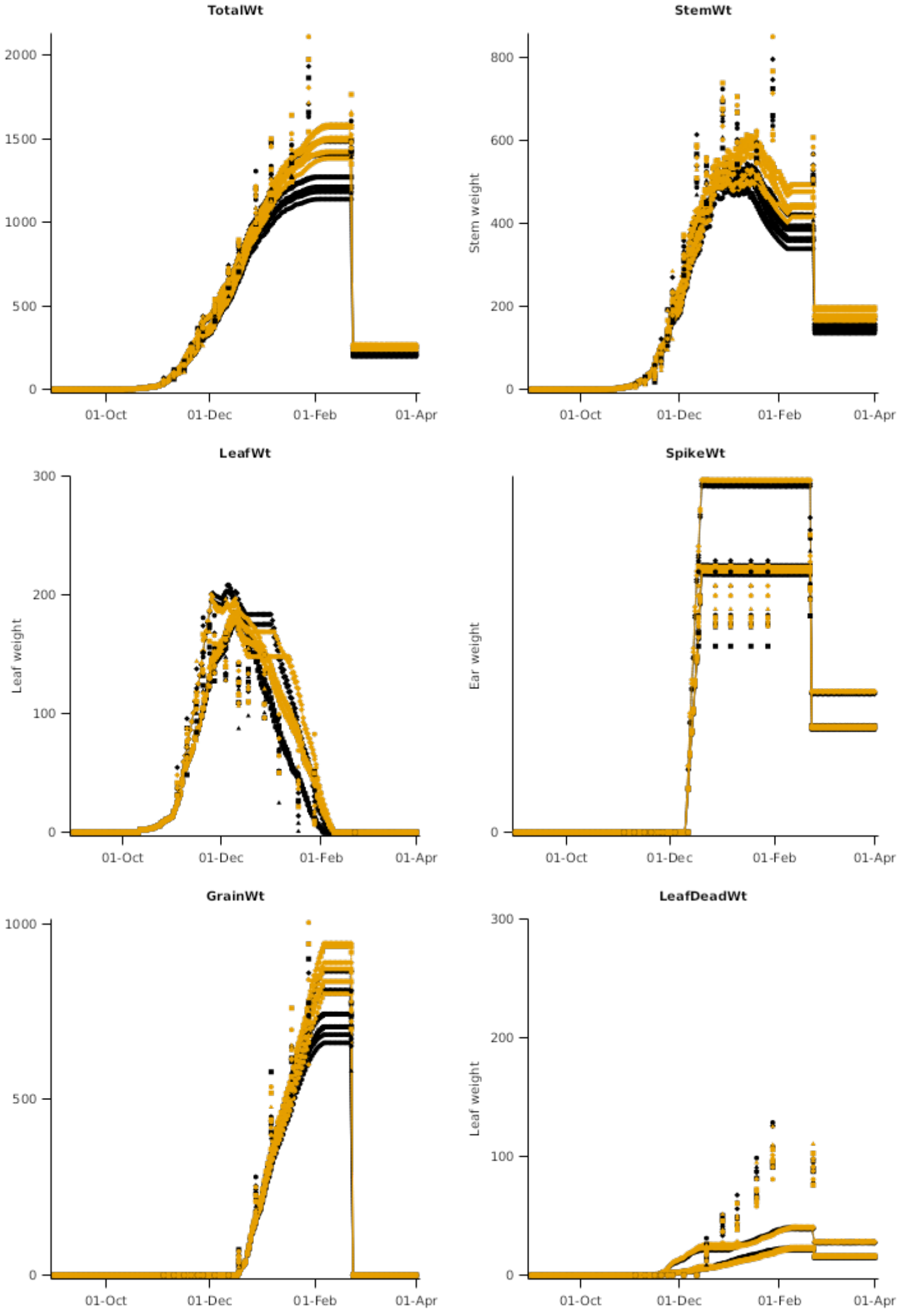

LAI
6
4
2
0
0
2
4
6

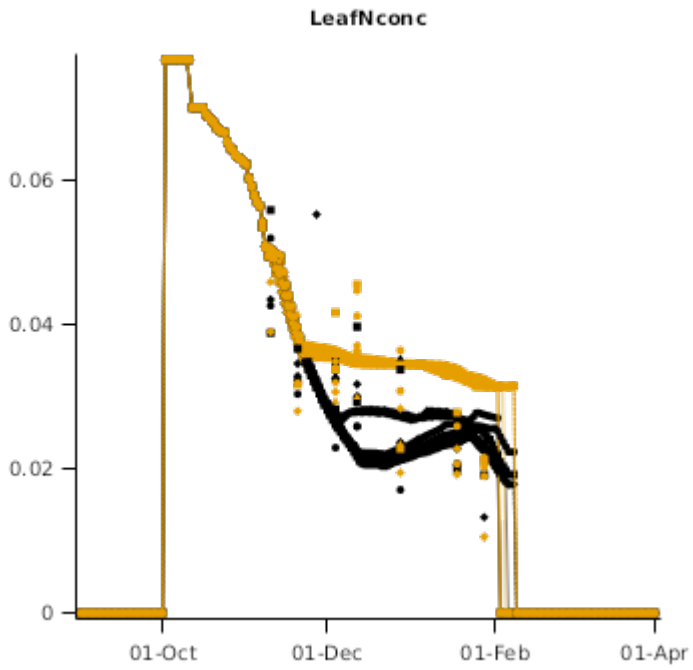


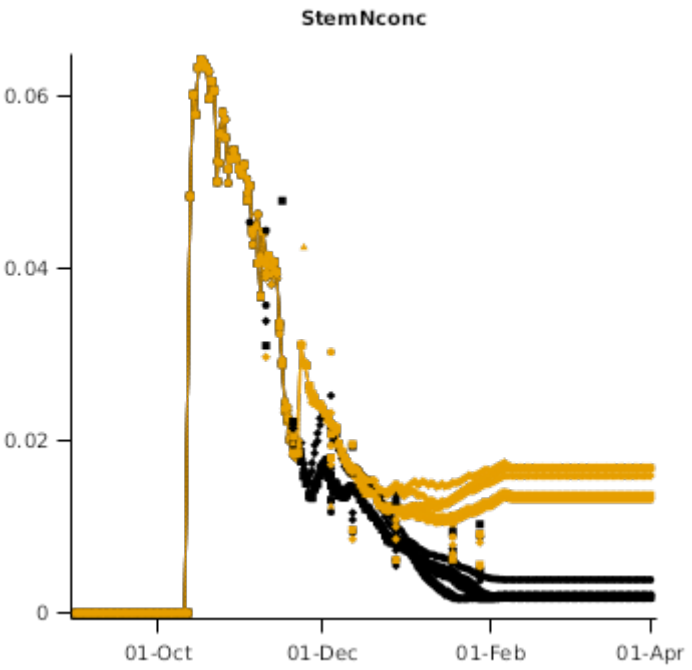
2.3.2 MCPD09_10

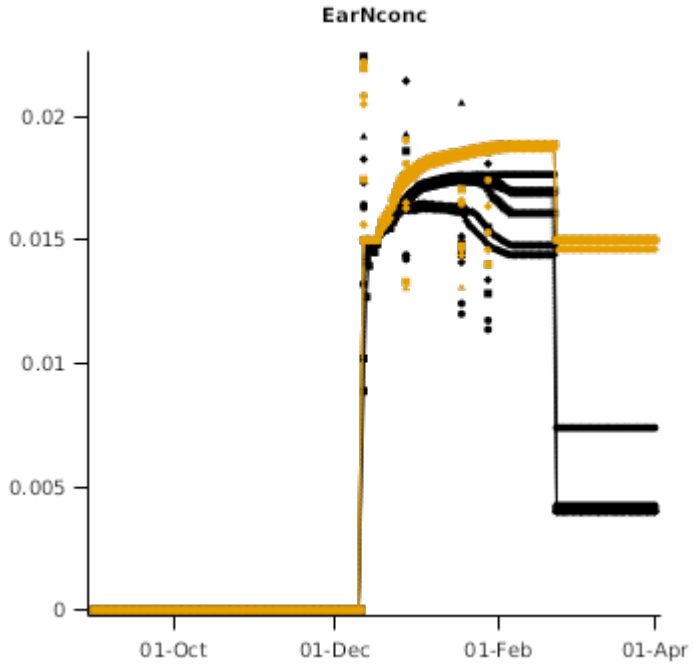
This experiment was conducted in A Block near Lincoln, New Zealand to determine if there were any differences in the water use efficiency of different commercial varieties of barley. The results are un-published to date.

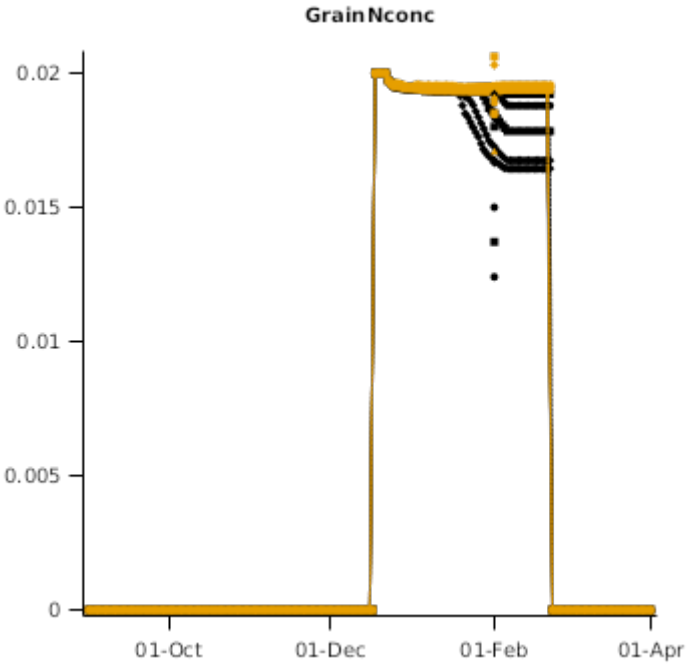
Four cultivars of Barley ('Omaka', 'Dash', 'Sherwood' and 'Booma') were sown on the 1st of October 2009 in a randomised complete block design with 4 replicates and two other factors, Irrigation and Nitrogen. The irrigation treatments consisted of full irrigation (to replace measured evapotranspiration) or nil irrigation (recieving only rainfall). The nitrogen treatments were 150 kg N broadcast in the early vegetative stage or nil fertiliser.
Biomass accumulation, organ N content, Leaf area index, radiation interception and soil water content were measured at regular frequencies throughout the experiment.

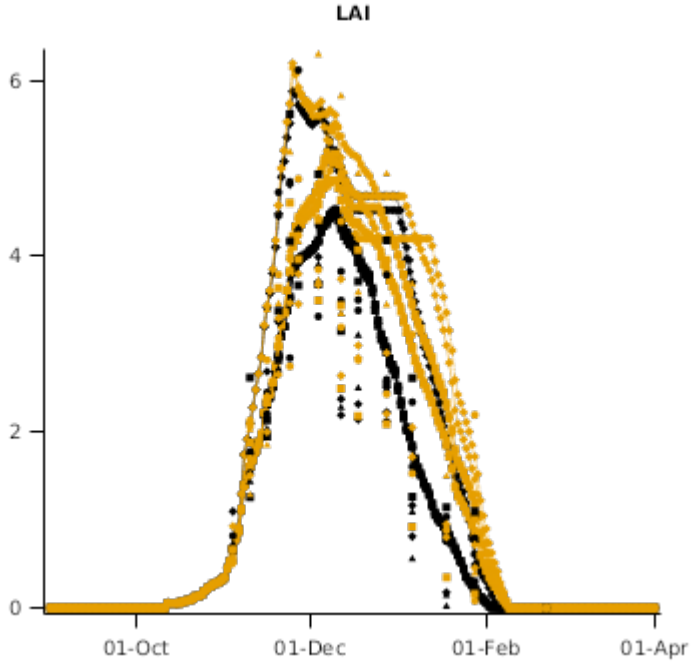

TotalWt
2000
1500
1000
500
0
01-Oct
01-Dec
01-Feb
01-Apr
StemWt
Stem weight
800
600
400
200
0
01-Oct
01-Dec
01-Feb
01-Apr
LeafWt
Leaf weight
300
200
100
0
01-Oct
01-Dec
01-Feb
01-Apr
SpikeWt
Ear weight
0
01-Oct
01-Dec
01-Feb
01-Apr
GrainWt
1000
500
0
01-Oct
01-Dec
01-Feb
01-Apr
LeafDeadWt
Leaf weight
300
200
100
0
01-Oct
01-Dec
01-Feb
01-Apr

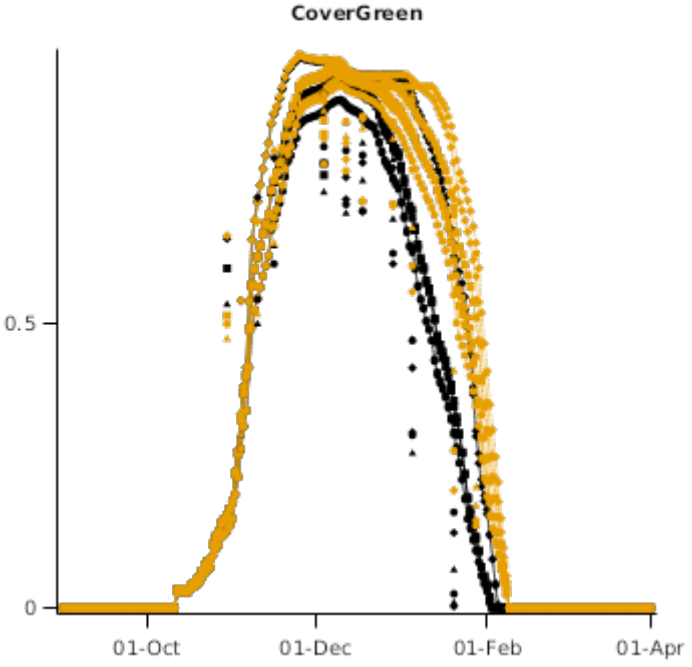

LeafNconc
0.06
0.04
0.02
0
01-Oct
01-Dec
01-Feb
01-Apr

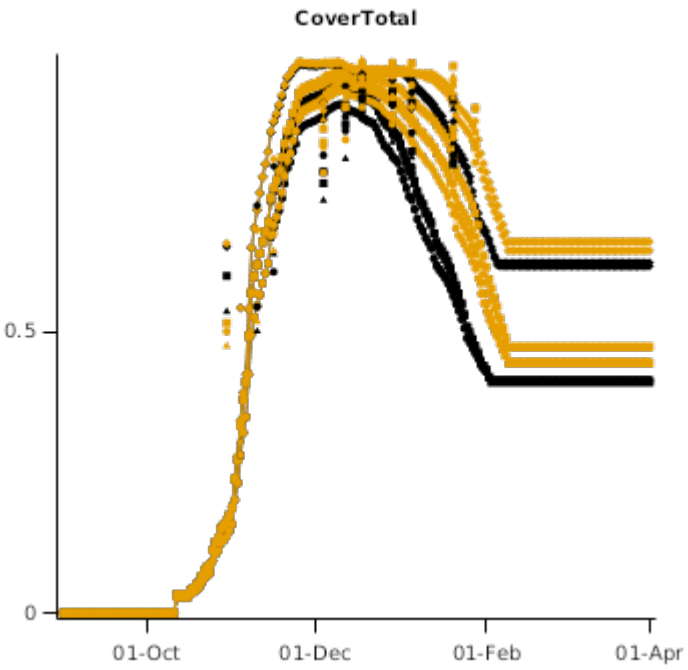

StemNconc
0.06
0.04
0.02
0
01-Oct
01-Dec
01-Feb
01-Apr

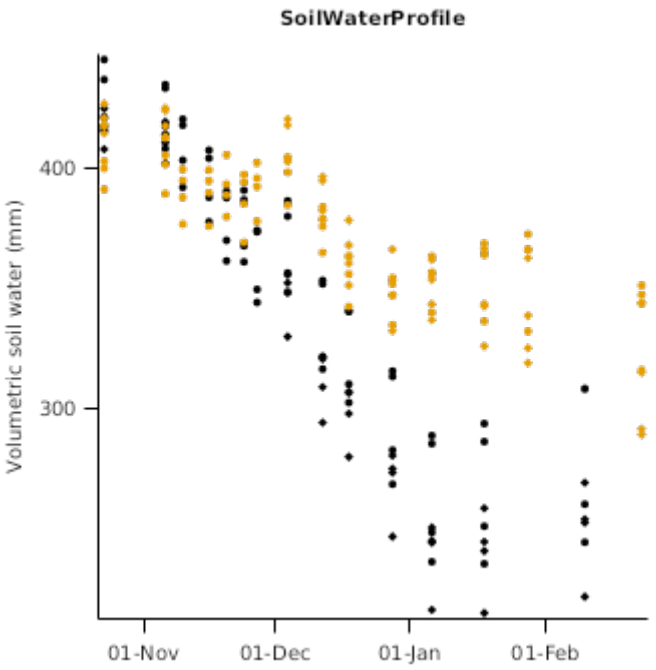

EarNconc
0.02
0.015
0.01
0.005
0
01-Oct
01-Dec
01-Feb
01-Apr

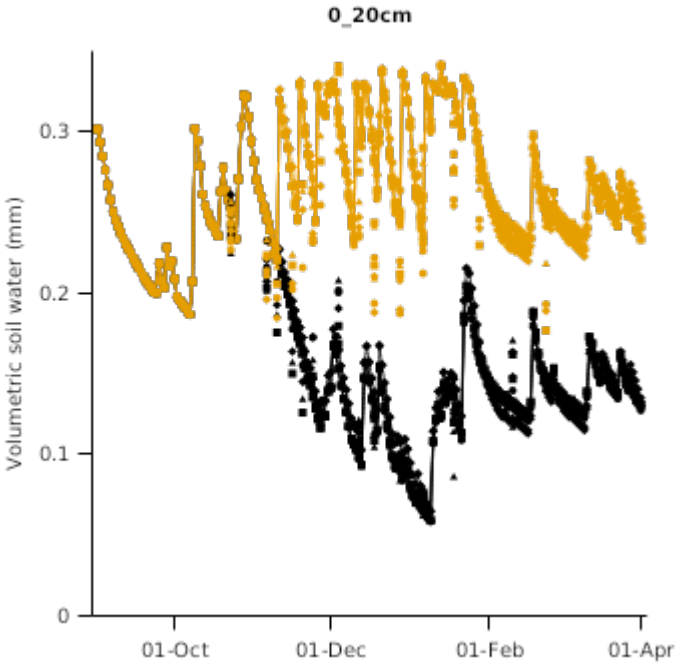

GrainNconc
0.02
0.015
0.01
0.005
0
01-Oct
01-Dec
01-Feb
01-Apr

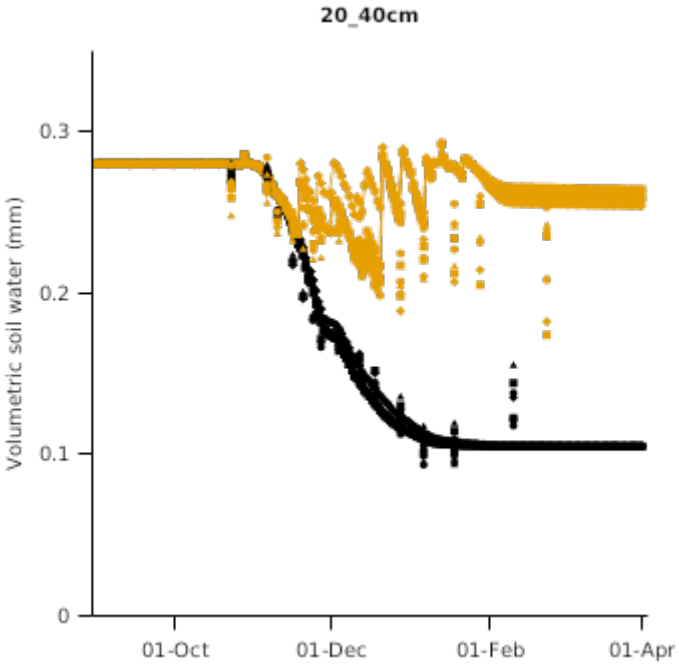

LAI
6
4
2
0
01-Oct
01-Dec
01-Feb
01-Apr

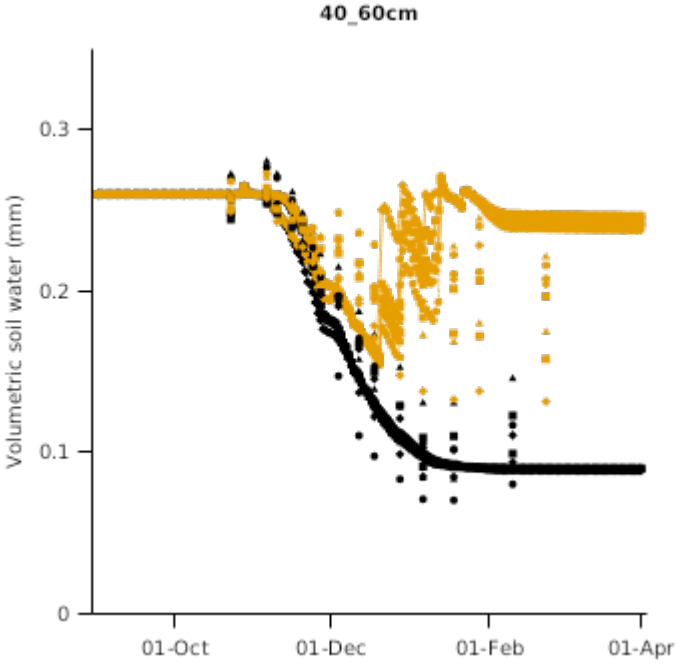

CoverGreen
0.5
0
01-Oct
01-Dec
01-Feb
01-Apr

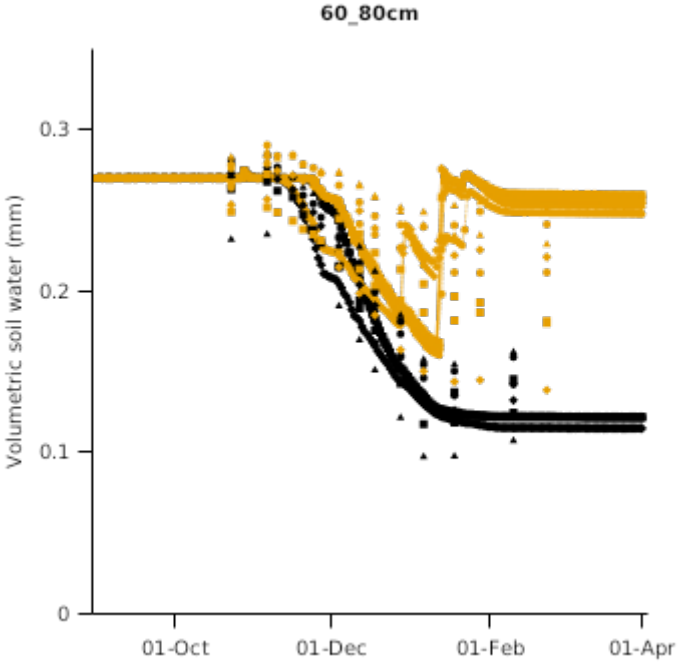

CoverTotal
0.5
0
01-Oct
01-Dec
01-Feb
01-Apr

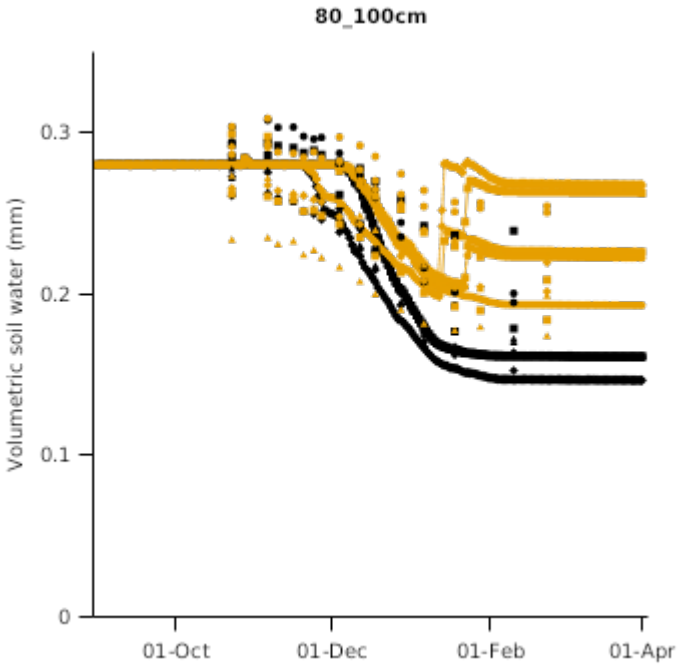

SoilWaterProfile
Volumetric soil water (mm)
400
300
01-Nov
01-Dec
01-Jan
01-Feb

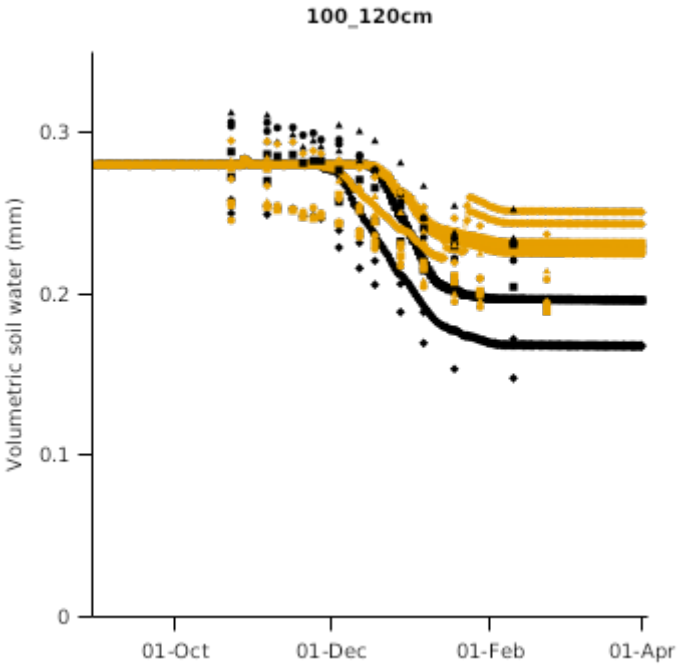

0_20cm
Volumetric soil water (mm)
0.3
0.2
0.1
0
01-Oct
01-Dec
01-Feb
01-Apr

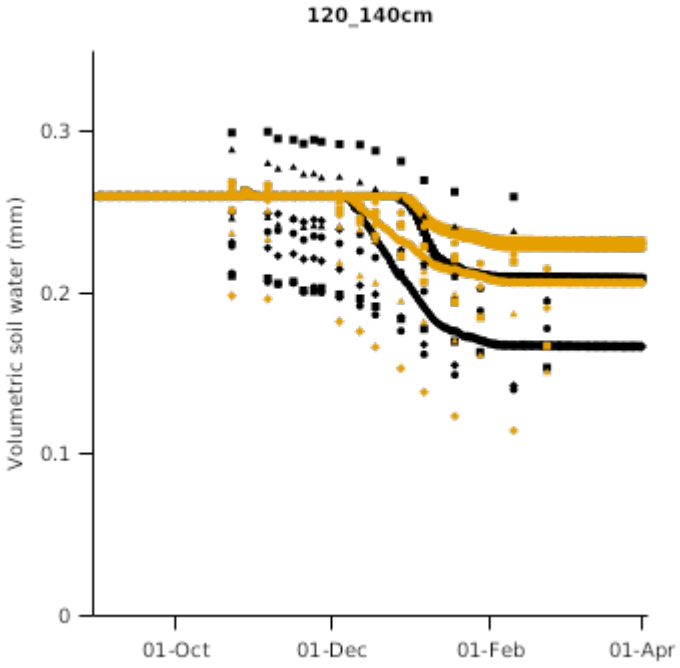

20_40cm
Volumetric soil water (mm)
0.3
0.2
0.1
0
01-Oct
01-Dec
01-Feb
01-Apr

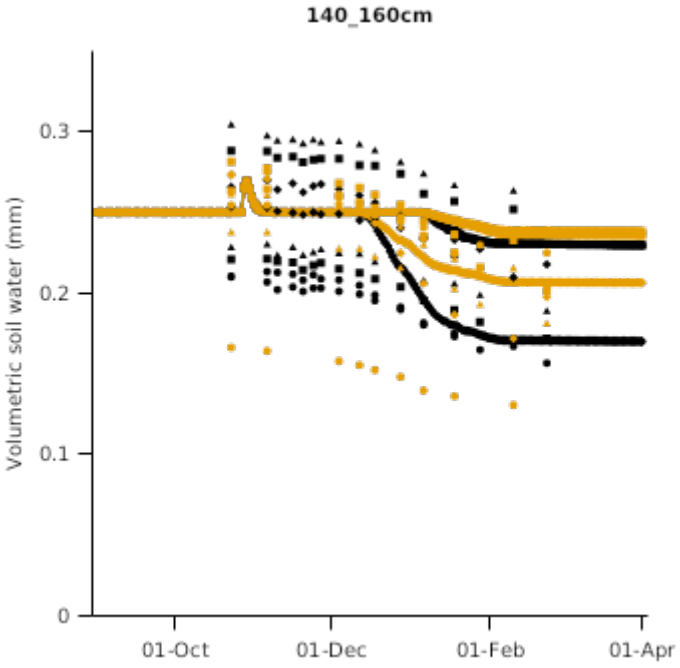

40_60cm
Volumetric soil water (mm)
0.3
0.2
0.1
0
01-Oct
01-Dec
01-Feb
01-Apr

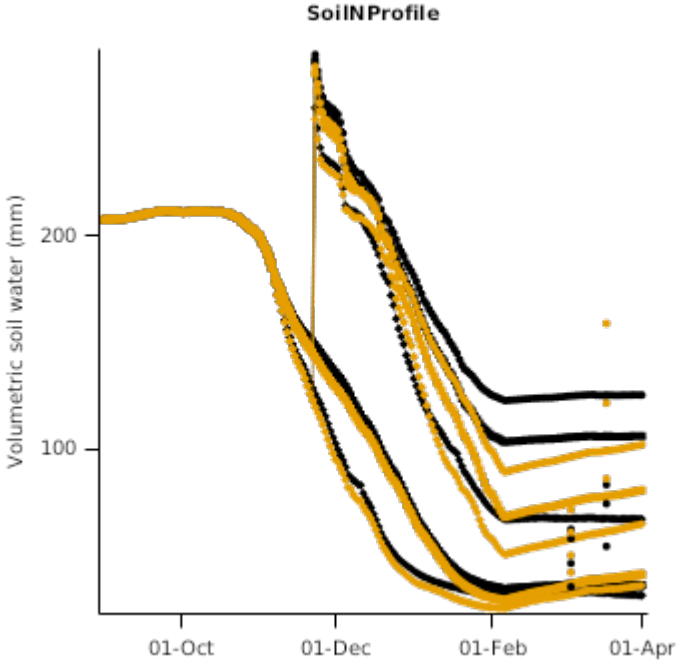

60_80cm
Volumetric soil water (mm)
0.3
0.2
0.1
0
01-Oct
01-Dec
01-Feb
01-Apr

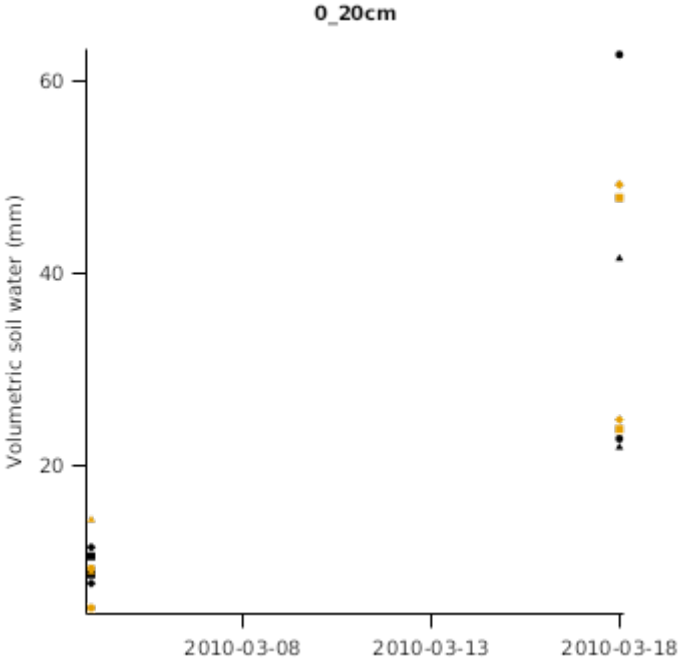

80_100cm
Volumetric soil water (mm)
0
0.1
0.2
0.3
01-Oct
01-Dec
01-Feb
01-Apr

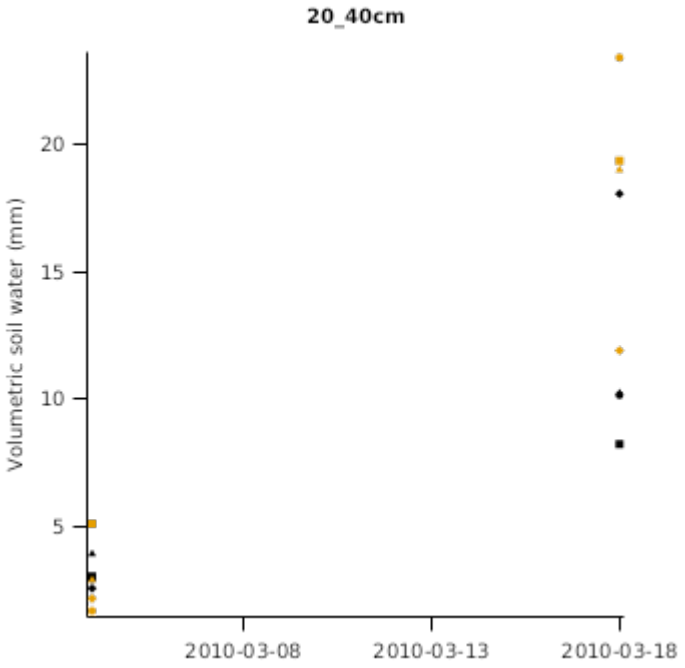

100_120cm
Volumetric soil water (mm)
0
0.1
0.2
0.3
01-Oct
01-Dec
01-Feb
01-Apr

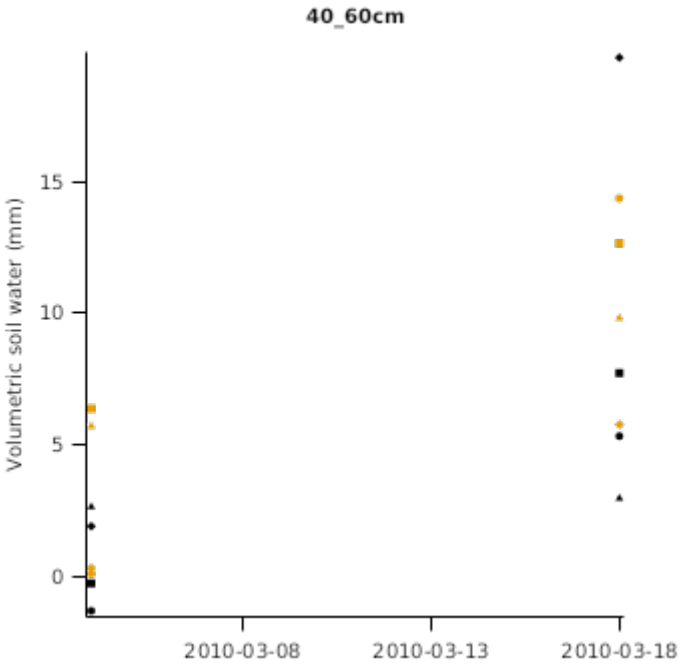

120_140cm
Volumetric soil water (mm)
0
0.1
0.2
0.3
01-Oct
01-Dec
01-Feb
01-Apr

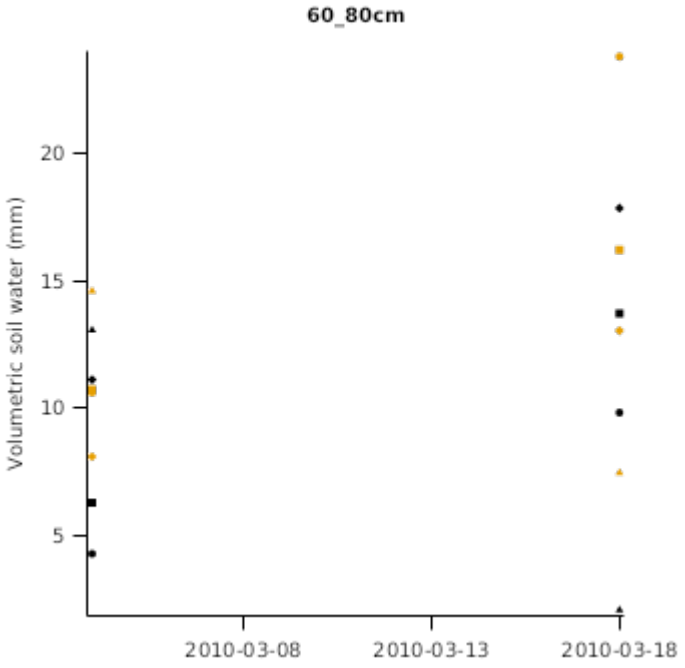

140_160cm
Volumetric soil water (mm)
0
0.1
0.2
0.3
01-Oct
01-Dec
01-Feb
01-Apr

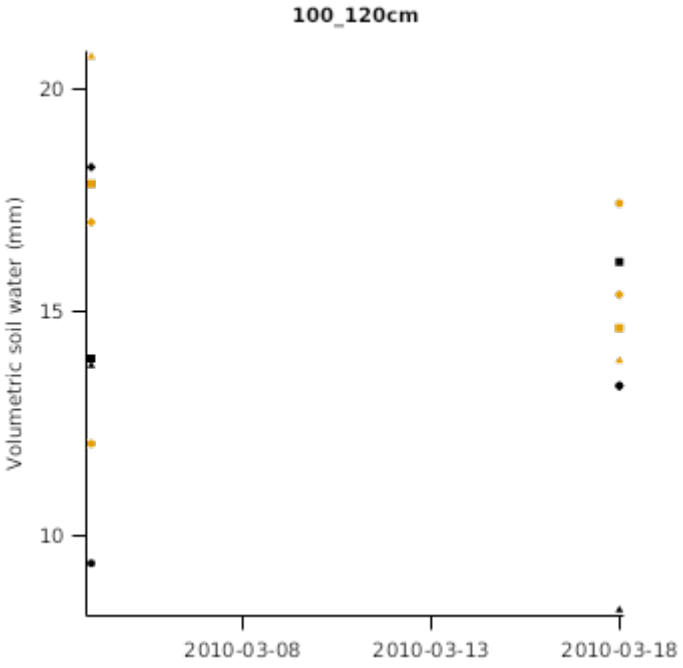

SoilNProfile
Volumetric soil water (mm)
100
200
01-Oct
01-Dec
01-Feb
01-Apr

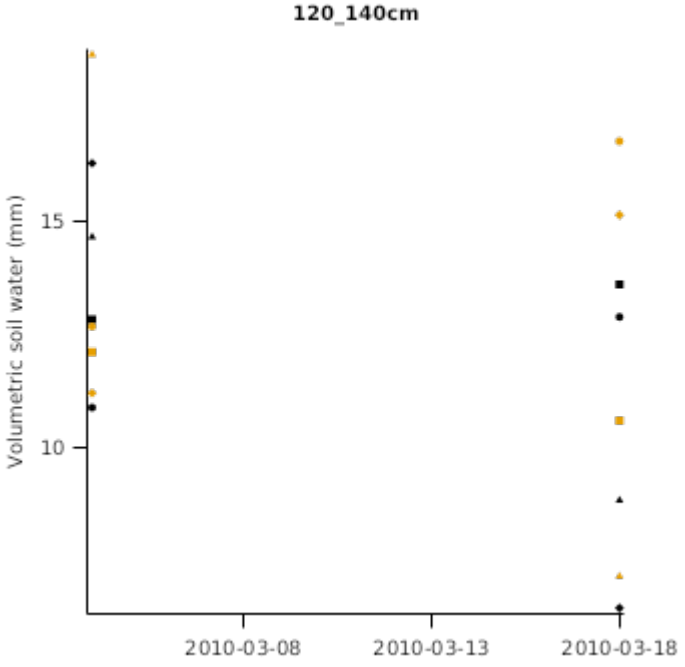

0_20cm
Volumetric soil water (mm)
20
40
60
2010-03-08
2010-03-13
2010-03-18


20_40cm
Volumetric soil water (mm)
20
15
10
5
2010-03-08
2010-03-13
2010-03-18


40_60cm
Volumetric soil water (mm)
15
10
5
0
2010-03-08
2010-03-13
2010-03-18


60_80cm
Volumetric soil water (mm)
20
15
10
5
2010-03-08
2010-03-13
2010-03-18


100_120cm
Volumetric soil water (mm)
20
15
10
2010-03-08
2010-03-13
2010-03-18

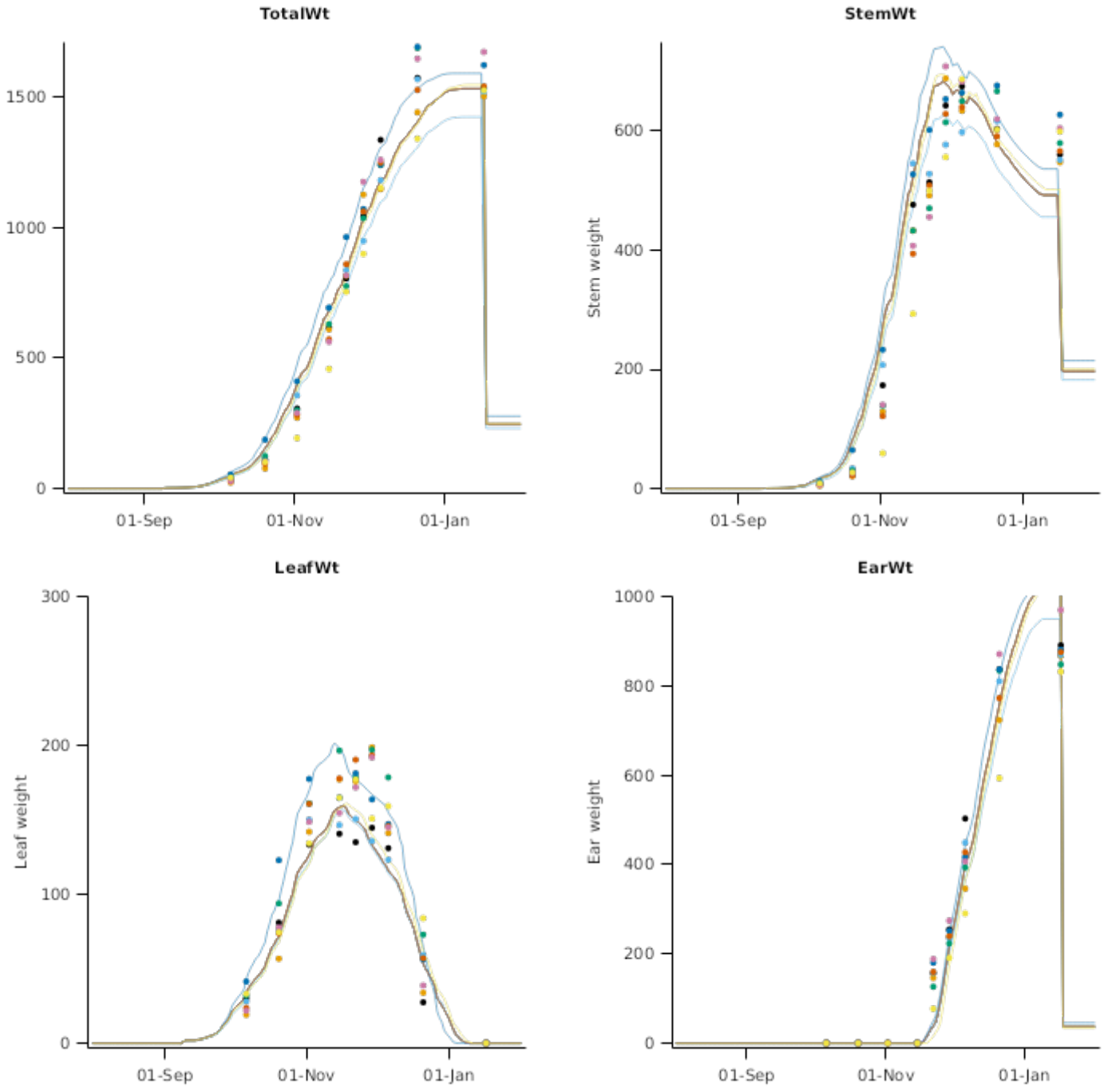

120_140cm
Volumetric soil water (mm)
15
10
2010-03-08
2010-03-13
2010-03-18

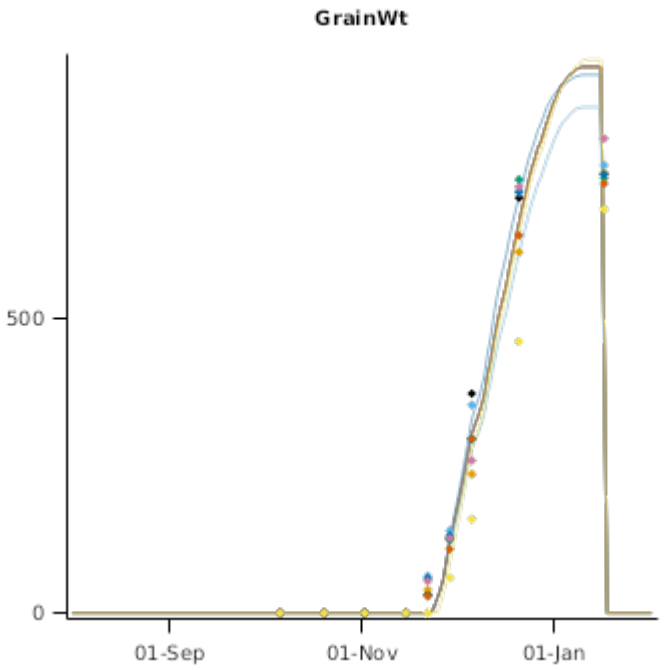
2.3.3 MCPD10_11

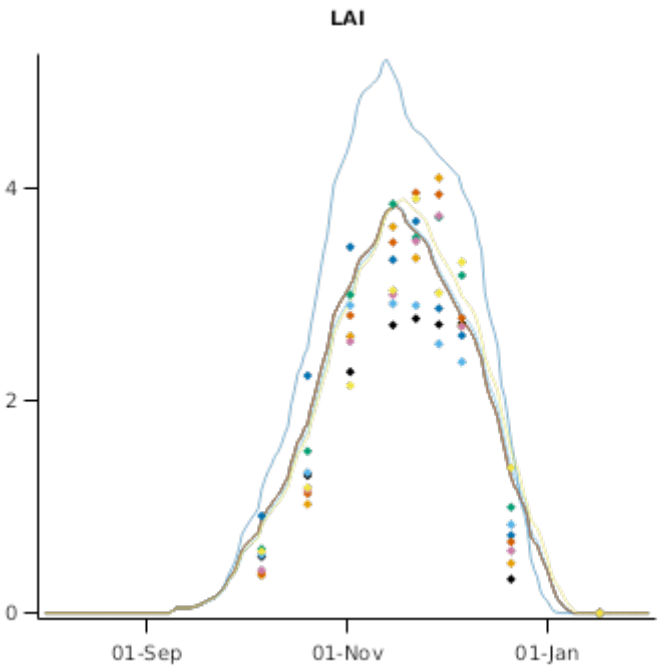
Following on from MCPD09_10, this experiment was conducted in A Block near Lincoln, New Zealand to test a wider range of barley genotypes for differences in water use efficiency. The results are un-published to date.

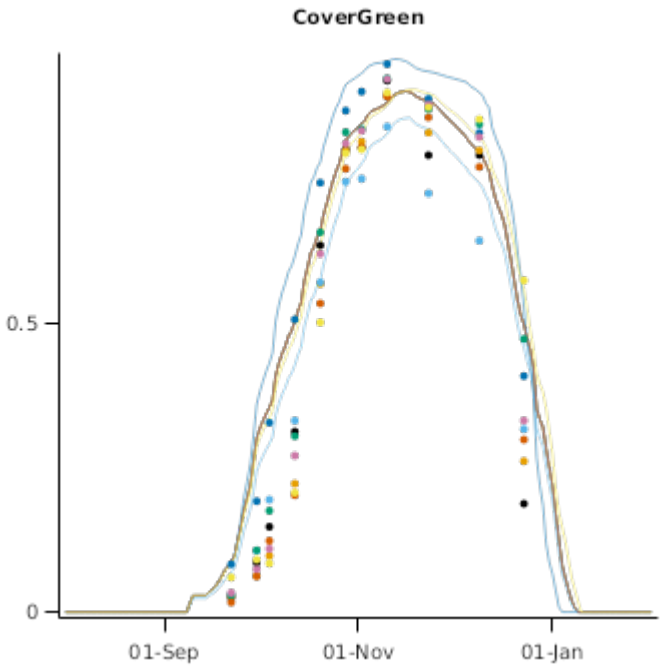
Treatments were simply 8 commercially available varieties of barley
('Booma','County','Dash','Hooded','Omaka','Optic','Quench' and 'Retriever')

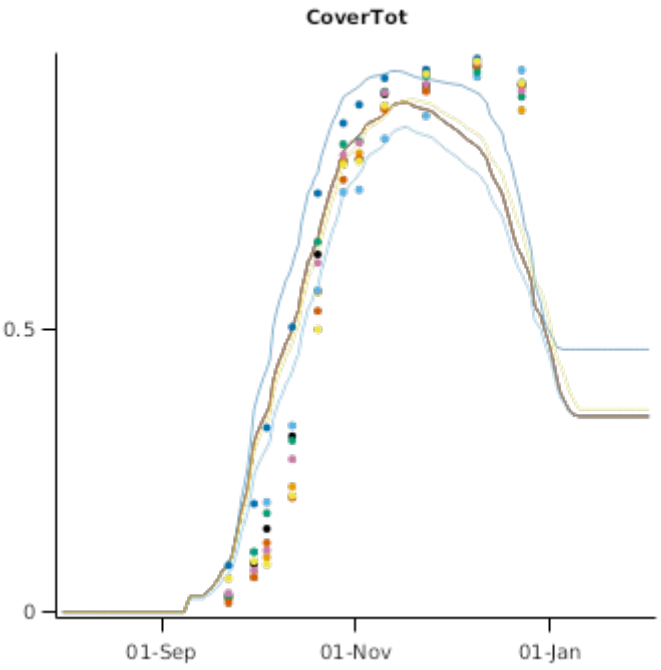
Biomass accumulation, Leaf area index, radiation interception and soil water content were measured at regular frequencies throughout the experiment.

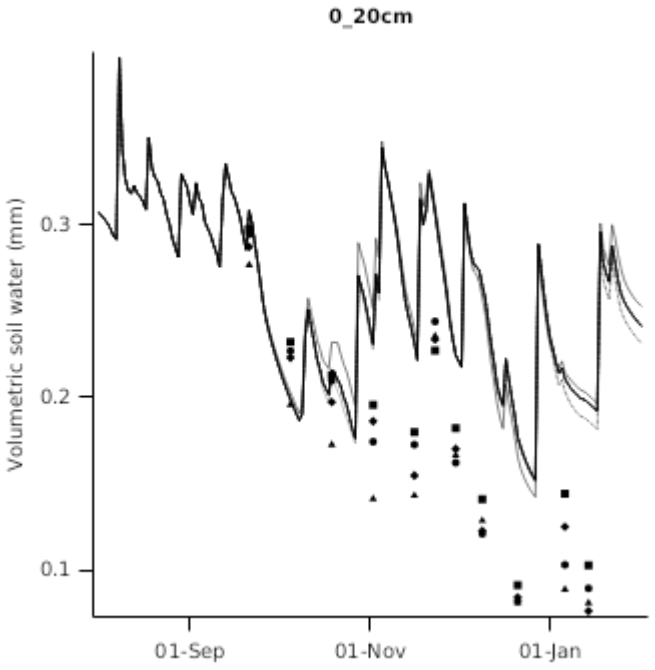


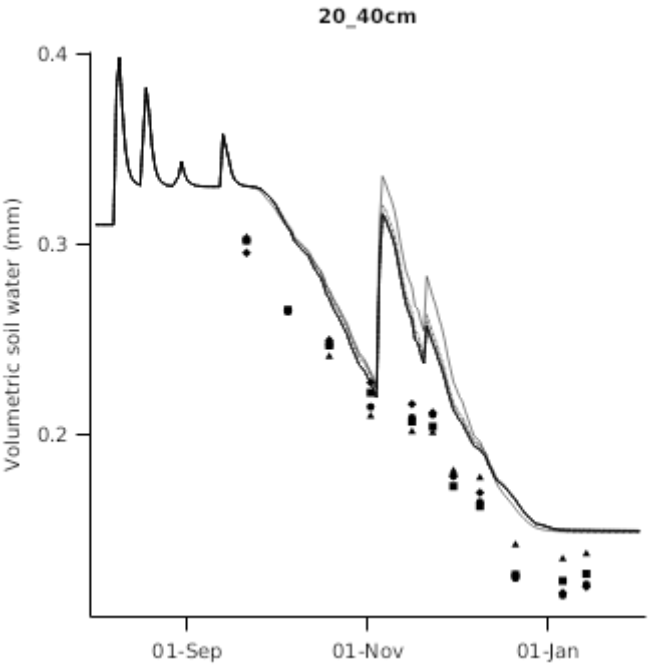

GrainWt
500
0
01-Sep
01-Nov
01-Jan

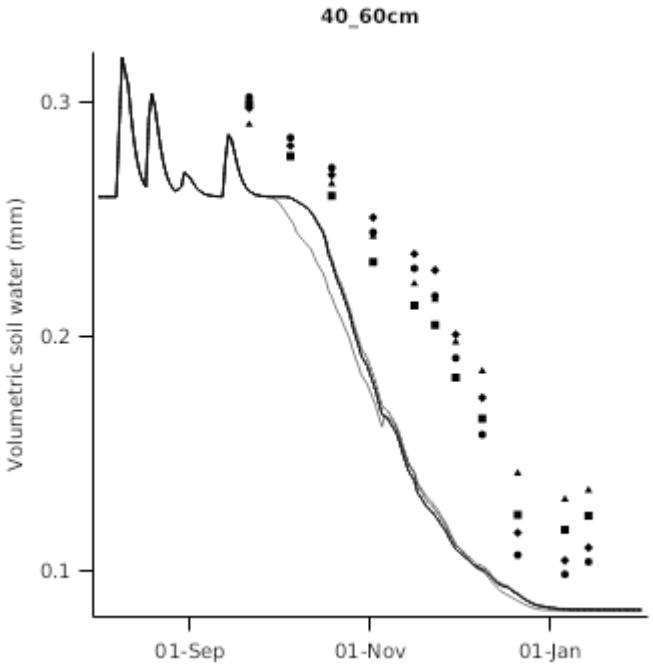

LAI
4
2
0
01-Sep
01-Nov
01-Jan

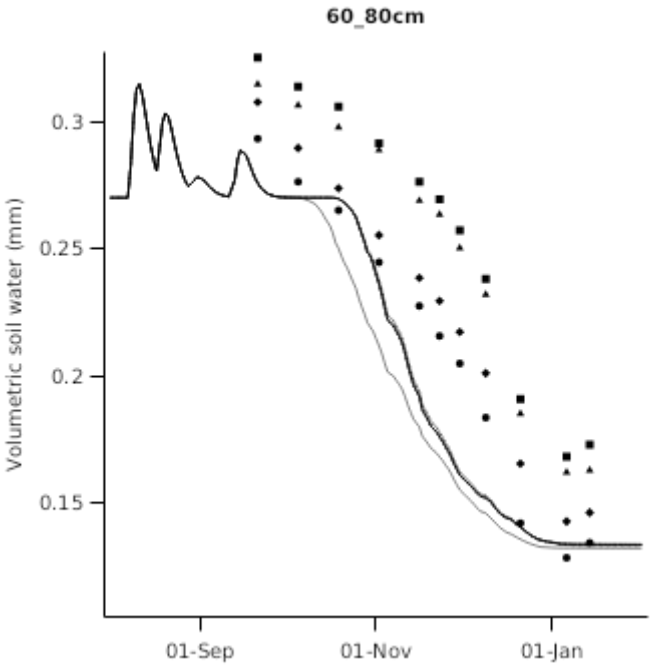

CoverGreen
0.5
0
01-Sep
01-Nov
01-Jan

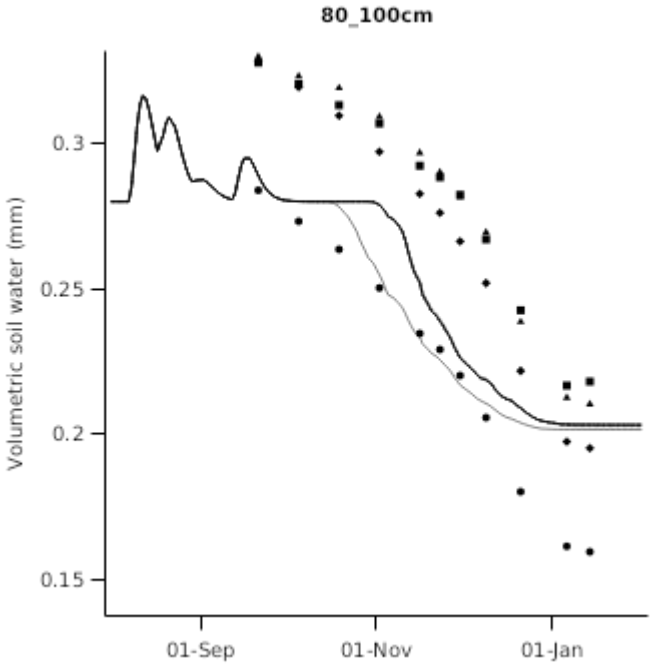

CoverTot
0.5
0
01-Sep
01-Nov
01-Jan

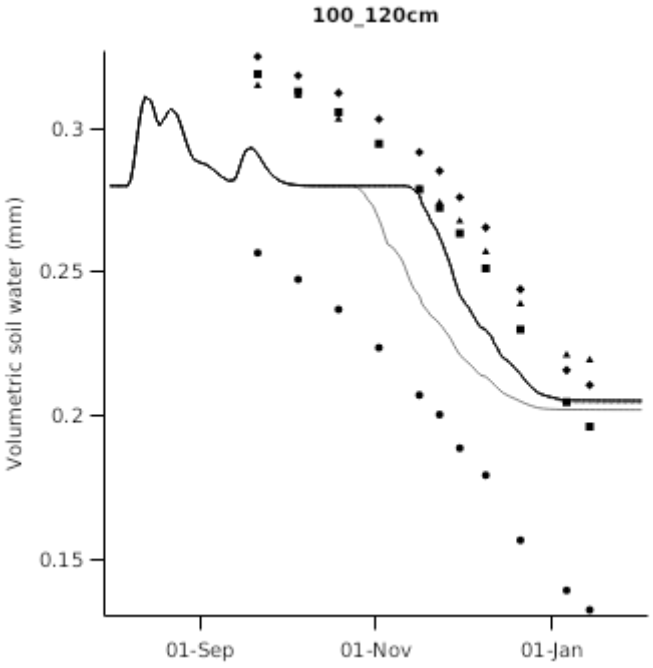

0_20cm
Volumetric soil water (mm)
0.3
0.2
0.1
01-Sep
01-Nov
01-Jan

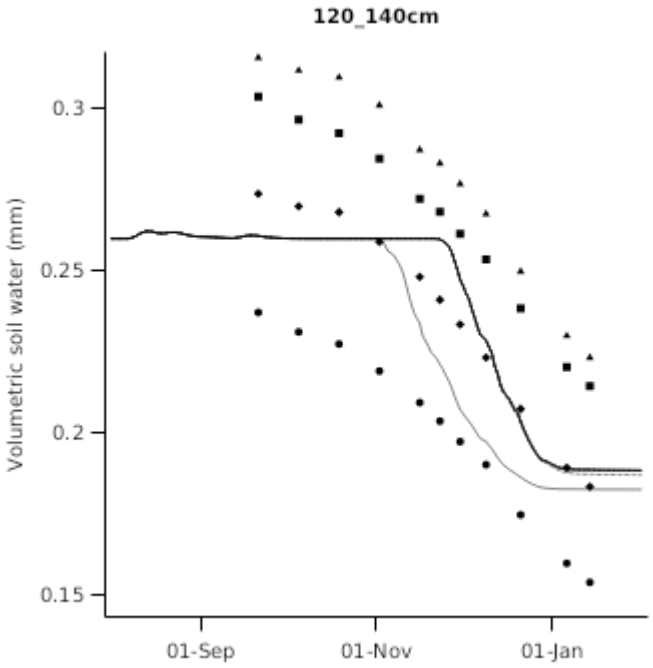

20_40cm
Volumetric soil water (mm)
0.4
0.3
0.2
01-Sep
01-Nov
01-Jan

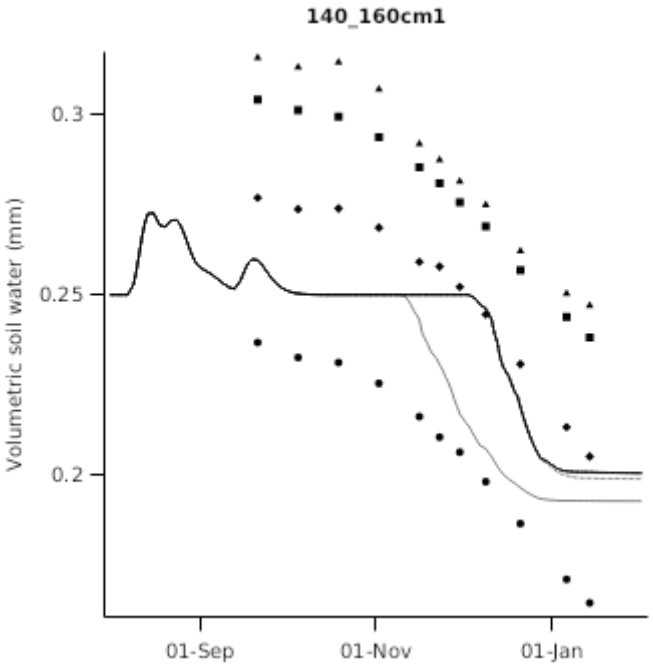

40_60cm
Volumetric soil water (mm)
0.3
0.2
0.1
01-Sep
01-Nov
01-Jan

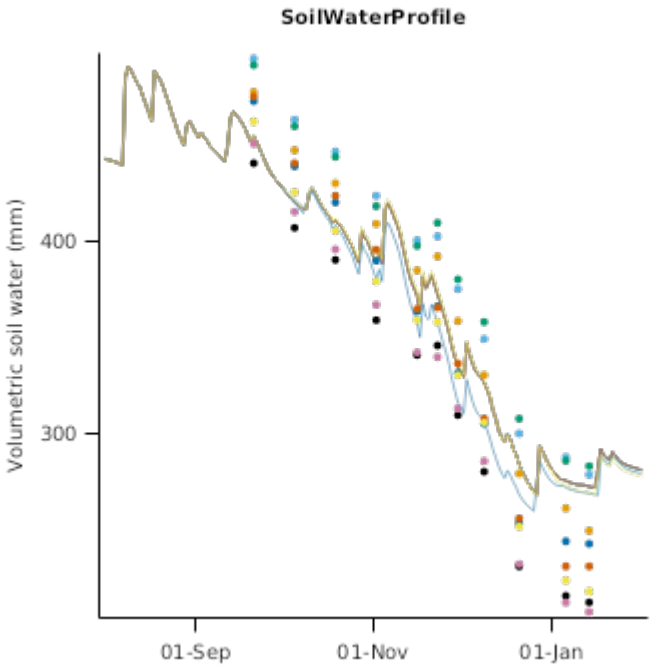

60_80cm
Volumetric soil water (mm)
0.3
0.25
0.2
0.15
01-Sep
01-Nov
01-Jan


80_100cm
Volumetric soil water (mm)
0.3
0.25
0.2
0.15
01-Sep
01-Nov
01-Jan


100_120cm
Volumetric soil water (mm)
0.3
0.25
0.2
0.15
01-Sep
01-Nov
01-Jan





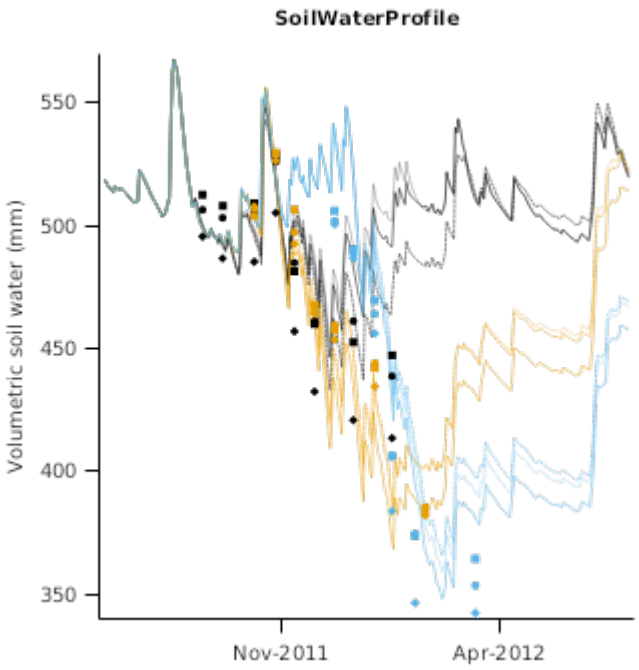


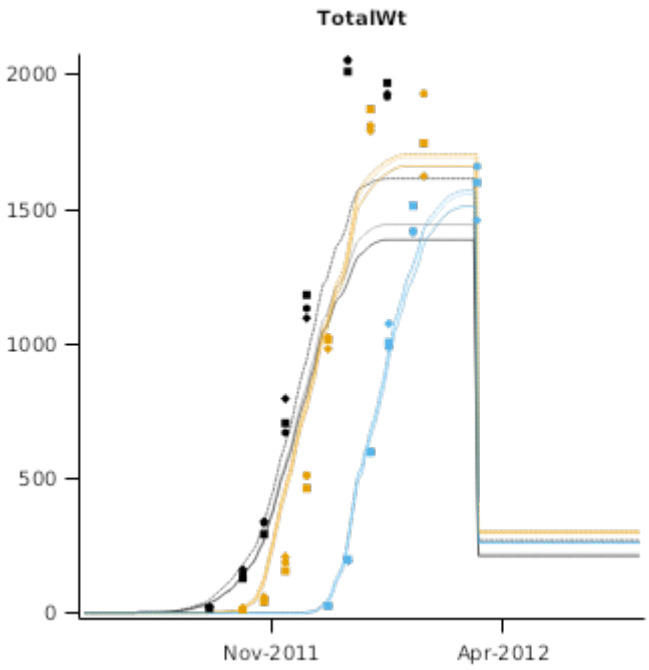
2.3.4 MCPD11_12

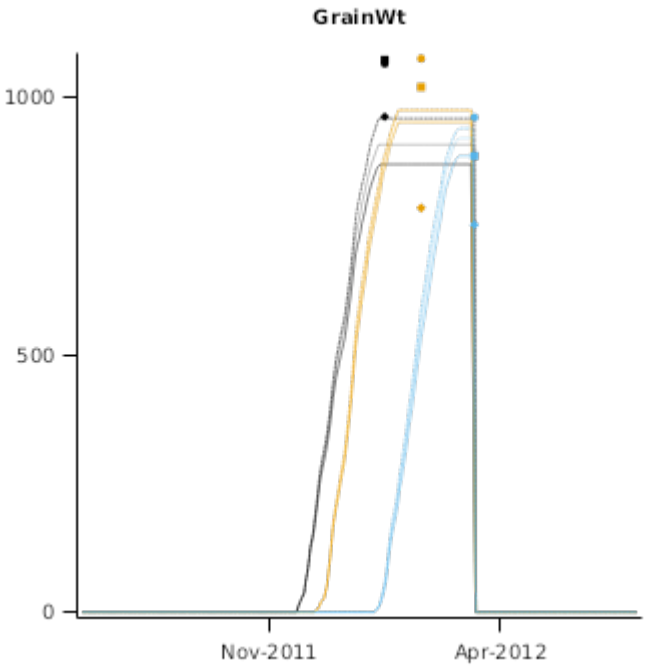
Following on from MCPD10_11, this experiment was conducted in A Block near Lincoln, New Zealand to test the effects of sowing time on apparent water use efficiency of three varieties of Barley. The results are un-published to date.

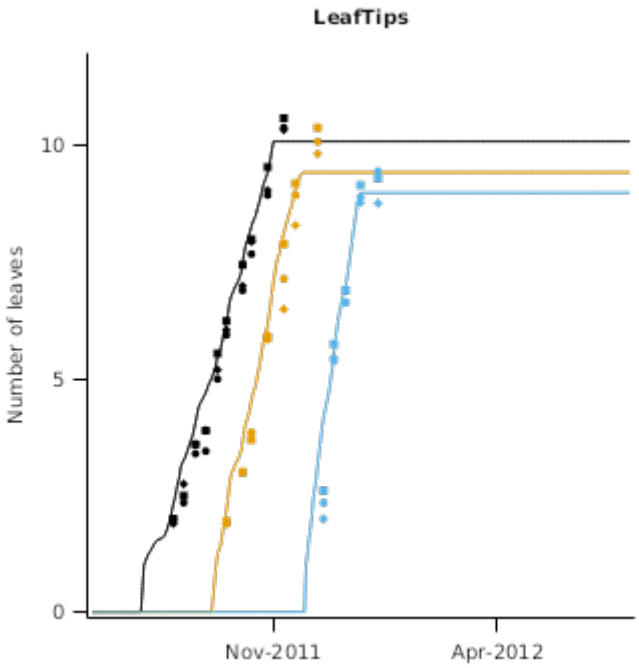
Treatments were simply 3 commercially available varieties of barley ('Booma','Dash' and 'Omaka') sown on three different sowing dates (13 Aug, 9 Sep and 15 Nov).

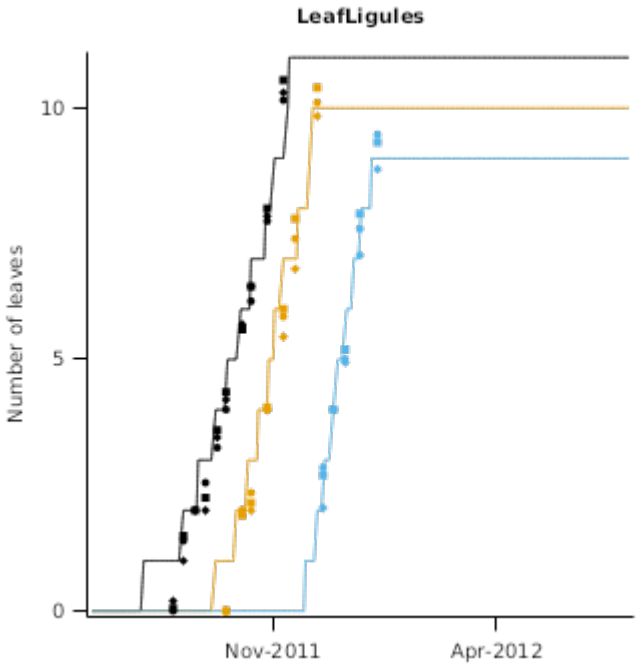
Biomass accumulation, Leaf appearance, leaf size, radiation interception and soil water content were measured at regular frequencies throughout the experiment.

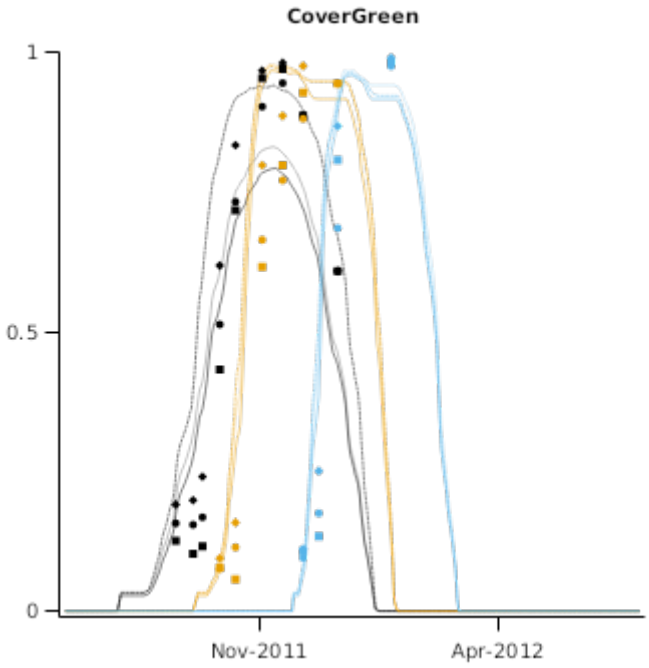

SoilWaterProfile
Volumetric soil water (mm)
550
500
450
400
350
Nov-2011
Apr-2012

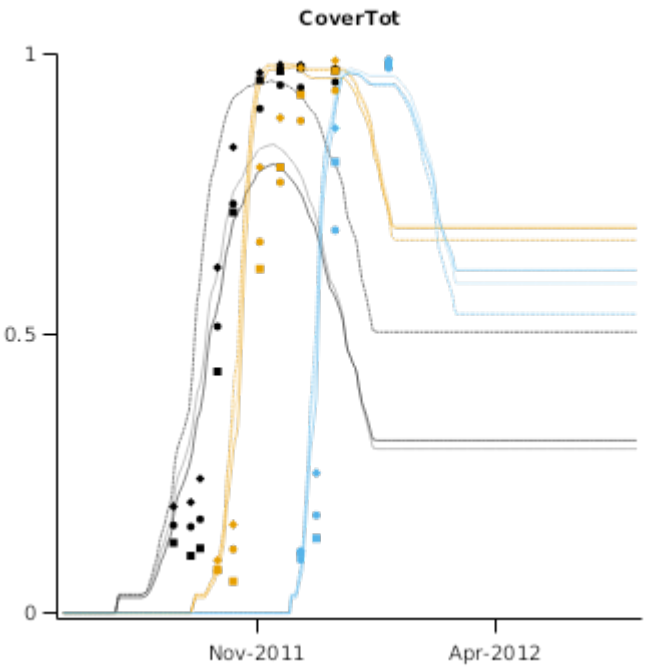

TotalWt
2000
1500
1000
500
0
Nov-2011
Apr-2012

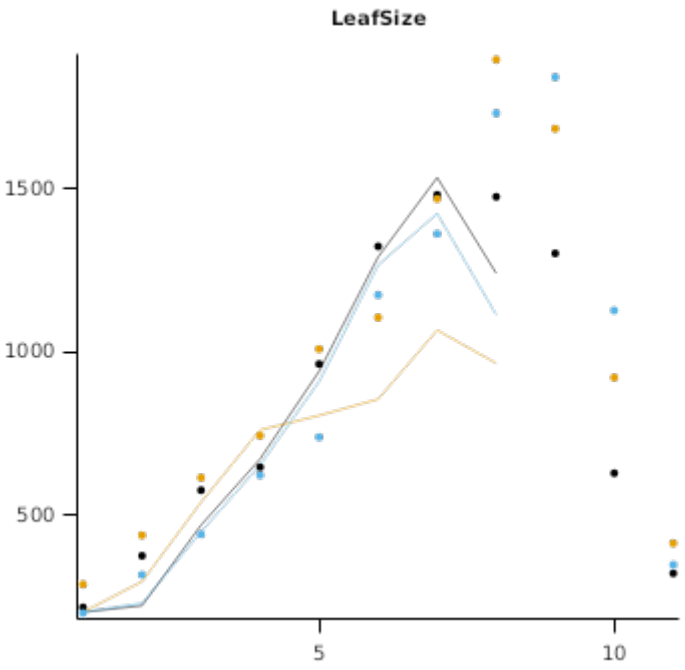

GrainWt
1000
500
0
Nov-2011
Apr-2012

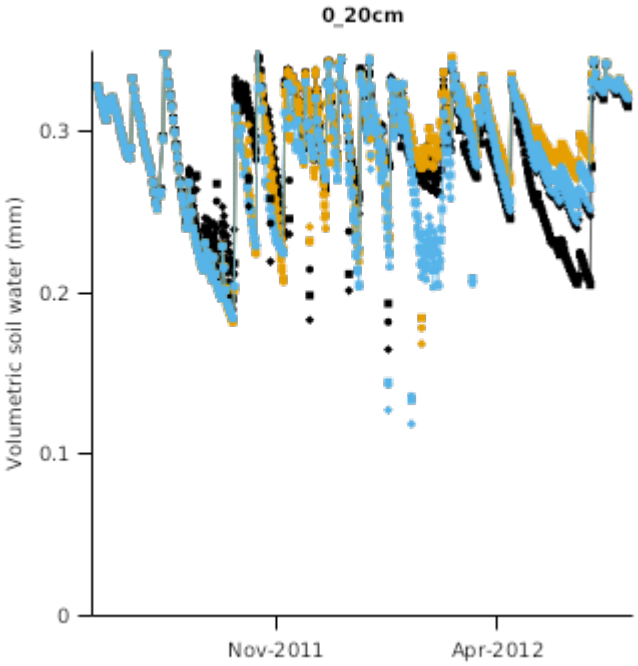

LeafTips
Number of leaves
10
5
0
Nov-2011
Apr-2012

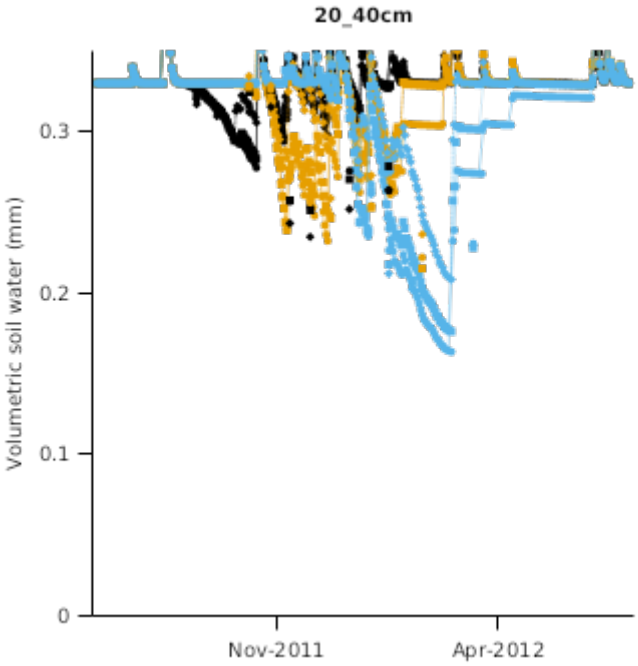

LeafLigules
Number of leaves
10
5
0
Nov-2011
Apr-2012

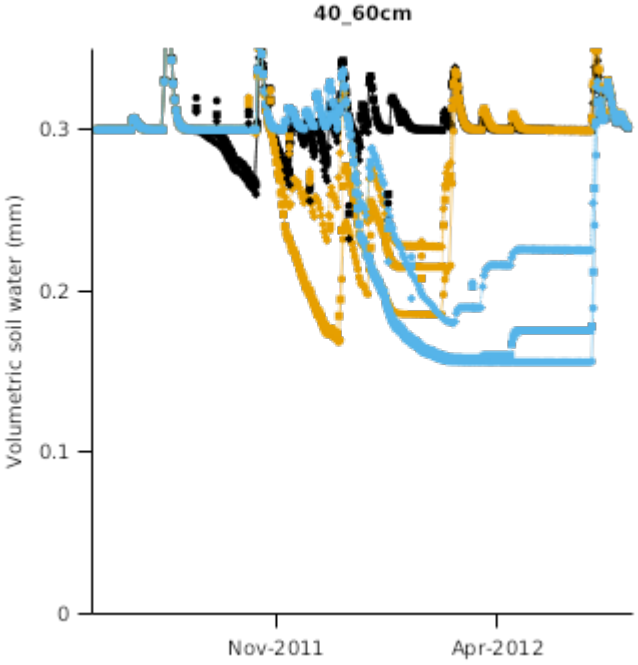

CoverGreen
1
0.5
0
Nov-2011
Apr-2012

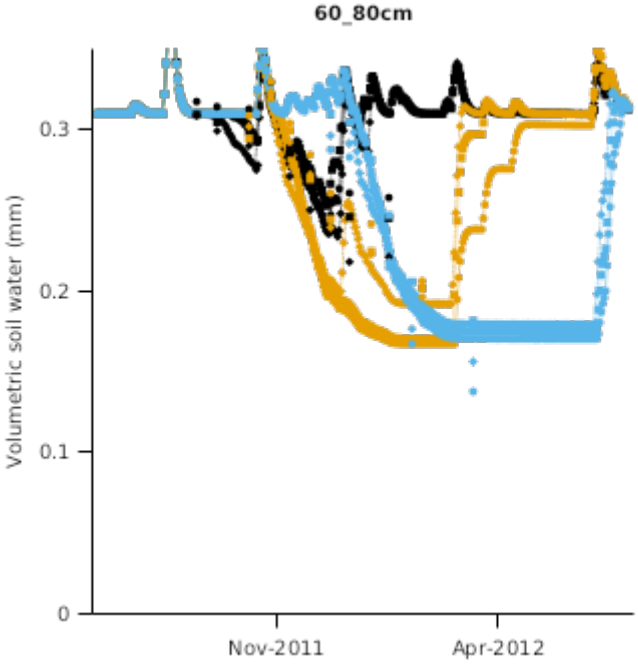

CoverTot
1
0.5
0
Nov-2011
Apr-2012

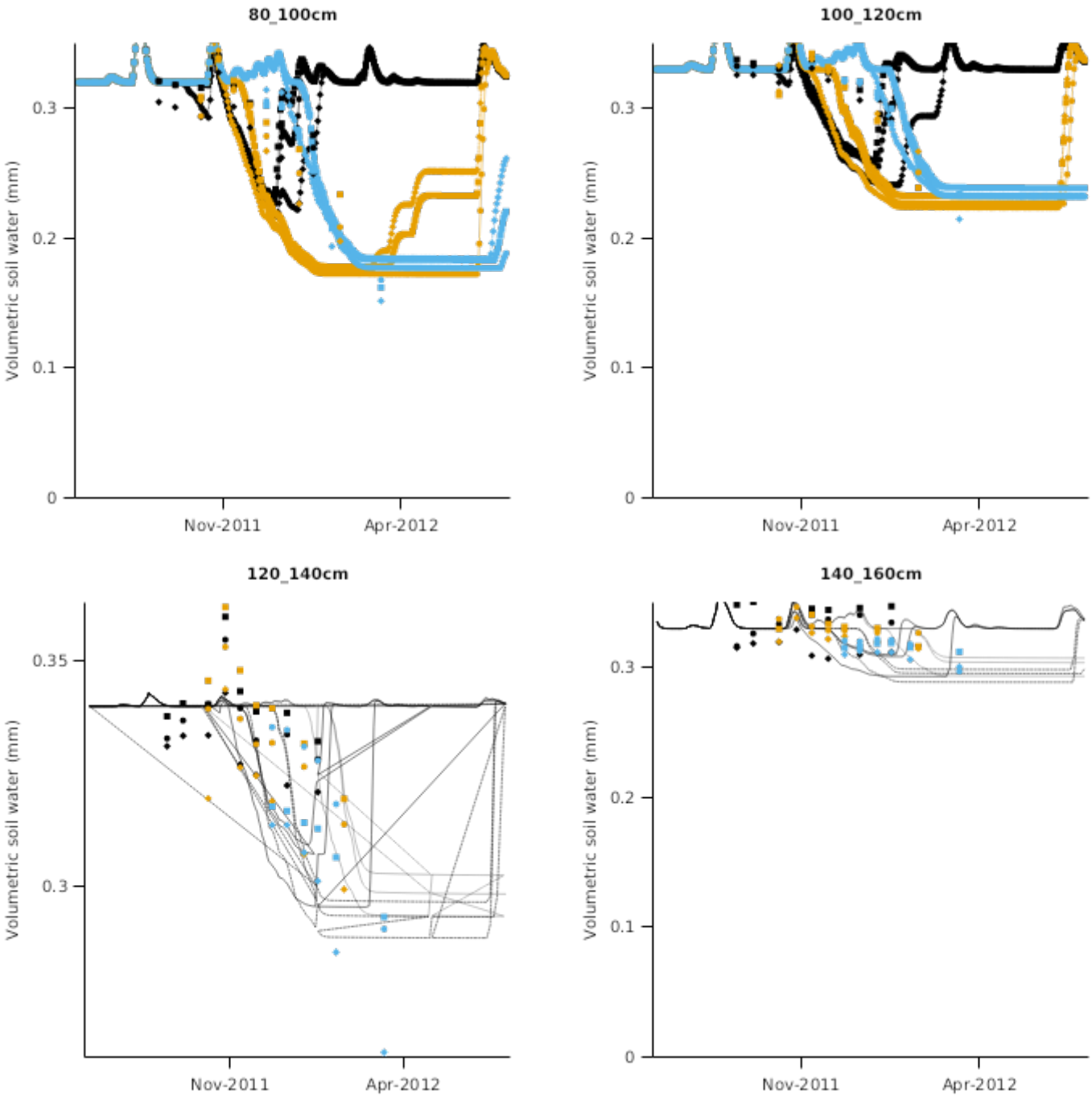

LeafSize
1500
1000
500
5
10


0_20cm
Volumetric soil water (mm)
0.3
0.2
0.1
0
Nov-2011
Apr-2012


20_40cm
Volumetric soil water (mm)
0.3
0.2
0.1
0
Nov-2011
Apr-2012


40_60cm
Volumetric soil water (mm)
0.3
0.2
0.1
0
Nov-2011
Apr-2012


60_80cm
Volumetric soil water (mm)
0.3
0.2
0.1
0
Nov-2011
Apr-2012



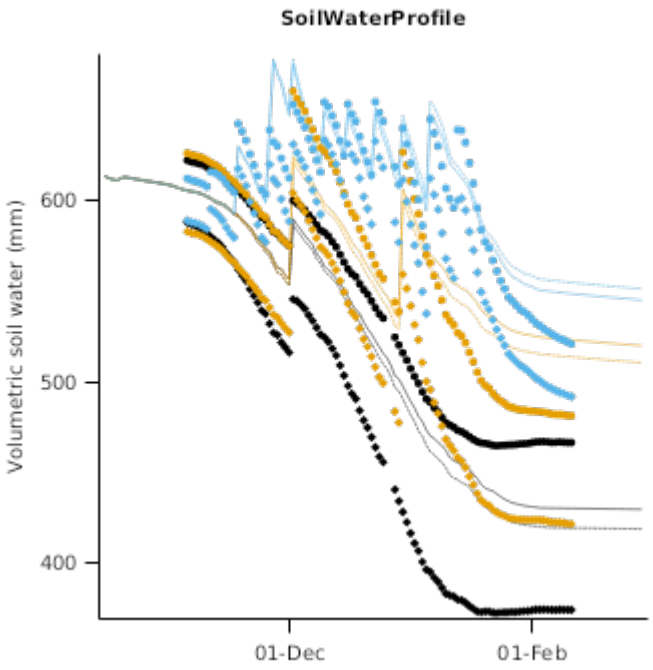
2.3.5 RS2014_15

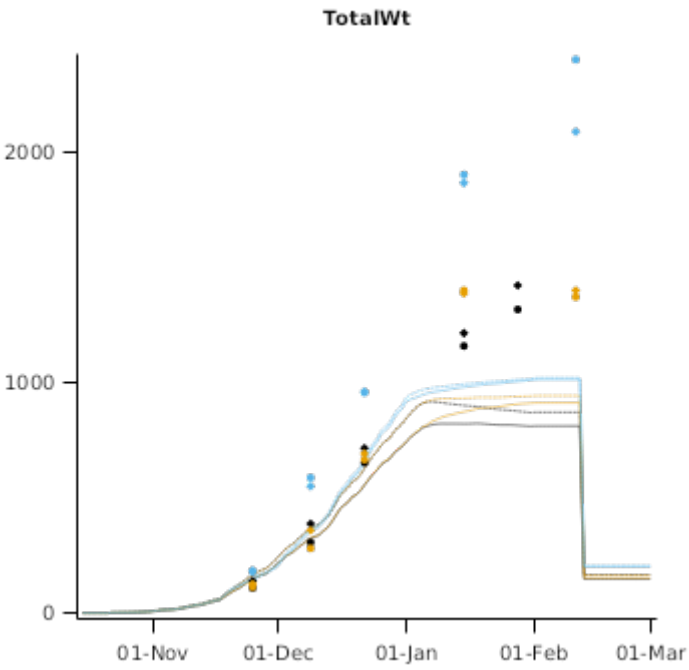
This was a field experiment established at the New Zealand Institute for Plant & Food Research Limited rain-out shelter in October 2014. Barley cultivars cv Dash and cv Omaka, differing canopy characteristics and water extraction capabilities were established with a range of irrigation treatments aimed at producing a range of soil moisture deficits.

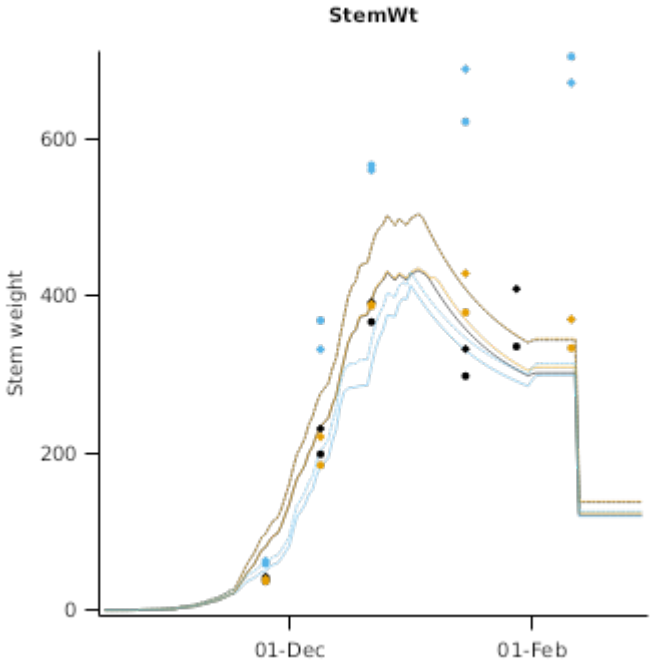
- High =Full replacement irrigation: replace weekly, measured crop water use;
- Mid =Intermediate replacement with reduced frequency and higher volume e.g. monthly application of Â½ measured crop water use;
- Low =Nil (or near nil) irrigation, e.g. irrigated once at anthesis.

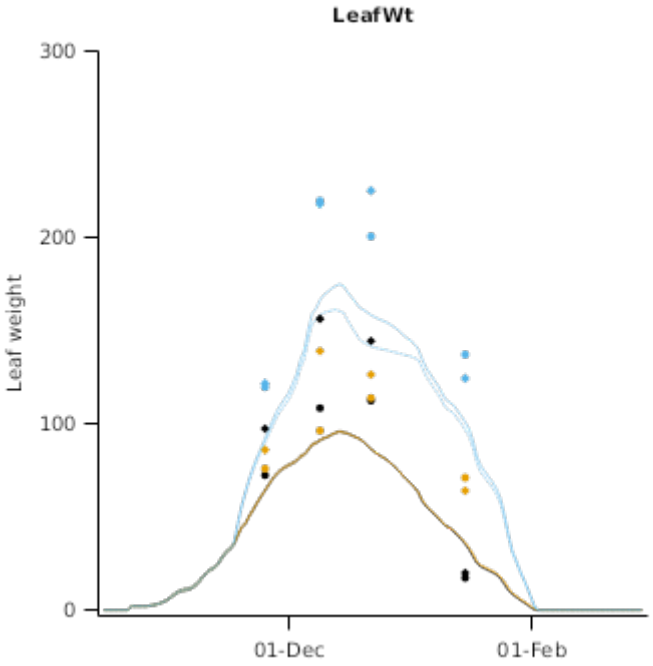
The treatments were monitored for:

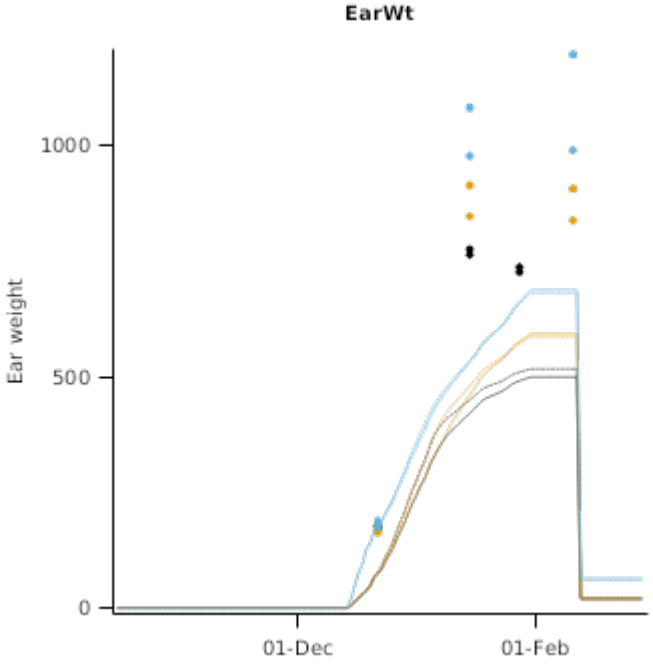
- Soil water - this was measured continuously using auto logging TDR and weekly using a neutron probe;
- Canopy light interception;
- Biomass - quantified four times during crop growth and at final harvest
- Leaf area index

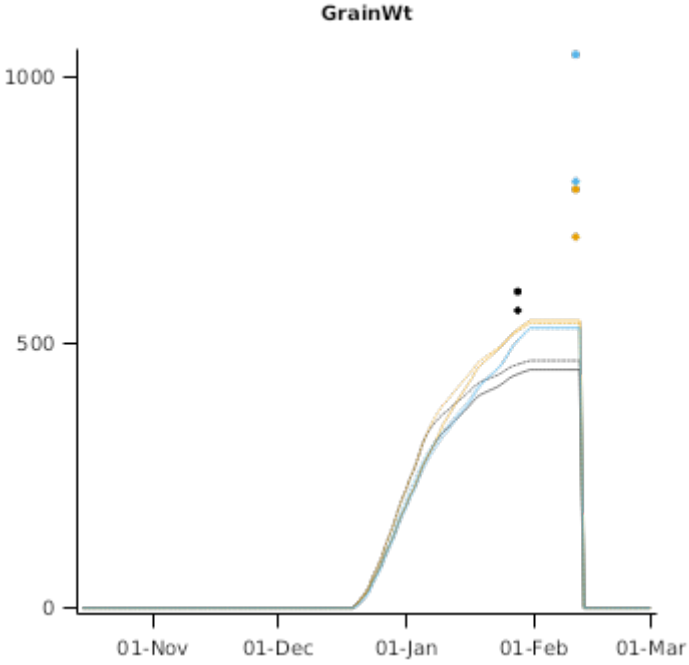

SoilWaterProfile
Volumetric soil water (mm)
600
500
400
01-Dec
01-Feb


TotalWt
2000
1000
0
01-Nov
01-Dec
01-Jan
01-Feb
01-Mar

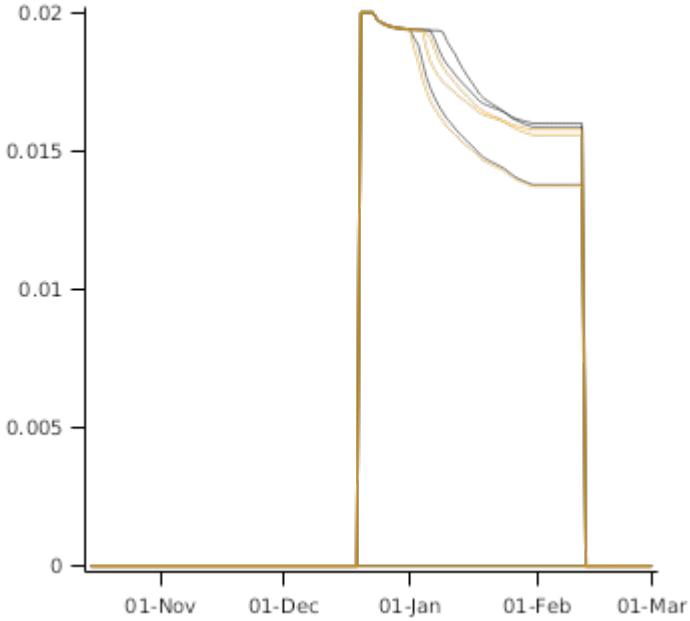

StemWt
Stem weight
600
400
200
0
01-Dec
01-Feb


LeafWt
Leaf weight
300
200
100
0
01-Dec
01-Feb

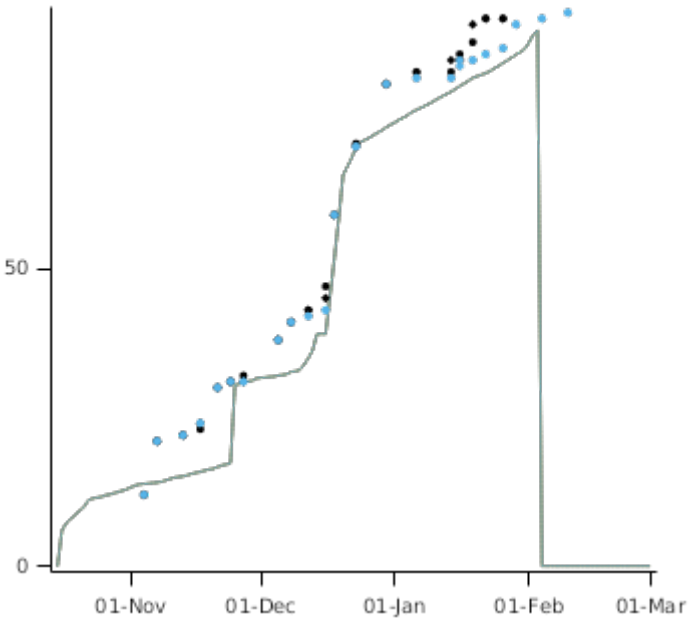

EarWt
Ear weight
1000
500
0
01-Dec
01-Feb


GrainWt
1000
500
0
01-Nov
01-Dec
01-Jan
01-Feb
01-Mar

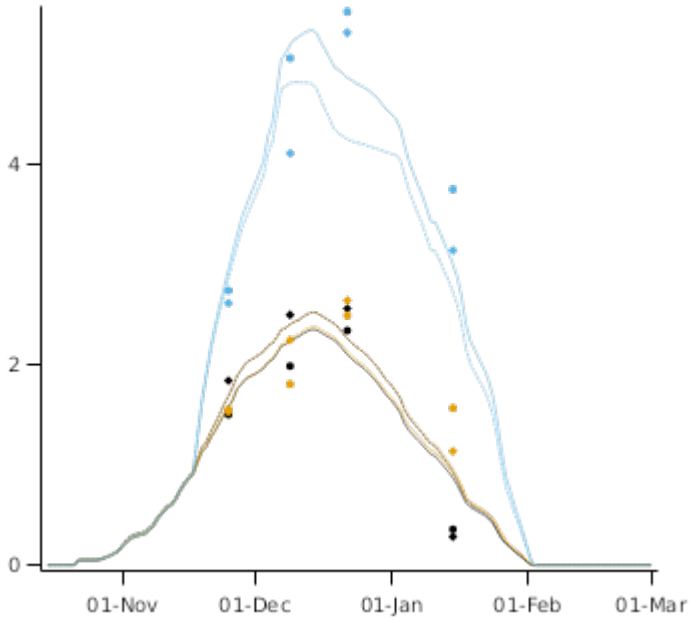
GrainN



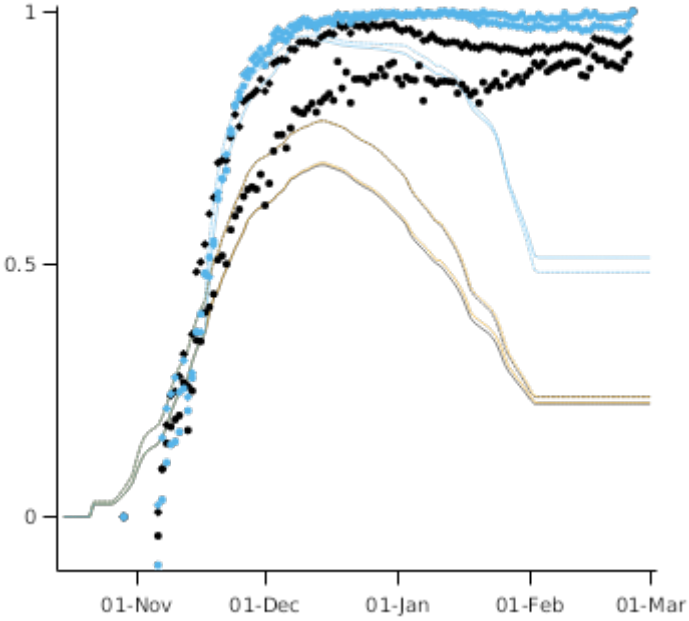
Zadok



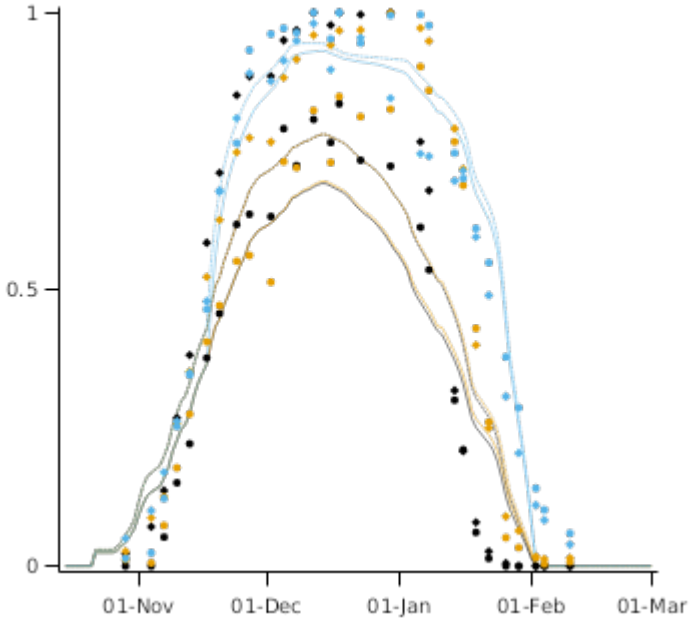
LAI



CoverTotal



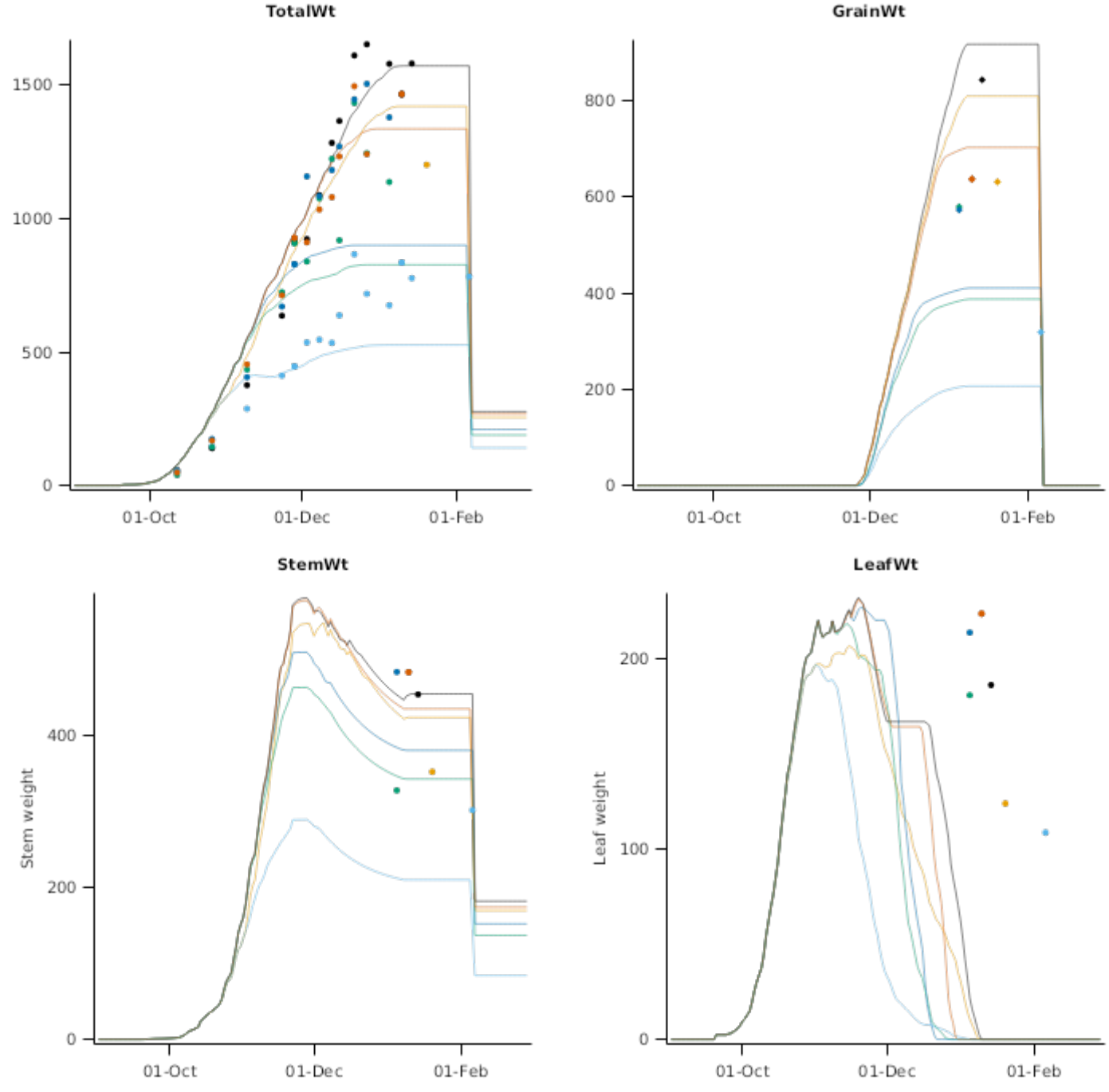
CoverGreen

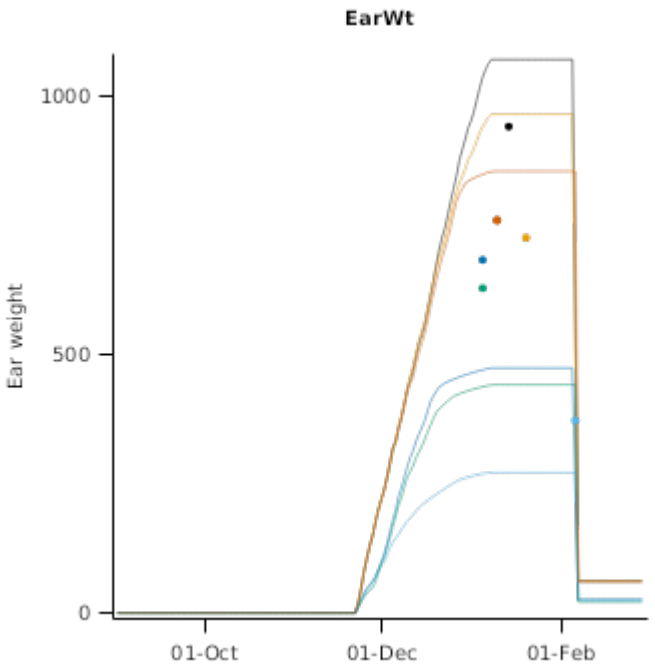


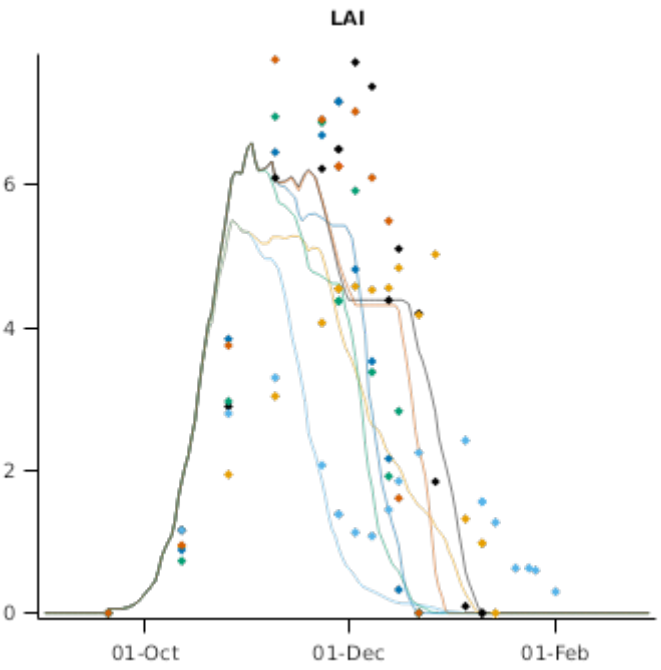
2.3.6 RS1988_89

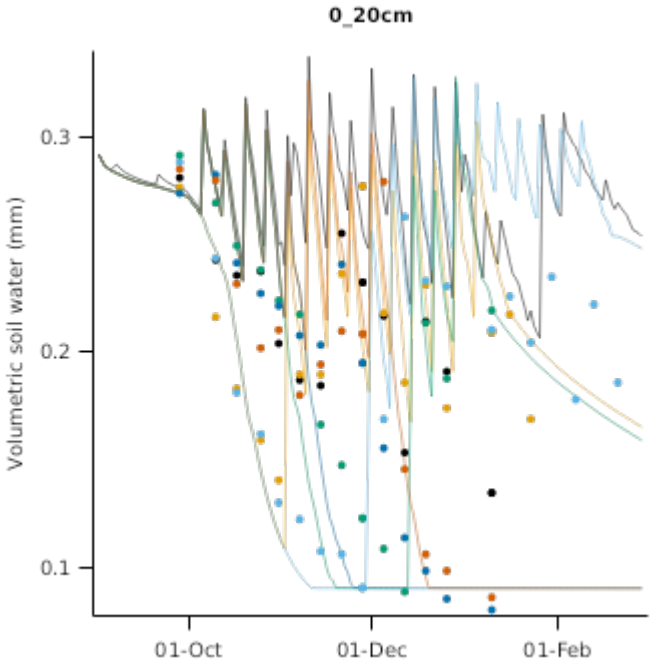
This experiment was conducted in the rainshelter at Plant and Food Research in Lincoln, New Zealand. The objective was to evaluate the effect of drought on the yield of barley crops. The experiment is fully described by Jamieson et al. (1995). Briefly, 'Triumph' barley was sown at 188kg/ha on 07 September 1988. This sowing rate resulted in a population of 291 Â± 6 plants/m2. Plants were evaluated for their response to drought of varying duration. The treatments were:

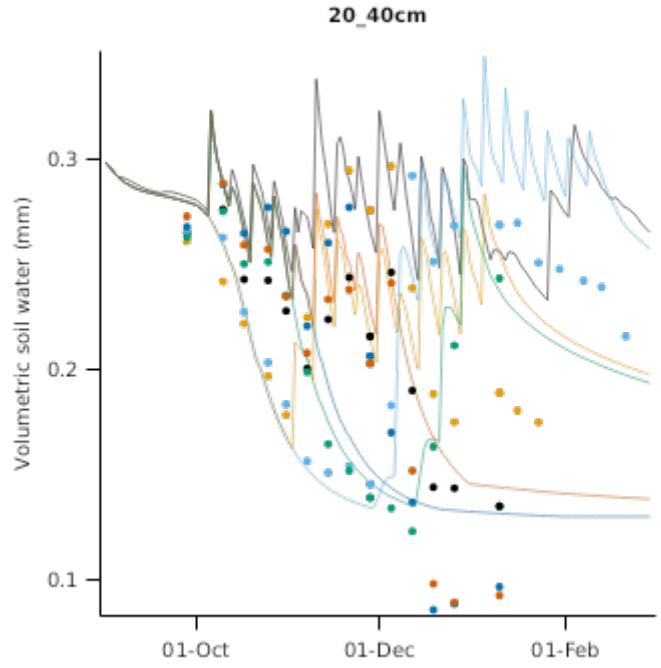
- Full irrigation â€“ measured ET replaced weekly (06 October to 29 December)
- Early Drought 1 â€“ irrigated from 03 November to 05 January
- Early Drought 2 â€“ irrigated from 17 November to 19 January
- Early Drought 3 â€“ irrigated from 24 November to 19 January
- Early Drought 3 â€“ irrigated from 01 December to 09 February
- Middle Drought 1 â€“ irrigated (06/10/1988 to 03/11/1988) and (24/11/1988 to 29/12/1989)
- Middle Drought 2 â€“ irrigated (06/10/1988 to 03/11/1988) and (01/12/1988 to 29/12/1989)
- Middle Drought 3 â€“ irrigated (06/10/1988 to 03/11/1988) and (15/12/1988 to 29/12/1989)
- Middle Drought 3 â€“ irrigated (06/10/1988 to 03/11/1988)
- Late Drought 1 â€“ irrigated (06/10/1988 to 17/11/1988)
- Late Drought 2 â€“ irrigated (06/10/1988 to 24/11/1988)
- Late Drought 3 â€“ irrigated (06/10/1988 to 01/12/1989)

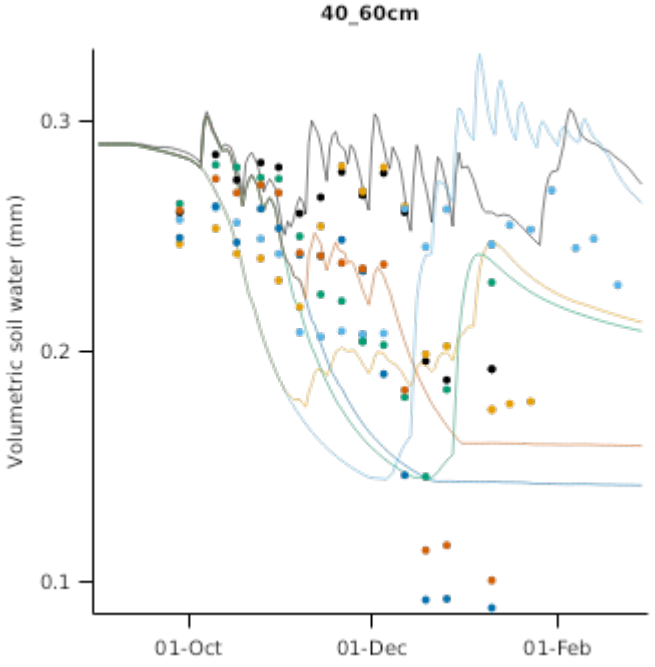


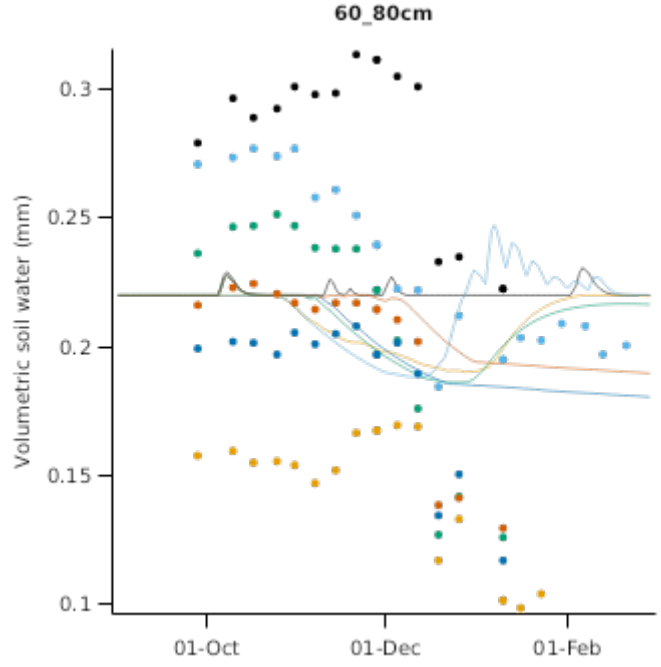

EarWt
Ear weight
1000
500
0
01-Oct
01-Dec
01-Feb

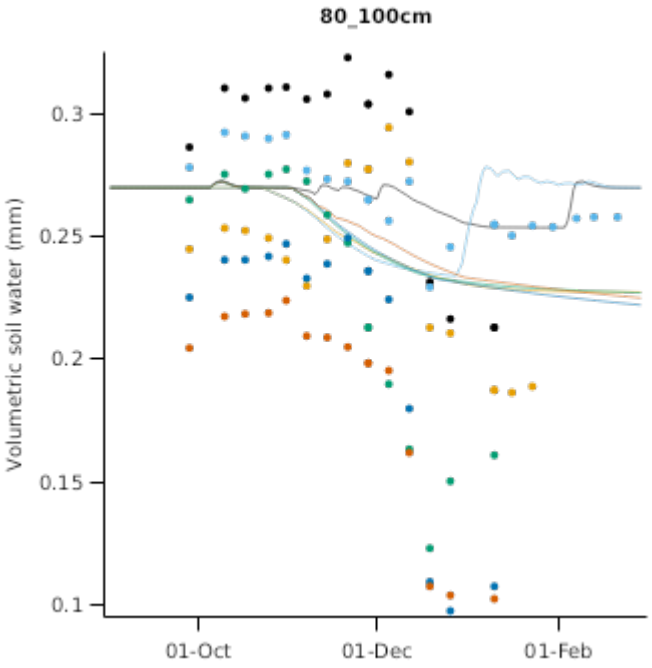

LAI
6
4
2
0
01-Oct
01-Dec
01-Feb

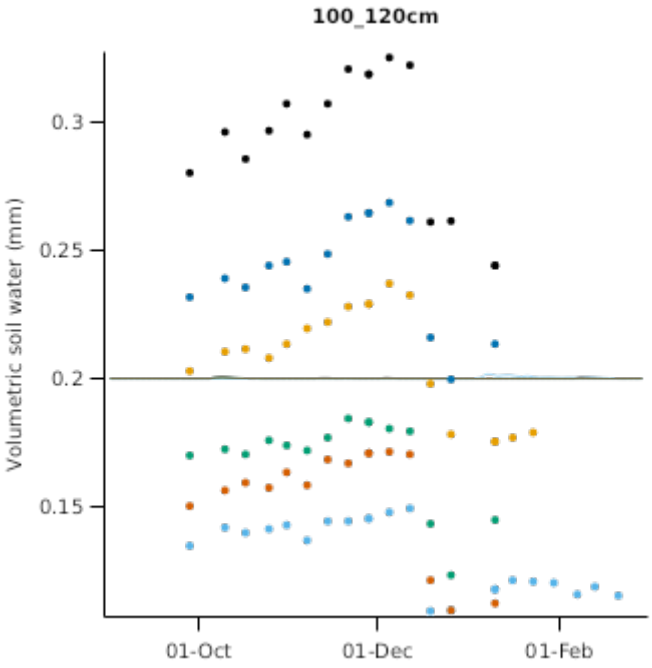

0_20cm
Volumetric soil water (mm)
0.3
0.2
0.1
01-Oct
01-Dec
01-Feb

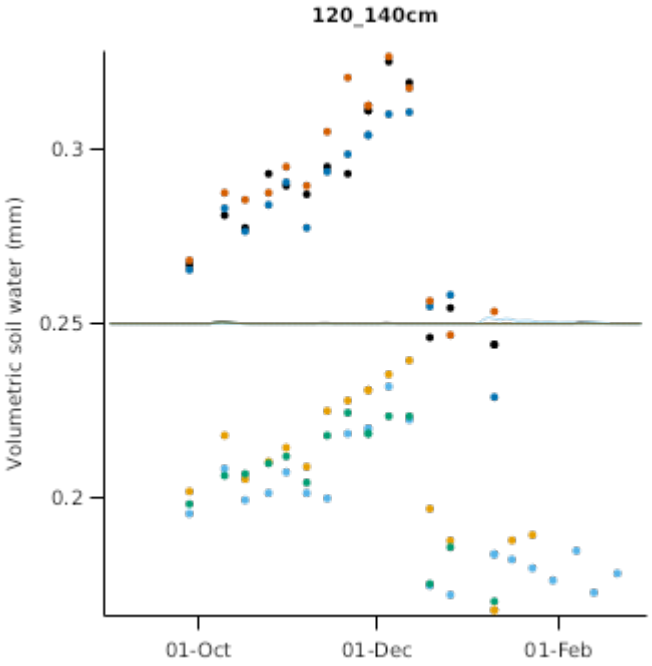

20_40cm
Volumetric soil water (mm)
0.3
0.2
0.1
01-Oct
01-Dec
01-Feb

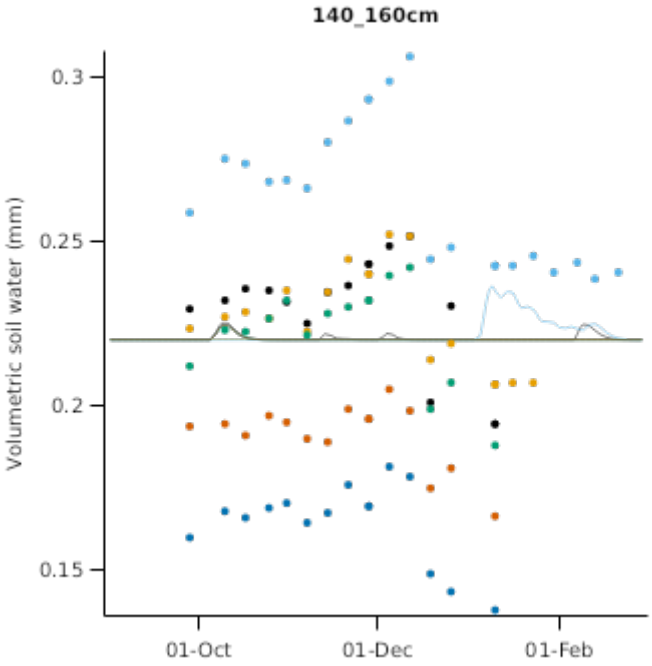

40_60cm
Volumetric soil water (mm)
0.3
0.2
0.1
01-Oct
01-Dec
01-Feb

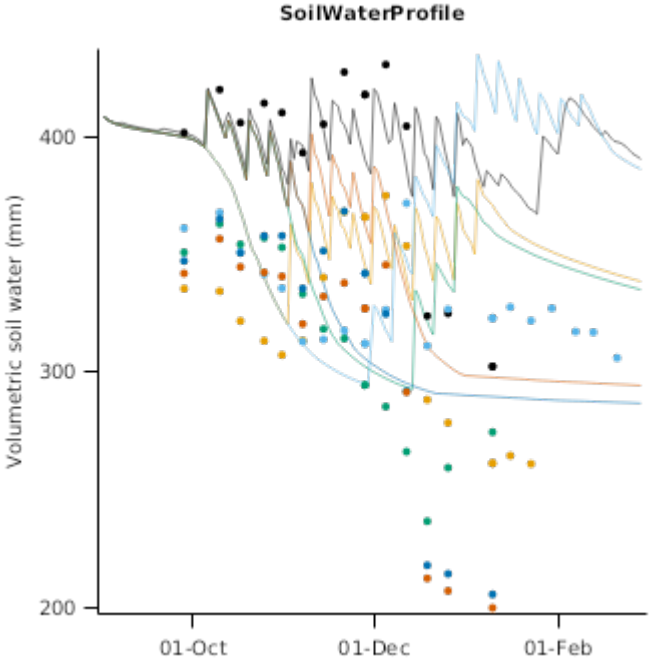

60_80cm
Volumetric soil water (mm)
0.3
0.25
0.2
0.15
0.1
01-Oct
01-Dec
01-Feb


80_100cm
Volumetric soil water (mm)
0.3
0.25
0.2
0.15
0.1
01-Oct
01-Dec
01-Feb


100_120cm
Volumetric soil water (mm)
0.3
0.25
0.2
0.15
01-Oct
01-Dec
01-Feb


120_140cm
Volumetric soil water (mm)
0.3
0.25
0.2
01-Oct
01-Dec
01-Feb

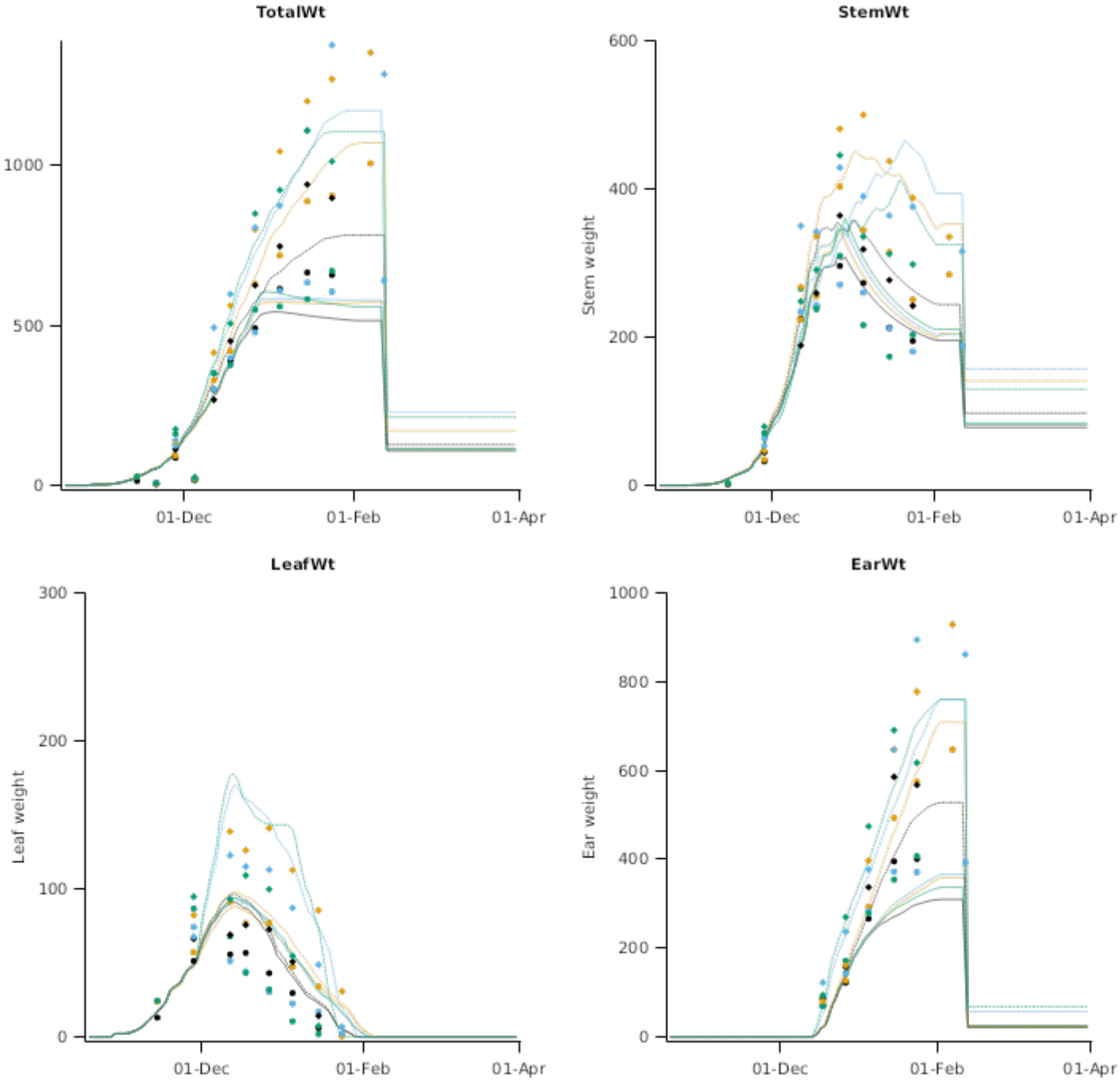

140_160cm
Volumetric soil water (mm)
0.3
0.25
0.2
0.15
01-Oct
01-Dec
01-Feb

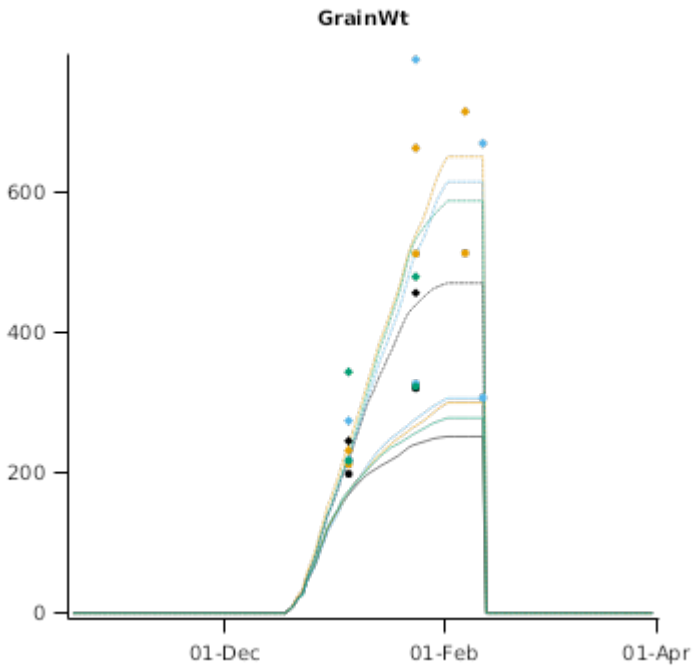

SoilWaterProfile
Volumetric soil water (mm)
400
300
200
01-Oct
01-Dec
01-Feb

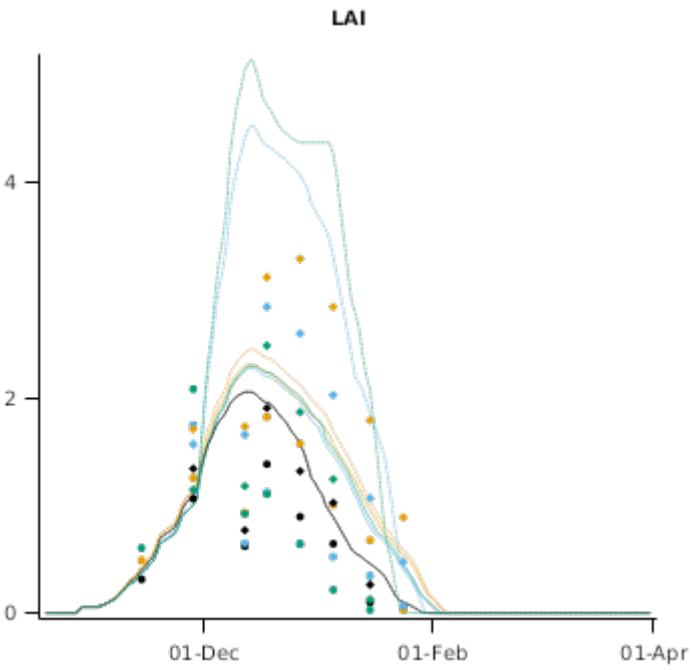
2.3.7 RS1995_96

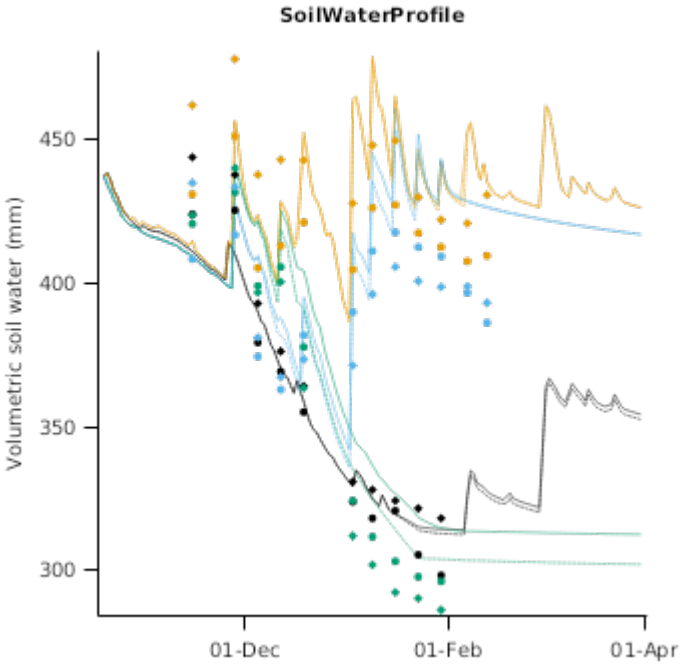
This is a water response trial conducted inside and outside the rain shelter at the New Zealand Institute for Plant & Food Research in Lincoln and described in De Ruiter et al (1999). Briefly, a vernalisation insensitive barley, variety "Valetta", was sown at 280 plant/m^2 on 20 October 1995 and subjected to five water treatments as follows:

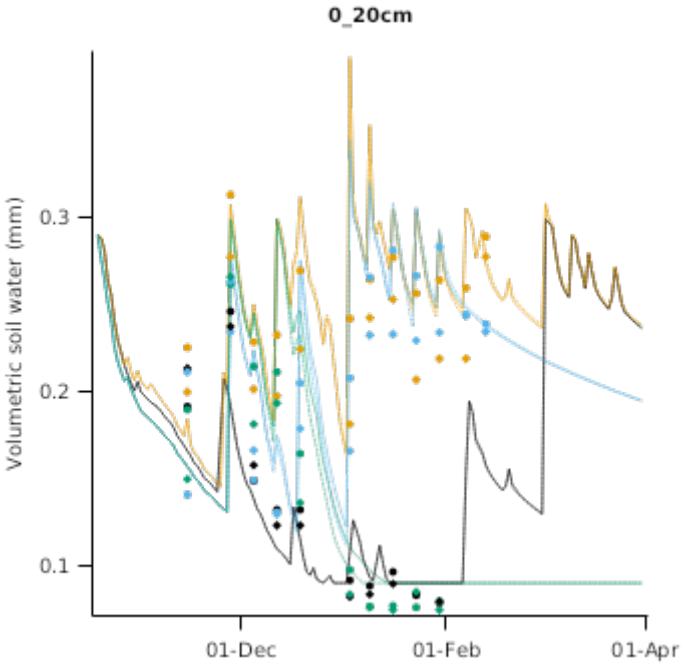
- Full drought (in rain shelter) â€“ was not irrigated except for 17 mm rainfall as a result of shelter failure 42 days after sowing;
- Early drought (in rain shelter) â€“ also receive 17 mm rainfall and the drought was fully relieved at the onset stem elongation;
- Late drought (in rain shelter) â€“ fully irrigated (i.e. net crop water use + soil water evaporation) up to stem elongation and nil irrigation thereafter;
- Rain-fed (outside the rain shelter) â€“ received all the rain but no irrigation;
- Full irrigation (located outside the rain shelter) â€“ received all the rain and irrigation to replace ET.

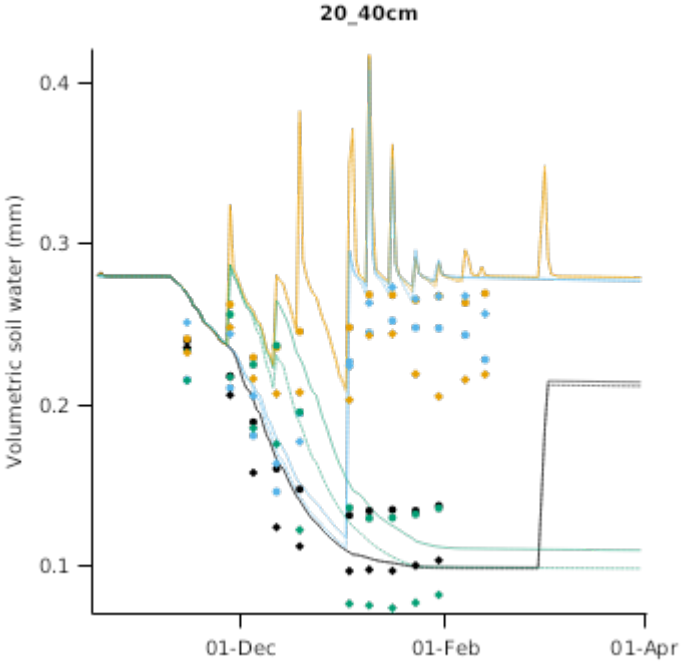


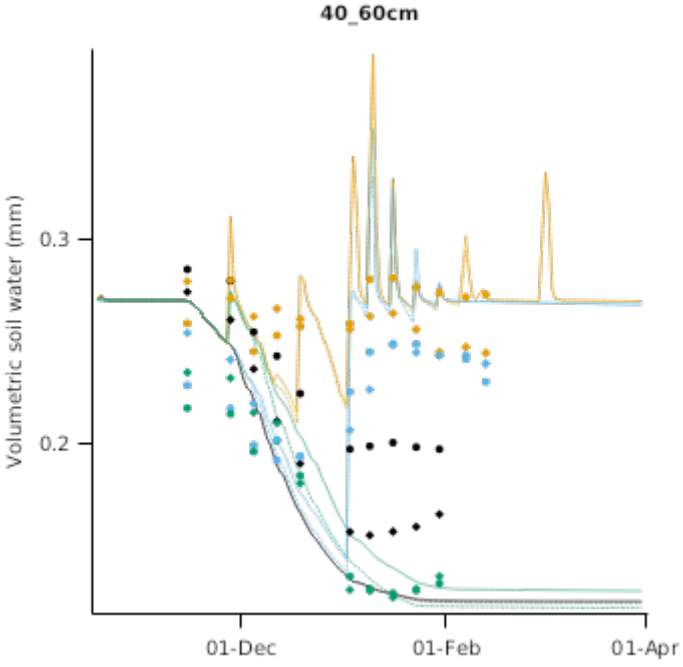

GrainWt
600
400
200
0
01-Dec
01-Feb
01-Apr

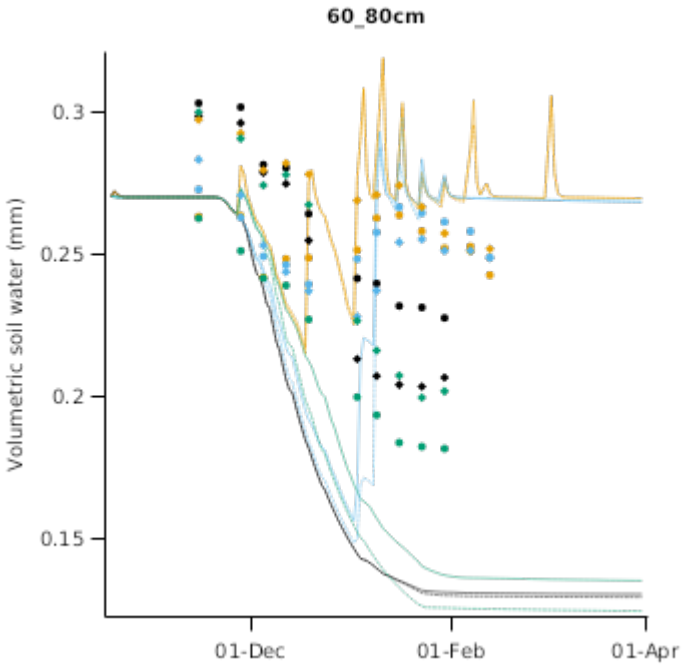

LAI
4
2
0
01-Dec
01-Feb
01-Apr

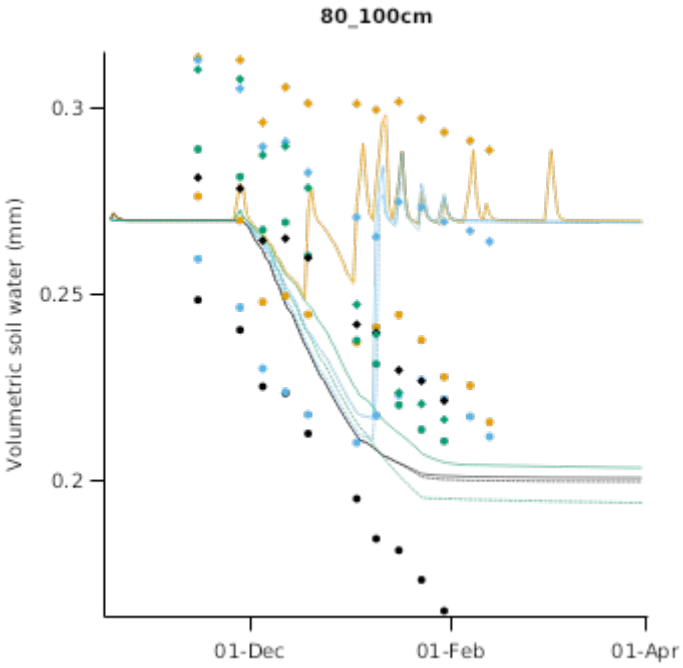

SoilWaterProfile
Volumetric soil water (mm)
450
400
350
300
01-Dec
01-Feb
01-Apr

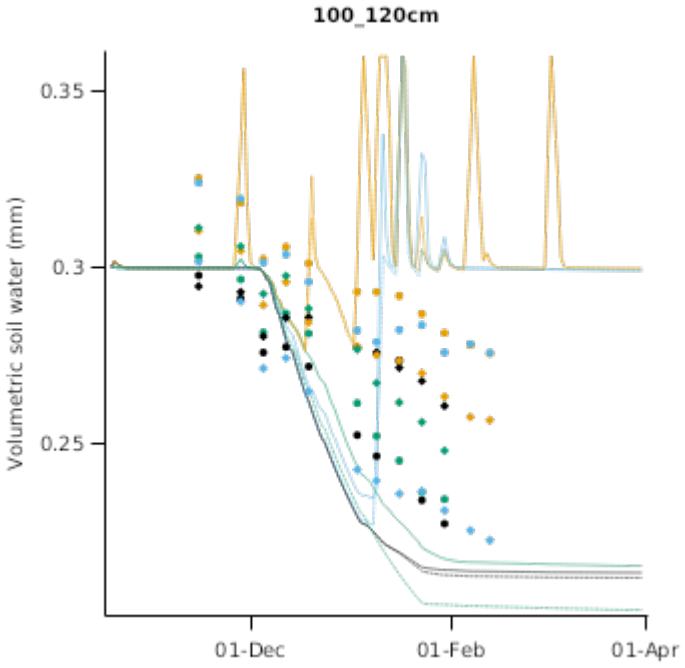

0_20cm
Volumetric soil water (mm)
0.3
0.2
0.1
01-Dec
01-Feb
01-Apr

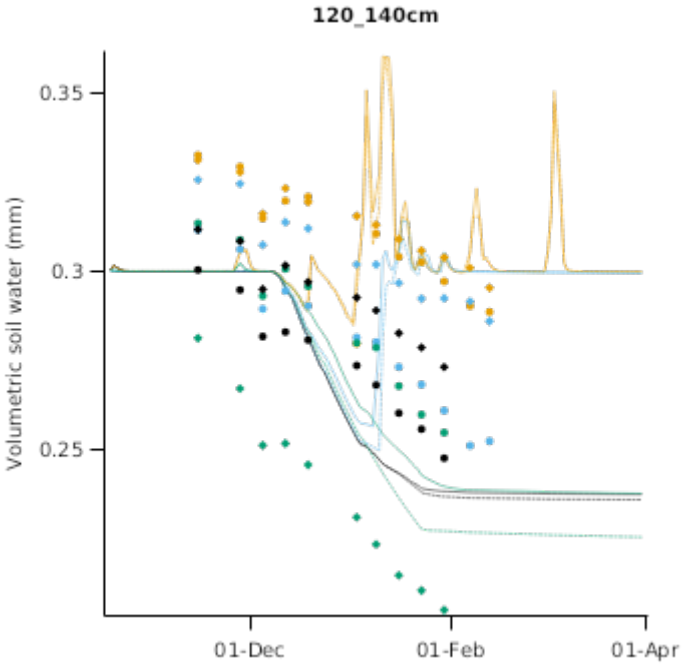

20_40cm
Volumetric soil water (mm)
0.4
0.3
0.2
0.1
01-Dec
01-Feb
01-Apr

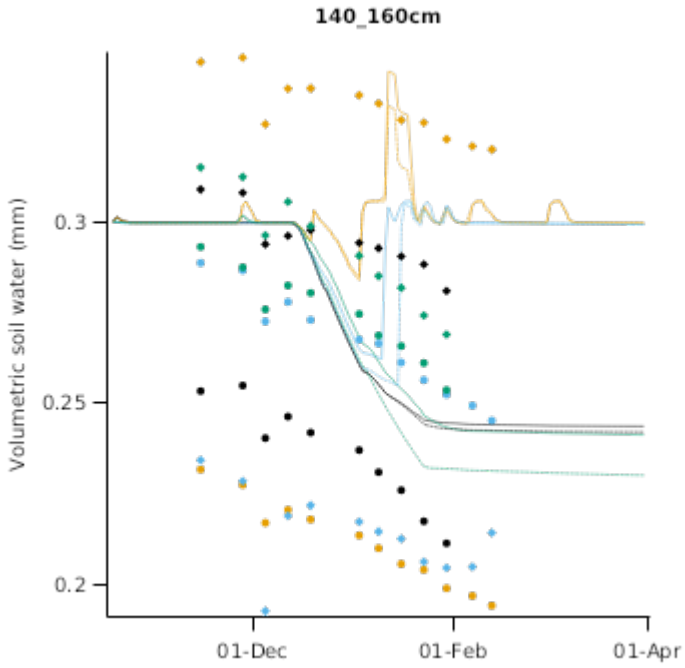

40_60cm
Volumetric soil water (mm)
0.3
0.2
01-Dec
01-Feb
01-Apr

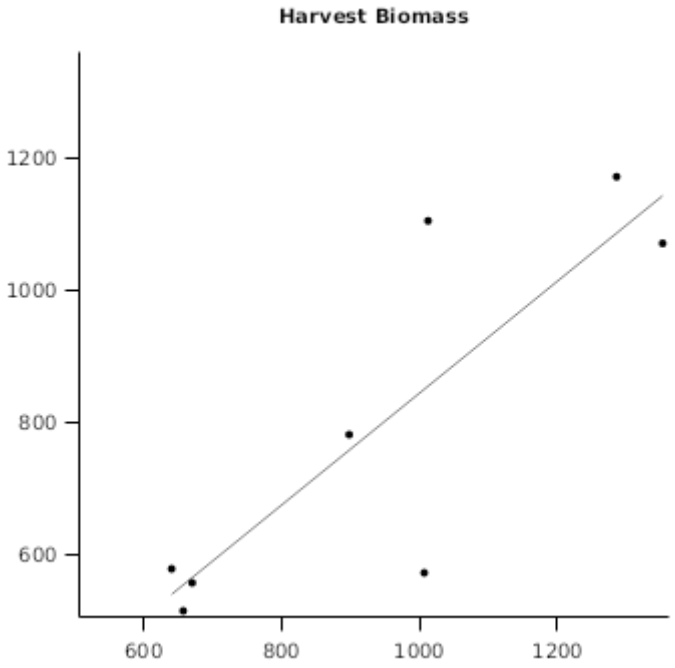

60_80cm
Volumetric soil water (mm)
0.3
0.25
0.2
0.15
01-Dec
01-Feb
01-Apr

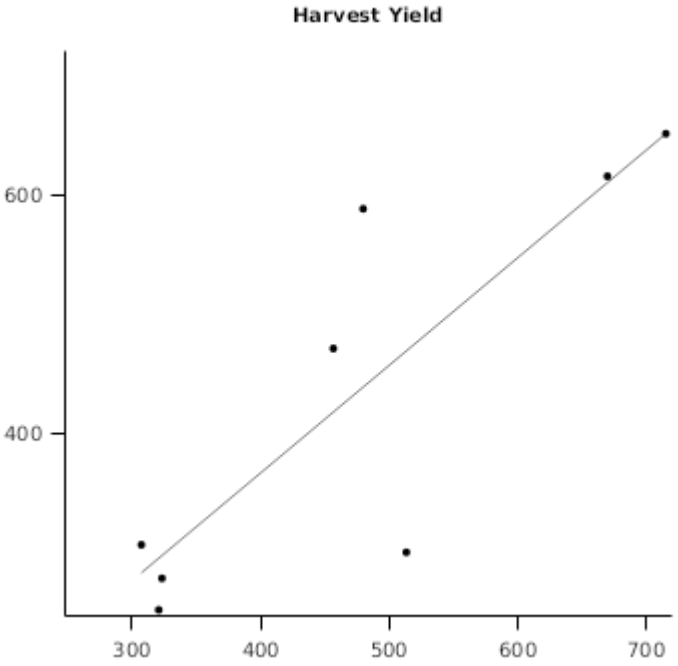

80_100cm
Volumetric soil water (mm)
0.3
0.25
0.2
01-Dec
01-Feb
01-Apr


100_120cm
Volumetric soil water (mm)
0.35
0.3
0.25
01-Dec
01-Feb
01-Apr


120_140cm
Volumetric soil water (mm)
0.35
0.3
0.25
01-Dec
01-Feb
01-Apr



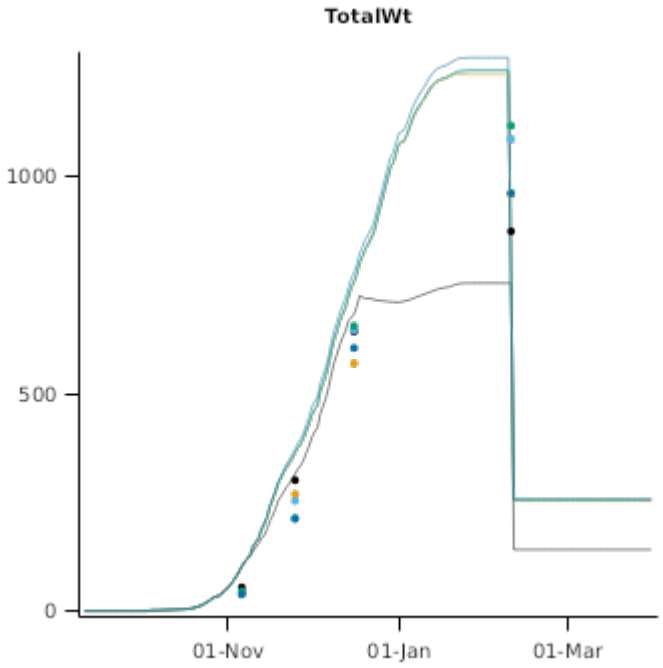


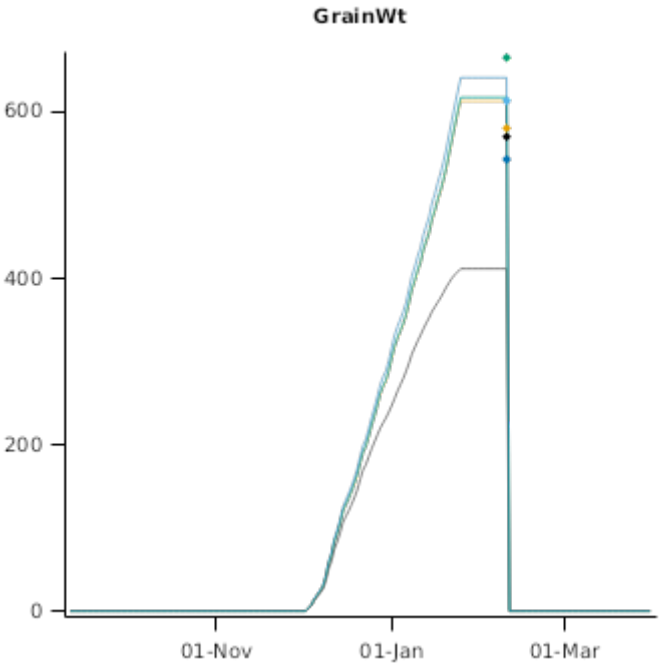


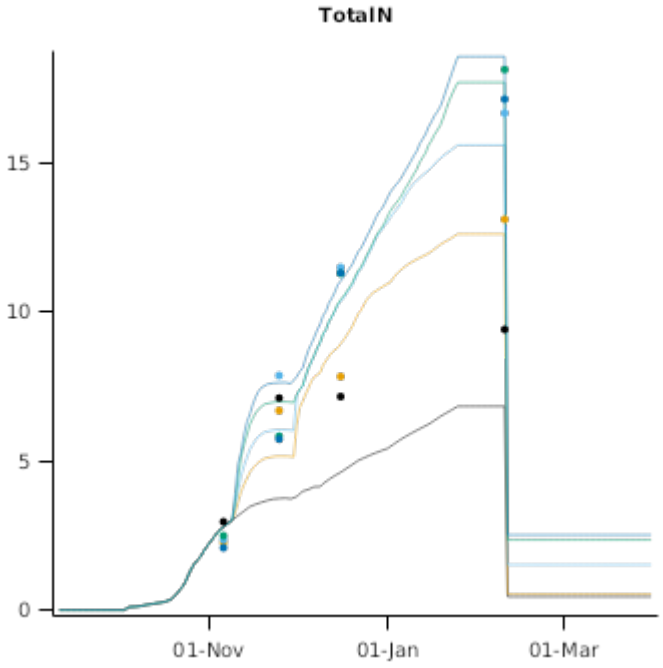
2.3.8 LUDF2015_16

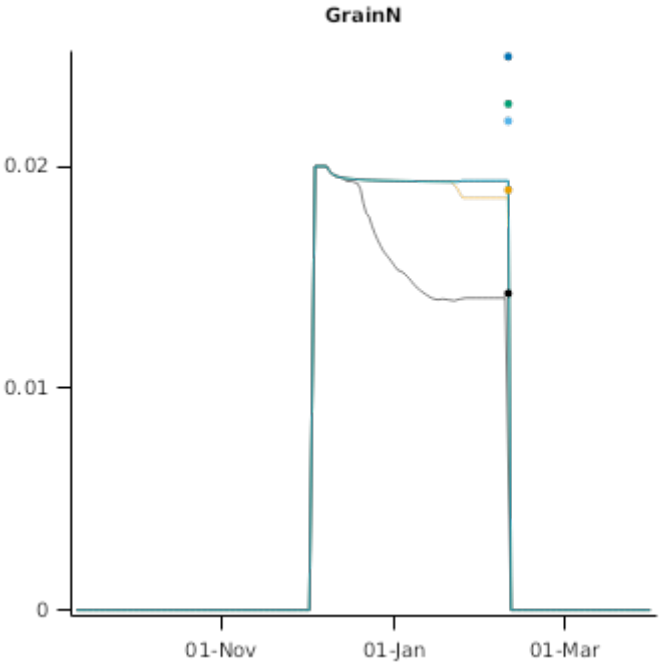
This is the mineral nitrogen (N) validation trial conducted by the New Zealannd Institure for Plant & Food Research from September 2015 to February 2016. The experiment was established at the Lincoln University Dairy Farm on a deep well-drained Templeton silt loam soil. Five N fertiliser treatments were evaluated:

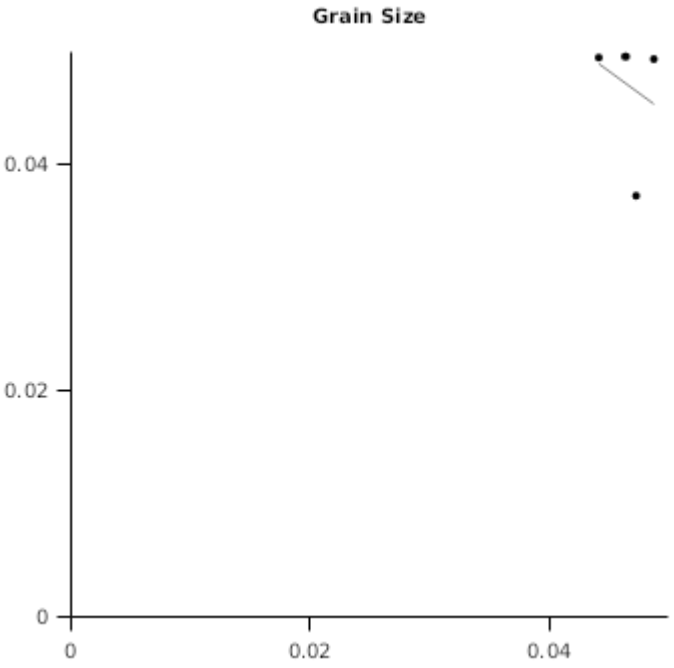
- Nil (0%) N - the crop did not get any fertiliser N
- 50% N - the crop received 50% of the required fertiliser N
- 75% N - the crop received 75% of the required fertiliser N
- 100% N - the crop received the required fertiliser N as estimated by the fertiliser calculator
- 125% N - the crop received 25% fertiliser N above the requirement.

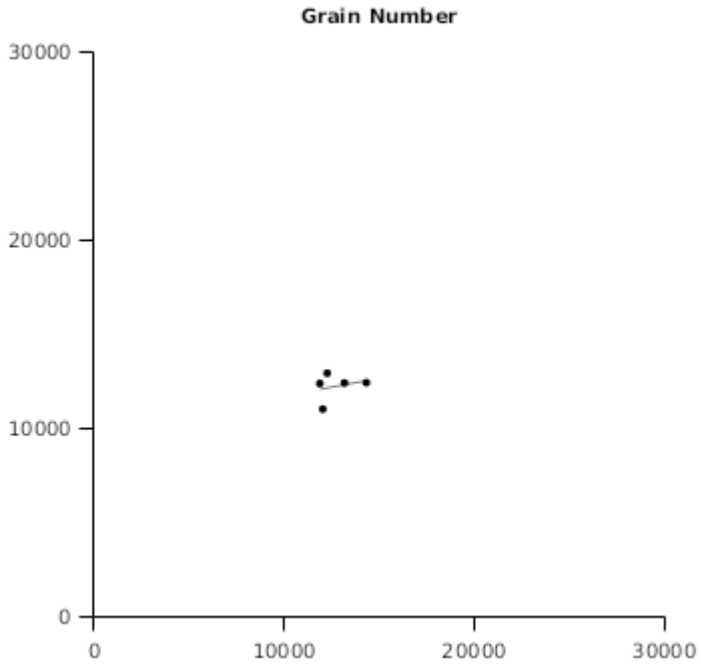

TotalWt
1000
500
0
01-Nov
01-Jan
01-Mar

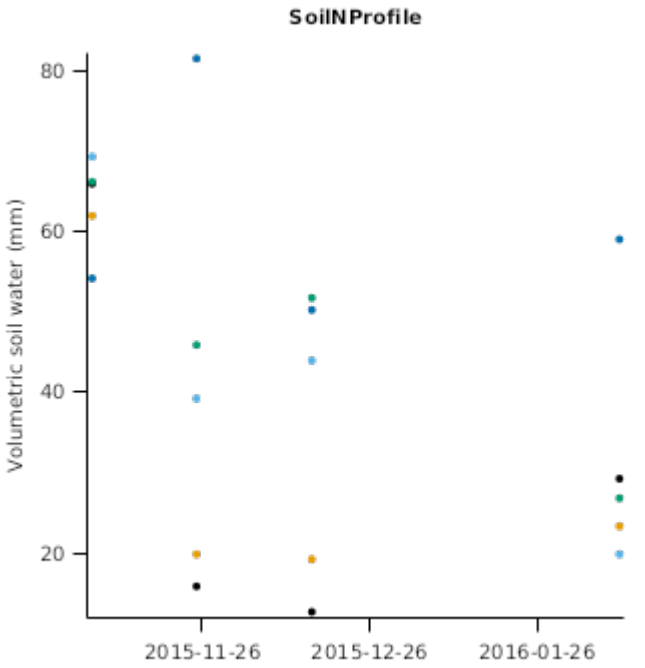

GrainWt
600
400
200
0
01-Nov
01-Jan
01-Mar


TotalN
15
10
5
0
01-Nov
01-Jan
01-Mar


GrainN
0.02
0.01
0
01-Nov
01-Jan
01-Mar



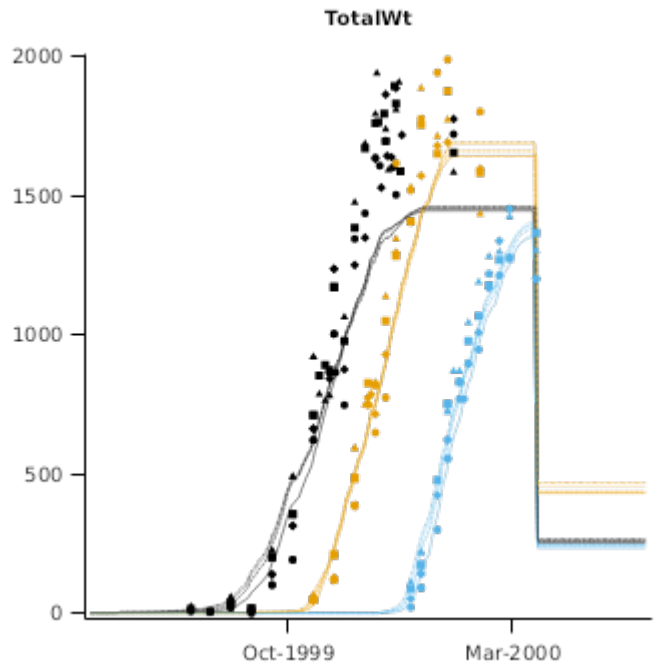


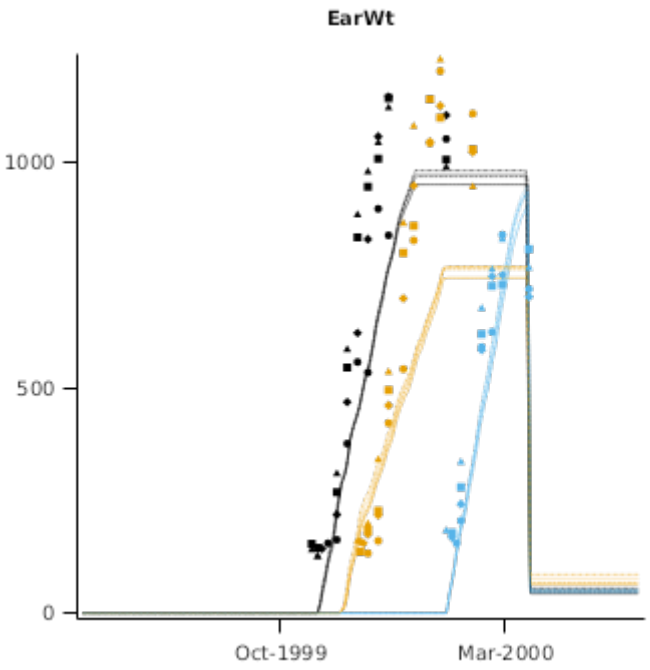


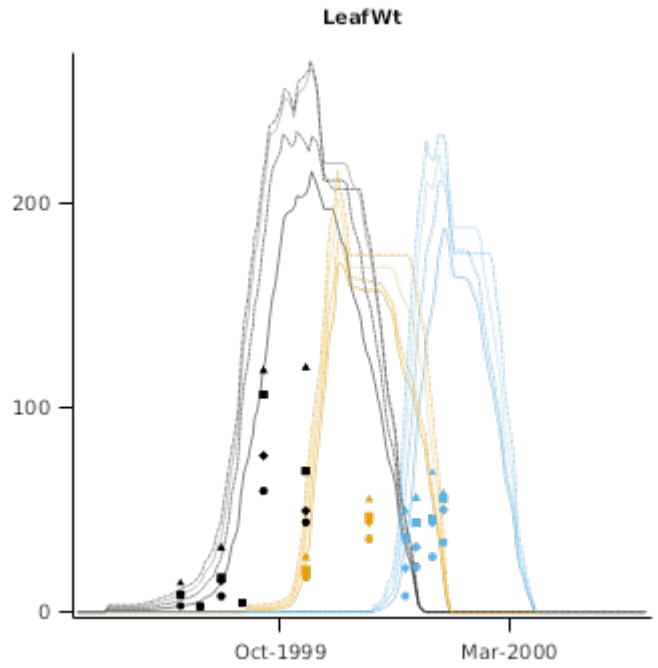
2.3.9 ABlock99_00

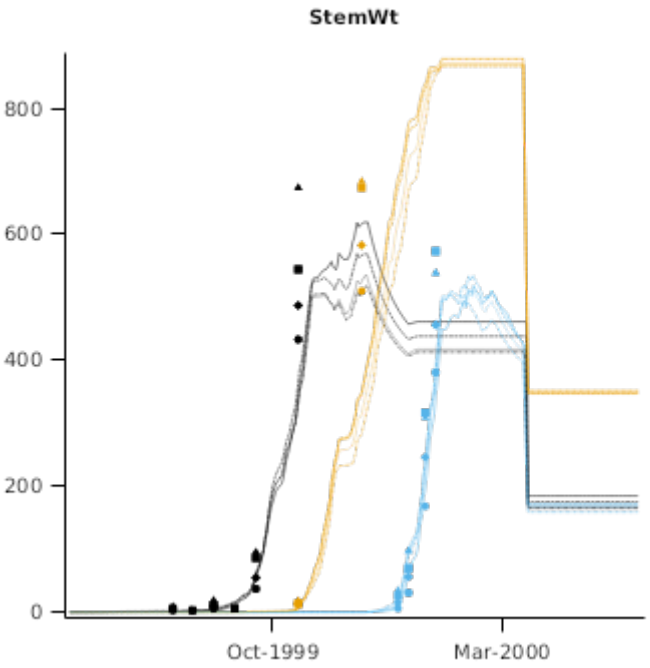
This was a sowing date by irrigation trial conducted at Lincoln. The following were evaluated:

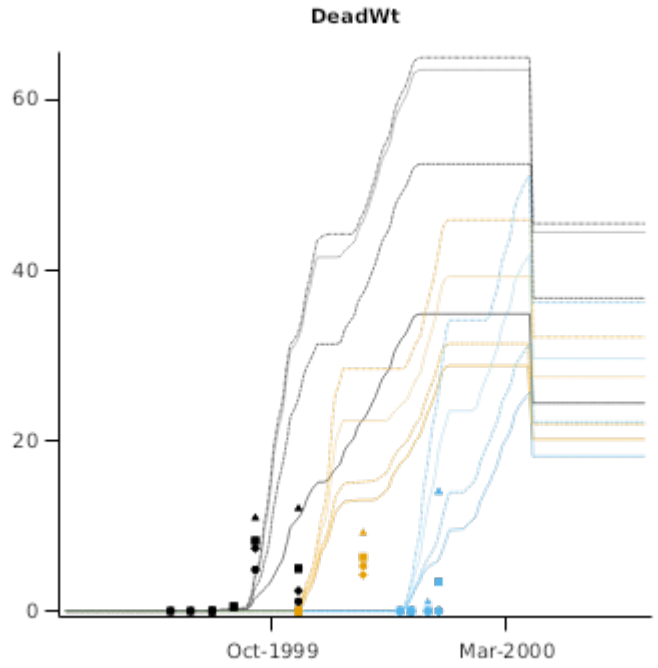
- Two water treatments; Rainfed (nil irrigation) and irrigated (310 mm)
- Two fertiliser N treatments; 0N (no fertiliser) and 150N (150 kg N/ha)

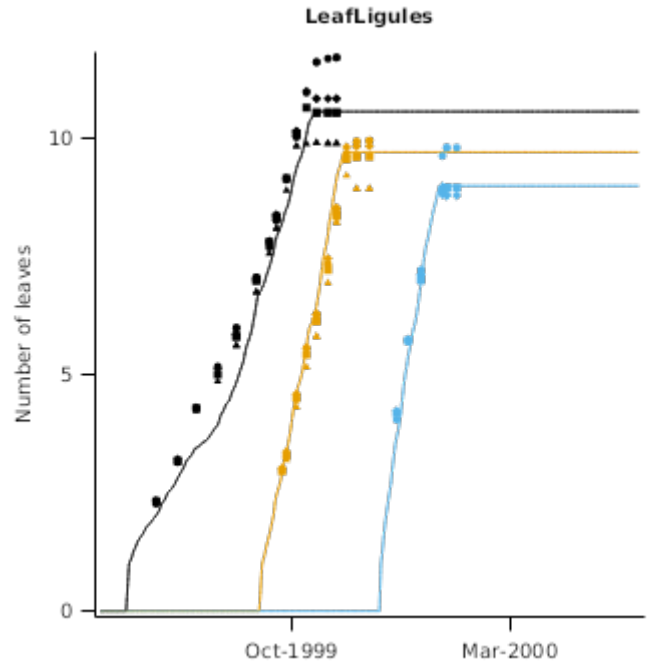

TotalWt
2000
1500
1000
500
0
Oct-1999
Mar-2000


EarWt
1000
500
0
Oct-1999
Mar-2000


LeafWt
200
100
0
Oct-1999
Mar-2000


StemWt
800
600
400
200
0
Oct-1999
Mar-2000


DeadWt
60
40
20
0
Oct-1999
Mar-2000

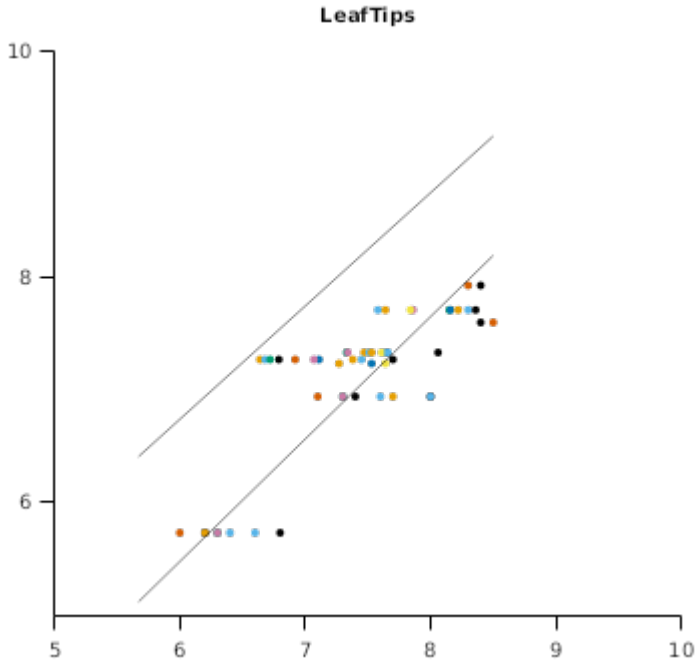

LeafLigules
Number of leaves
10
5
0
Oct-1999
Mar-2000

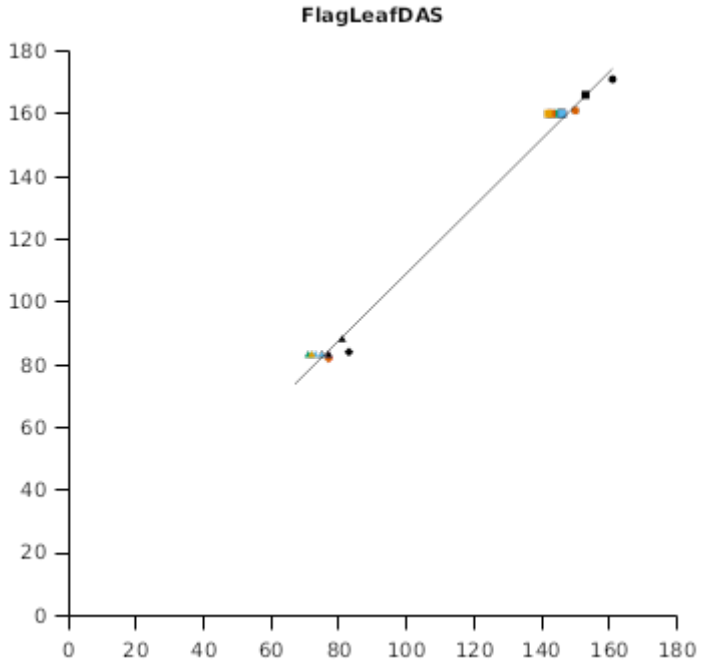
2.3.10 CPT

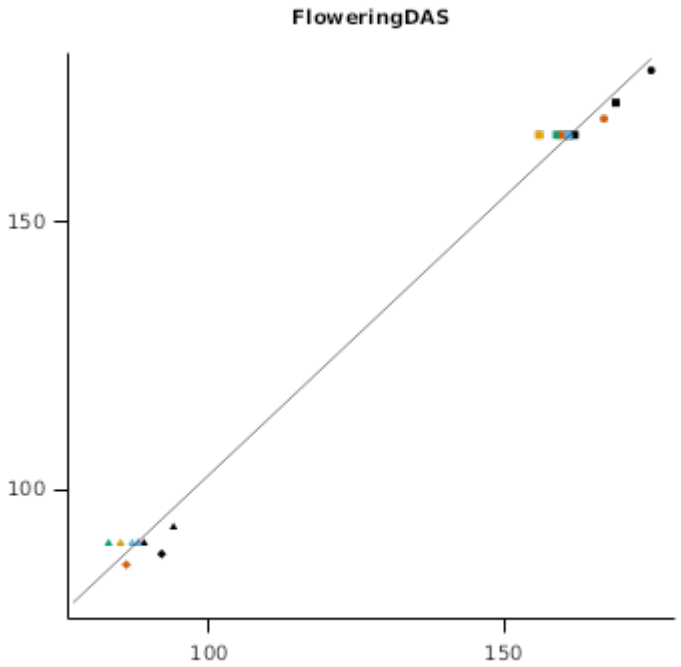
This was a cultivar evaluation trial conducted in Lincoln New Zealand between 2003 and 2006. Crops were sown in either May or September. Observations made were of (i) DAS to flag leaf appearance and (ii) DAS to flowering.

2.3.10.1 List of experiments

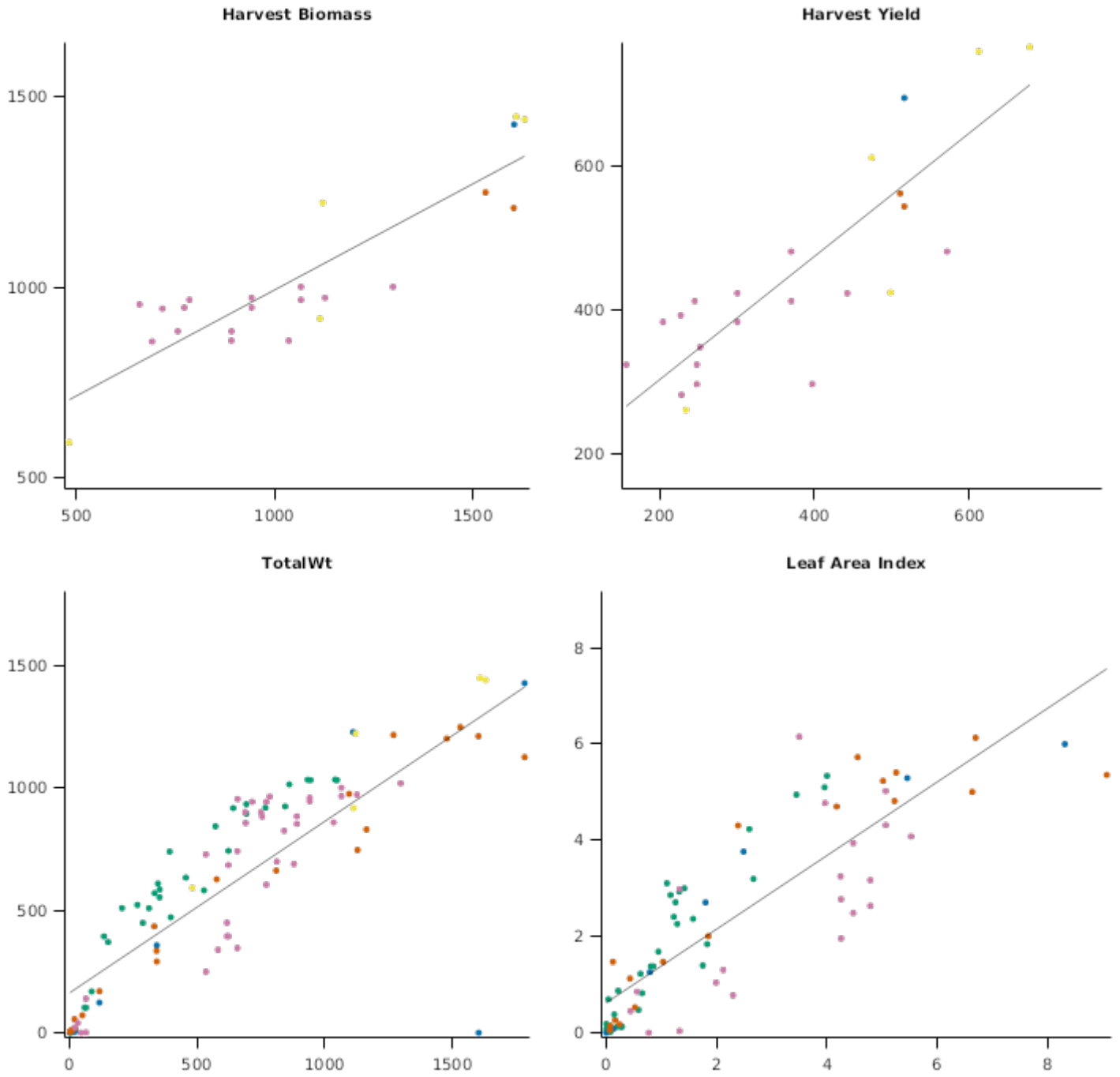
Experiment Name	Design (Number of Treatments)
CPT	Cult x SD (110)







2.4 Australia

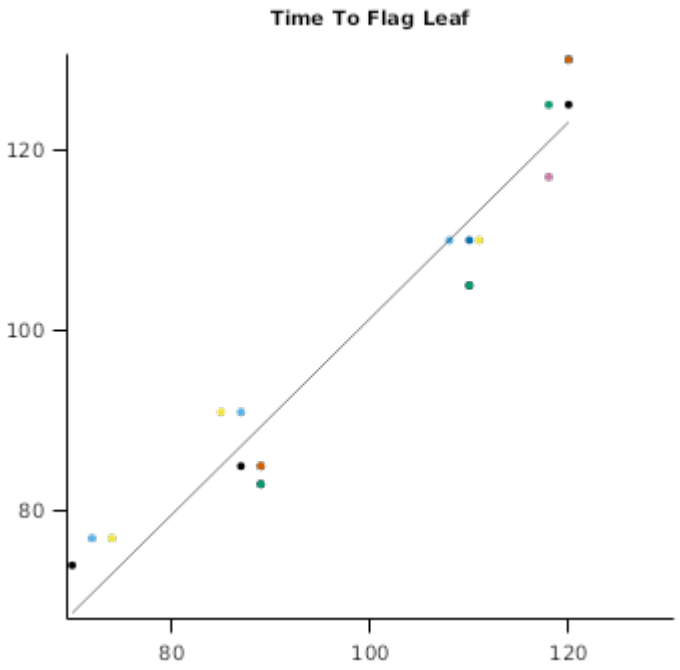


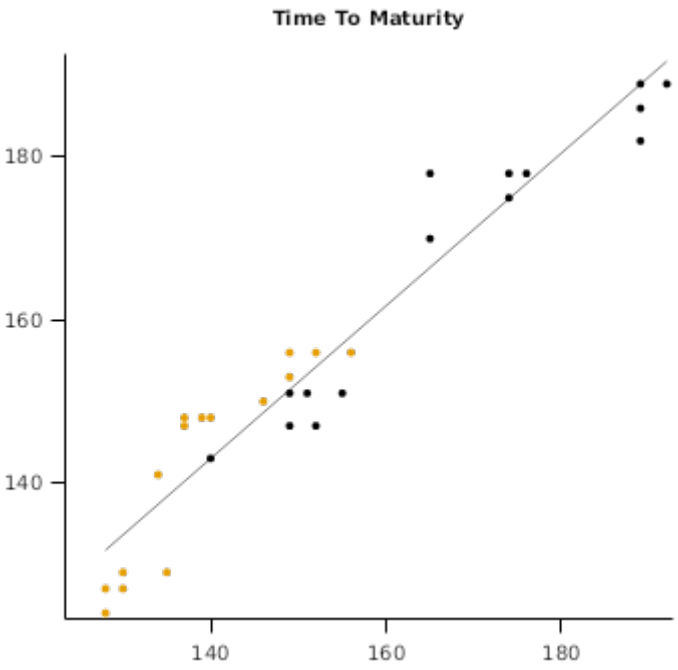
2.4.1 MCVP

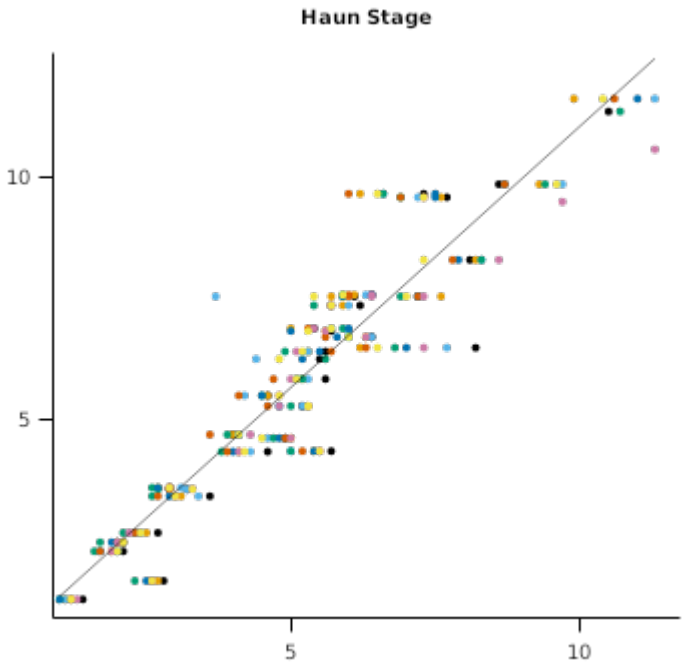
This experiment was funded as part of the Australian Managing Climate Variability Program. Barley cultivars were sown at two planting dates at three sites for the purpose of improving APSIM predictions of the phenology of commercial cultivars. The locations included Gatton in Queensland (subtropical location), Birchip in Victoria (temperate inland location) and Tarlee in South Australia (temperate location).

2.4.1.1 List of experiments

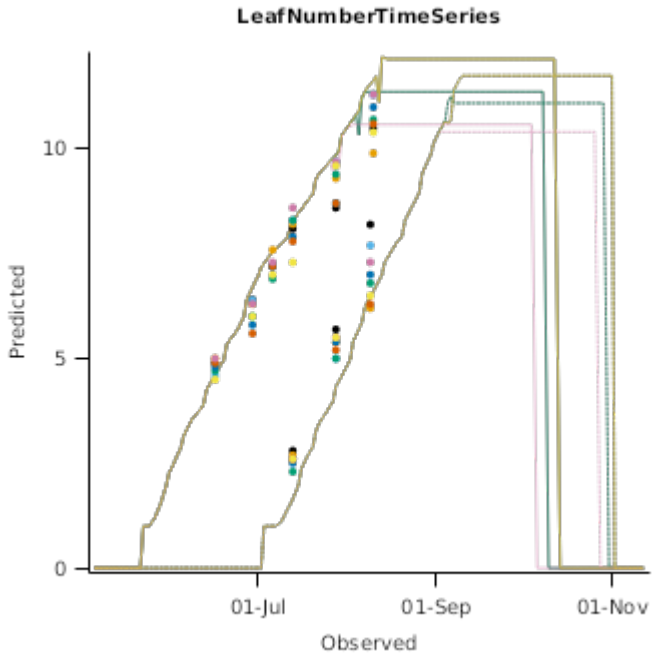
Experiment Name	Design (Number of Treatments)
Gatton2011	TOS x Cv (16)
Birchip2011	TOS x Cv (16)
Tarlee2011	TOS x Cv (16)

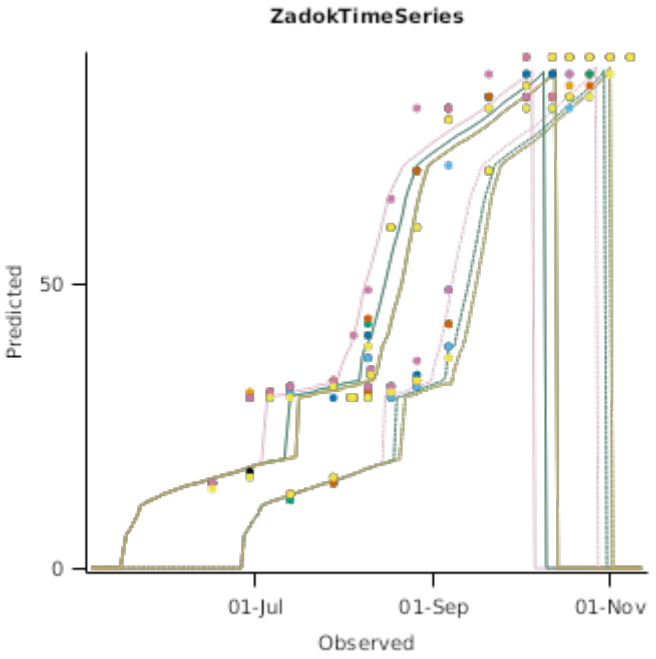


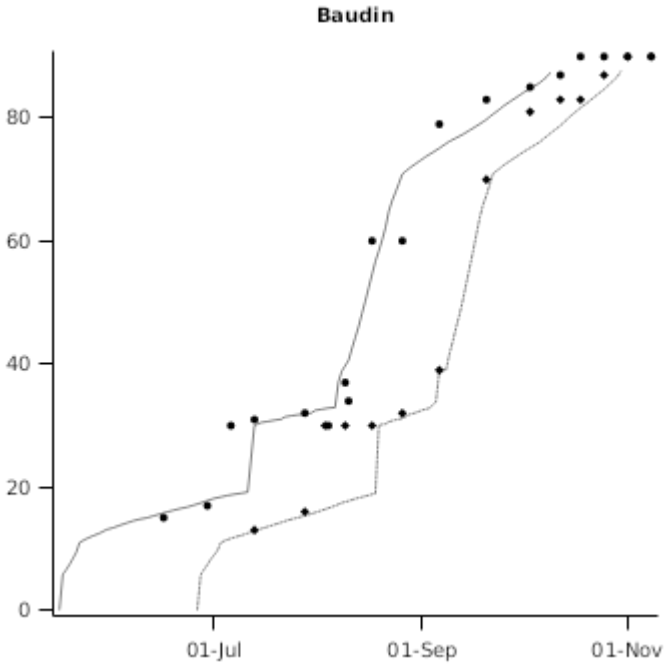


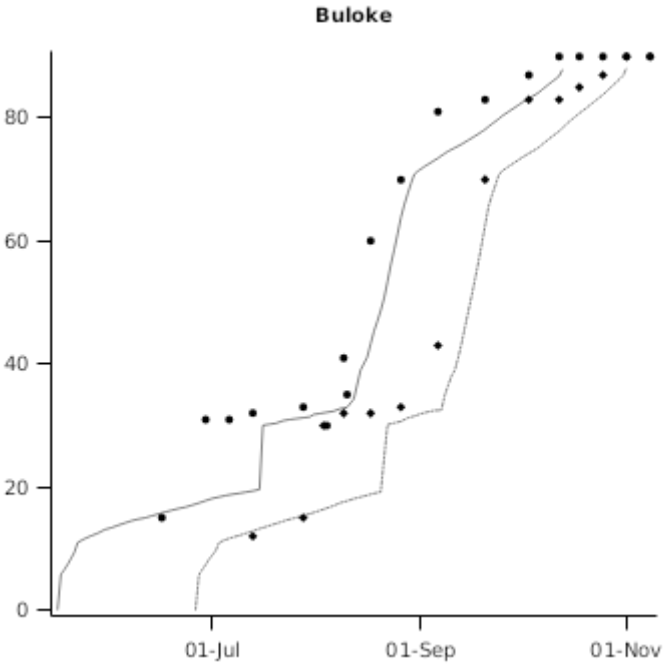


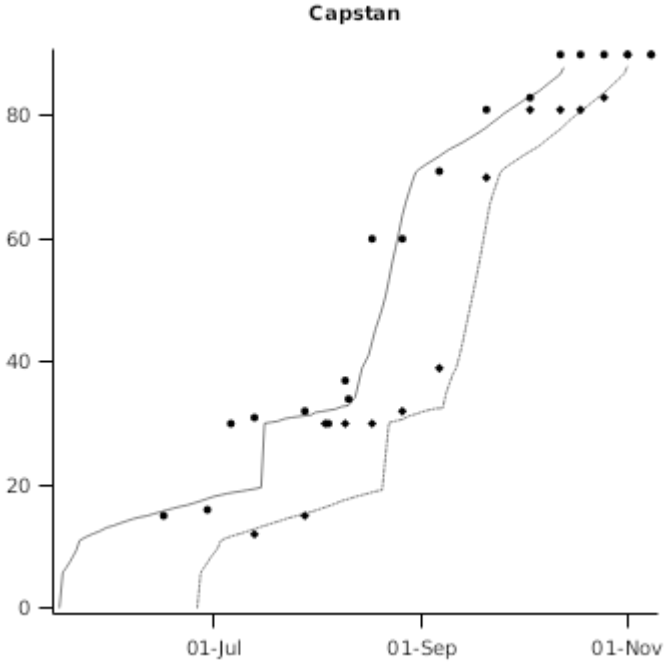
2.4.1.2 Gatton2011

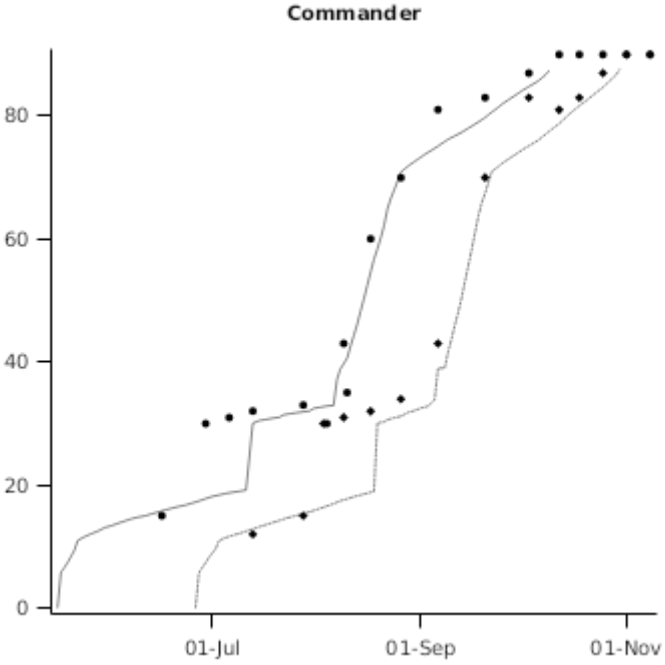

LeafNumberTimeSeries
Predicted
0
5
10
01-Jul
01-Sep
01-Nov
Observed

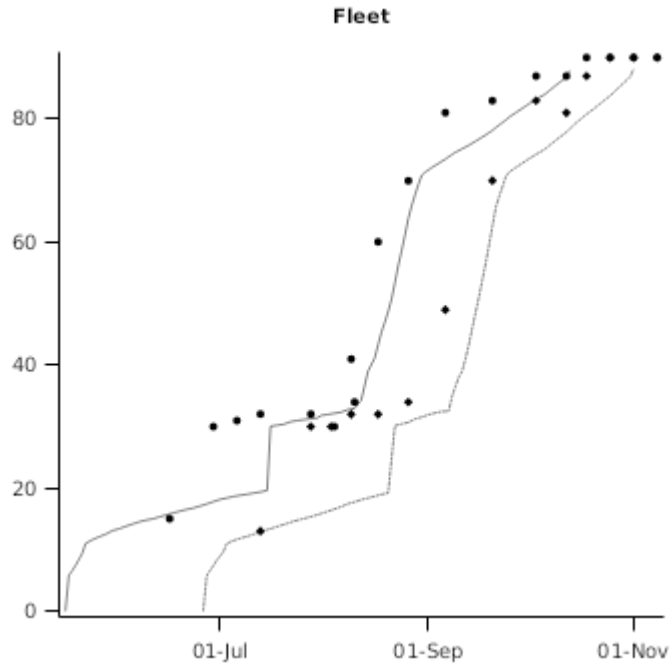

ZadokTimeSeries
Predicted
0
50
01-Jul
01-Sep
01-Nov
Observed

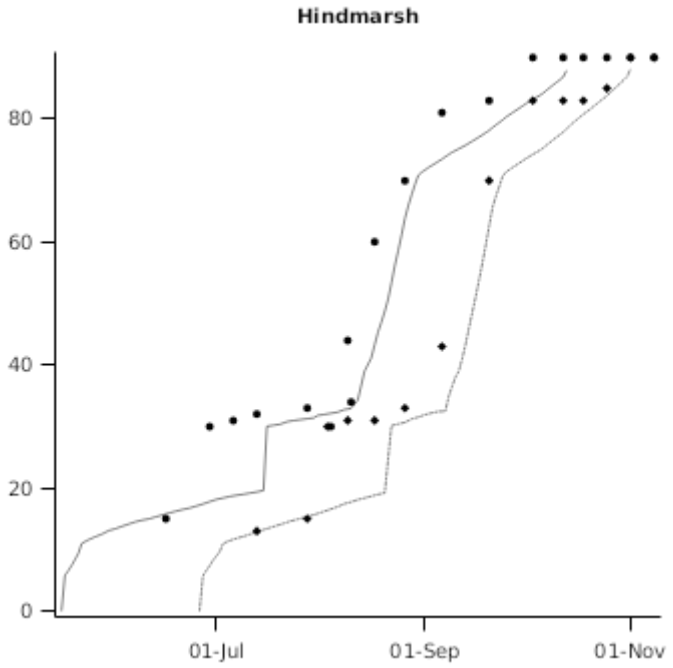

Baudin
0
20
40
60
80
01-Jul
01-Sep
01-Nov

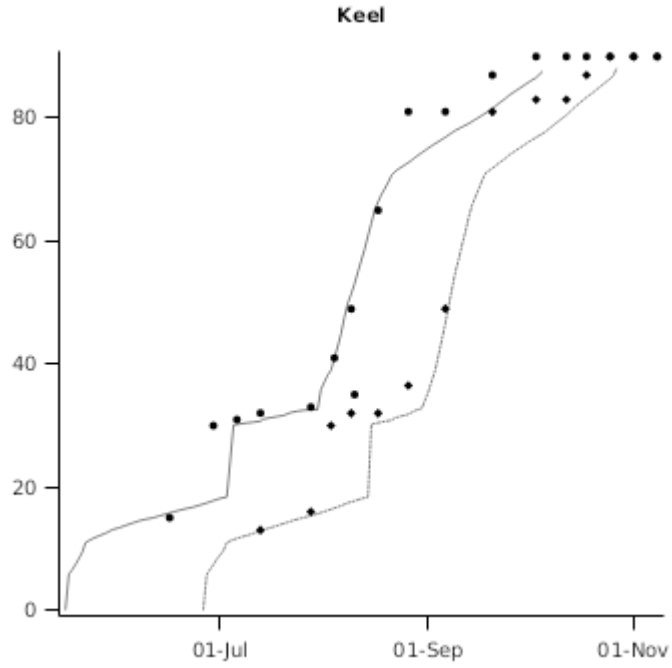

Buloke
0
20
40
60
80
01-Jul
01-Sep
01-Nov

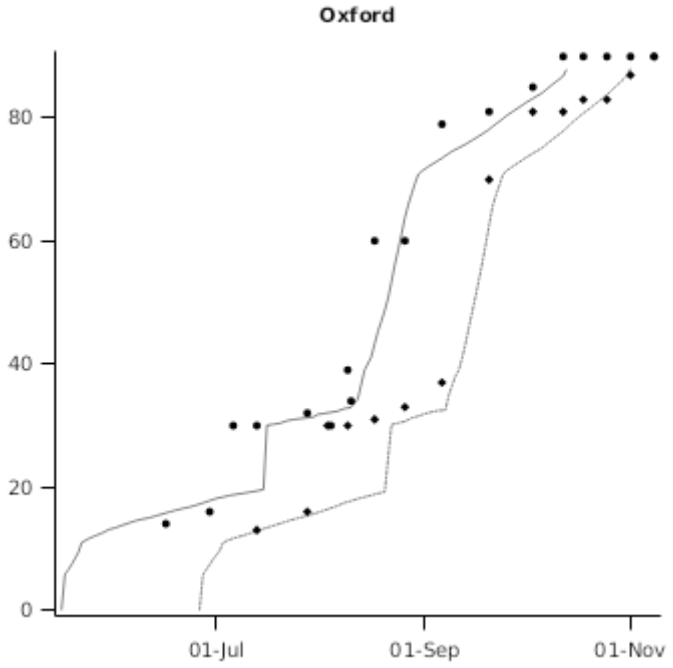

Capstan
0
20
40
60
80
01-Jul
01-Sep
01-Nov


Commander
0
20
40
60
80
01-Jul
01-Sep
01-Nov

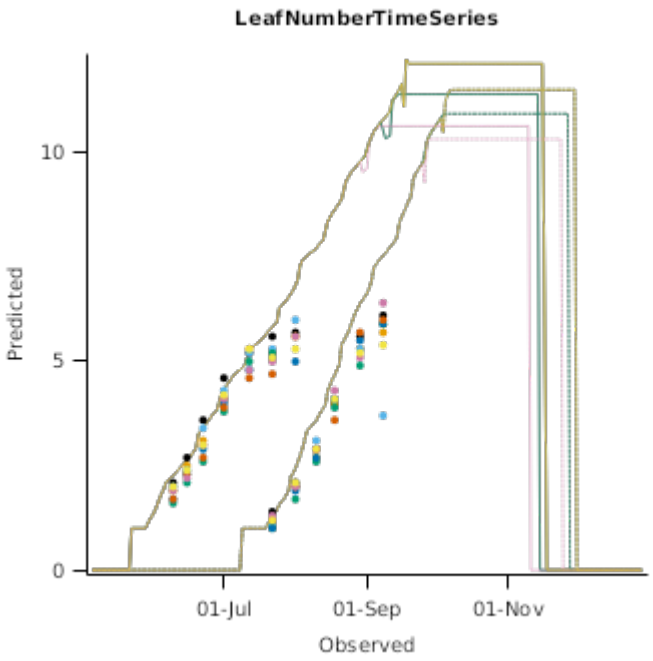


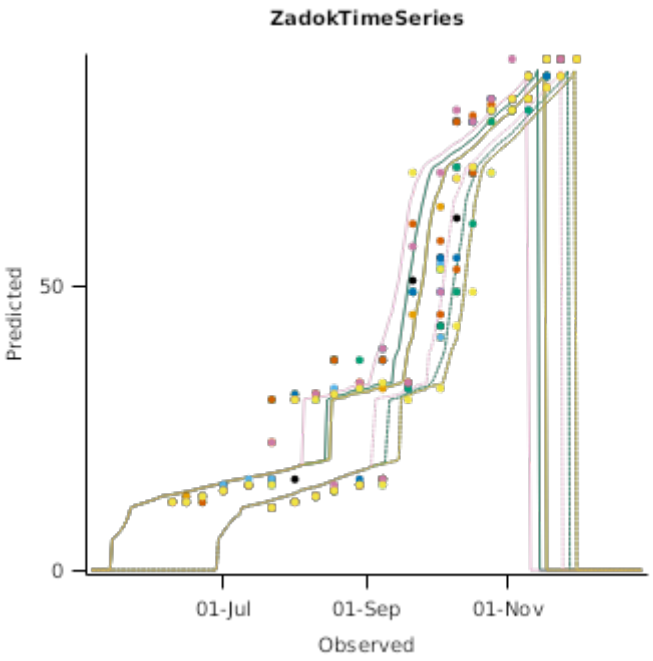


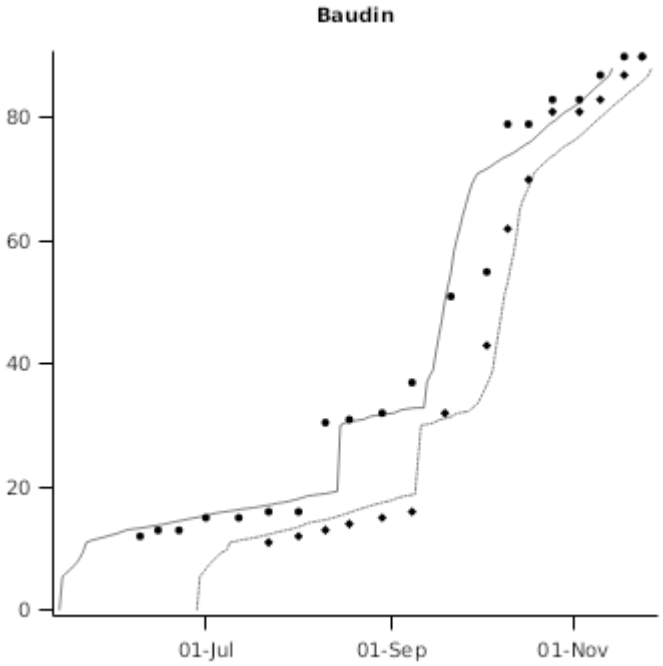


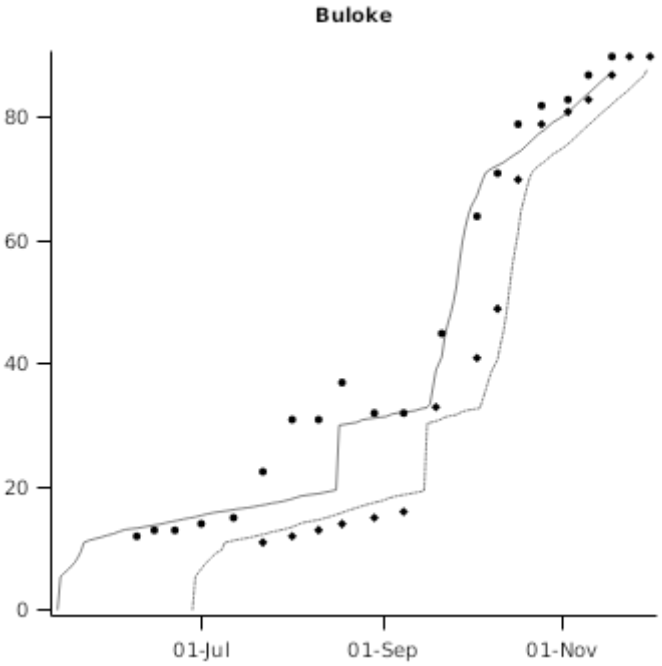


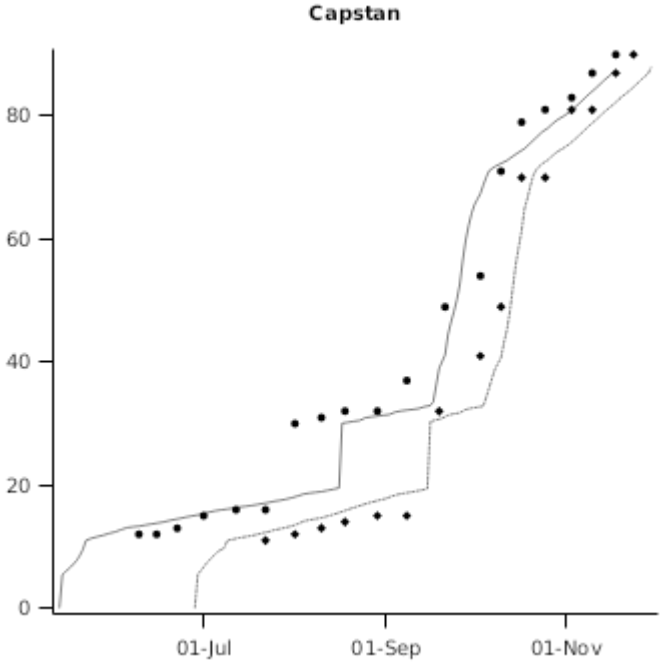
2.4.1.3 Birchip2011

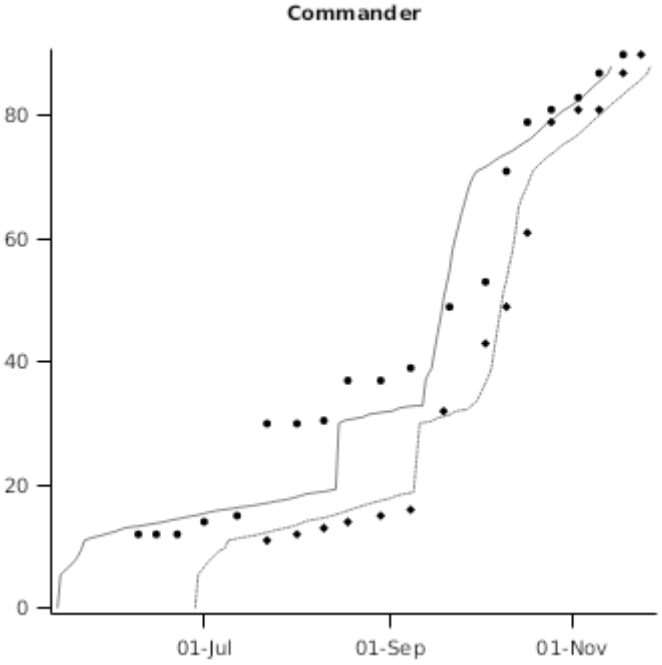

LeafNumberTimeSeries
Predicted
0
5
10
01-Jul
01-Sep
01-Nov
Observed

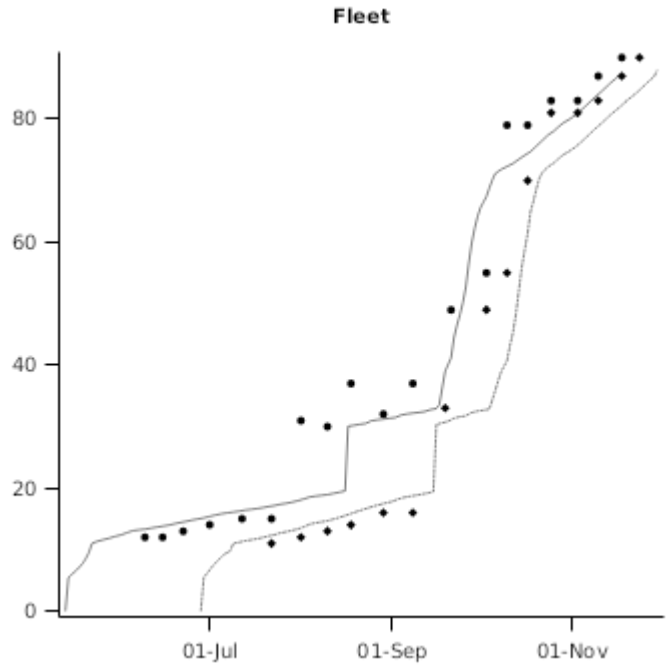

ZadokTimeSeries
Predicted
0
50
01-Jul
01-Sep
01-Nov
Observed

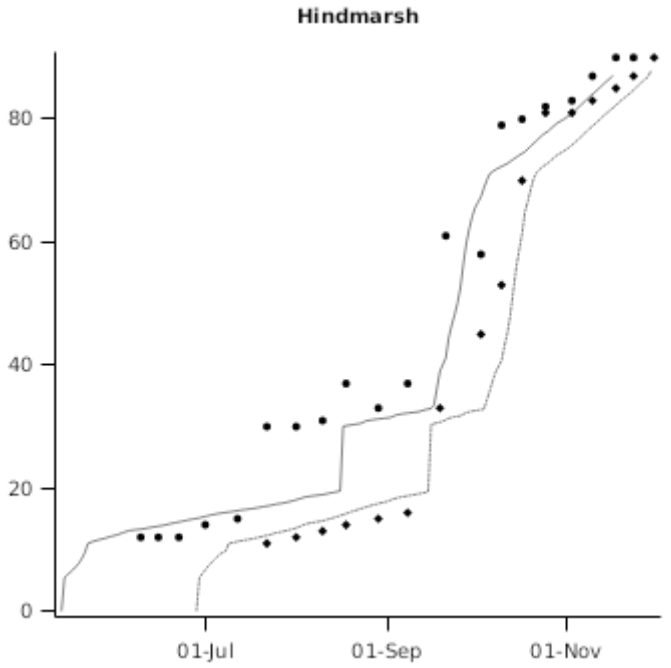

Baudin
0
20
40
60
80
01-Jul
01-Sep
01-Nov

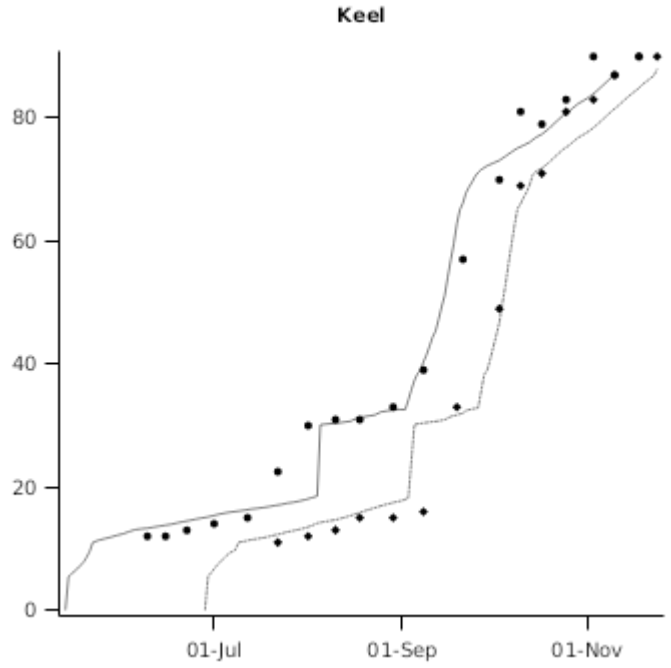

Buloke
0
20
40
60
80
01-Jul
01-Sep
01-Nov

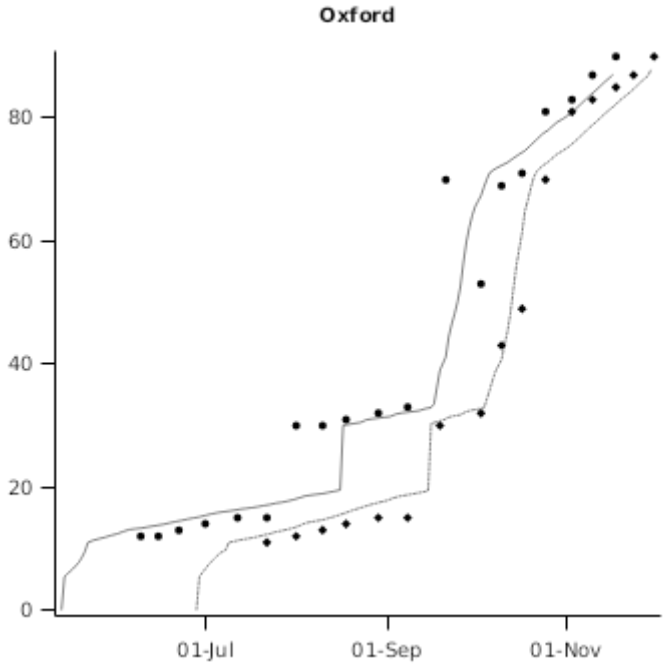

Capstan
0
20
40
60
80
01-Jul
01-Sep
01-Nov


Commander
0
20
40
60
80
01-Jul
01-Sep
01-Nov

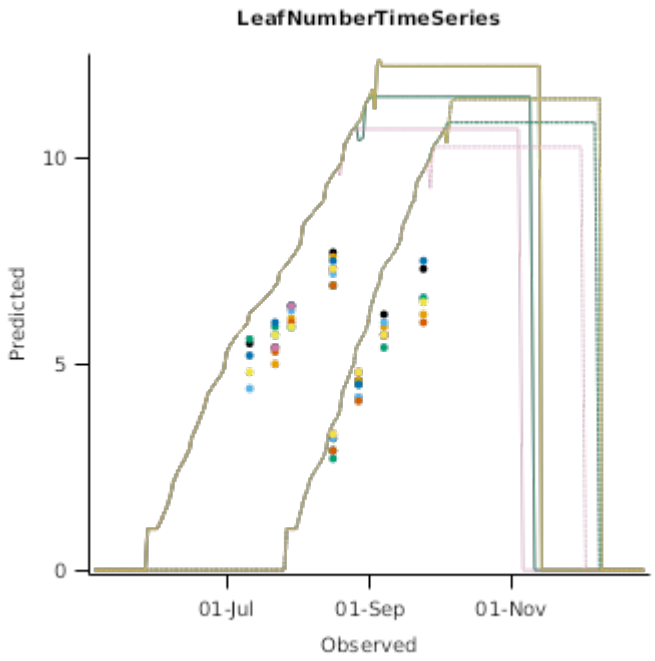


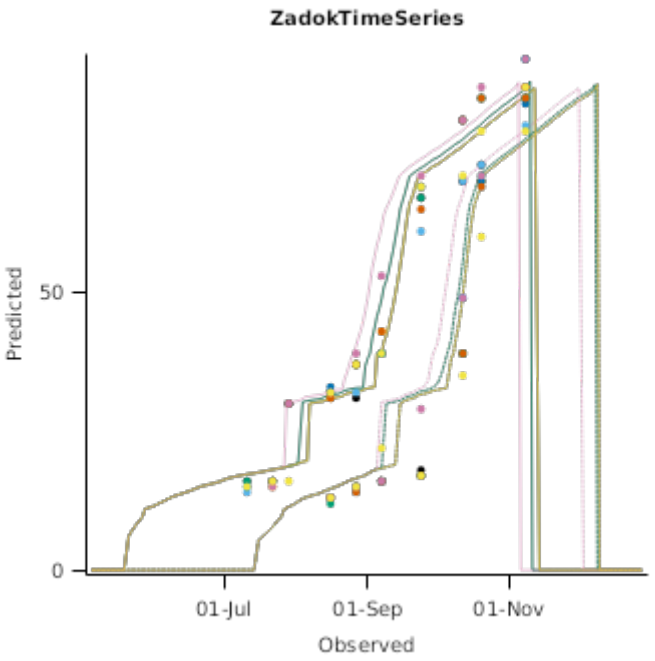


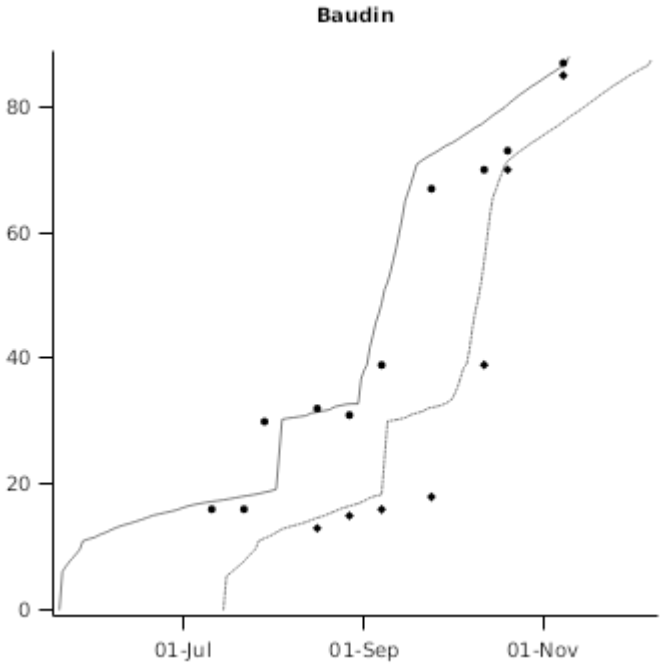


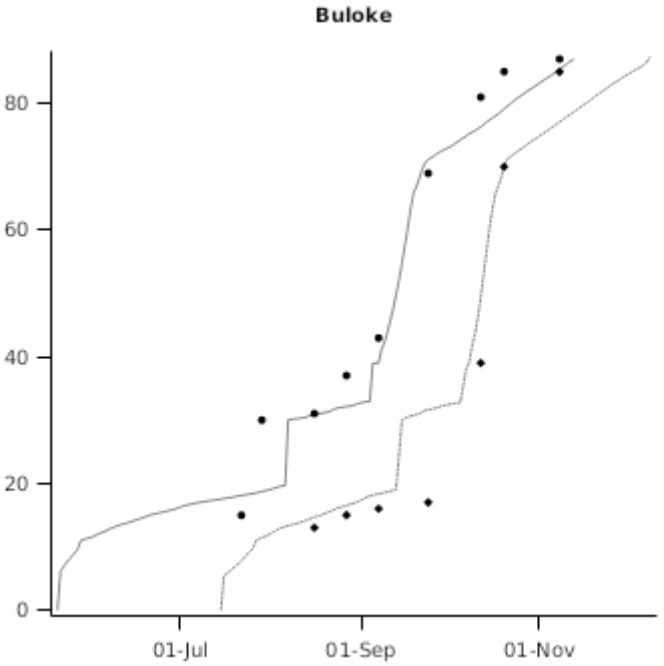


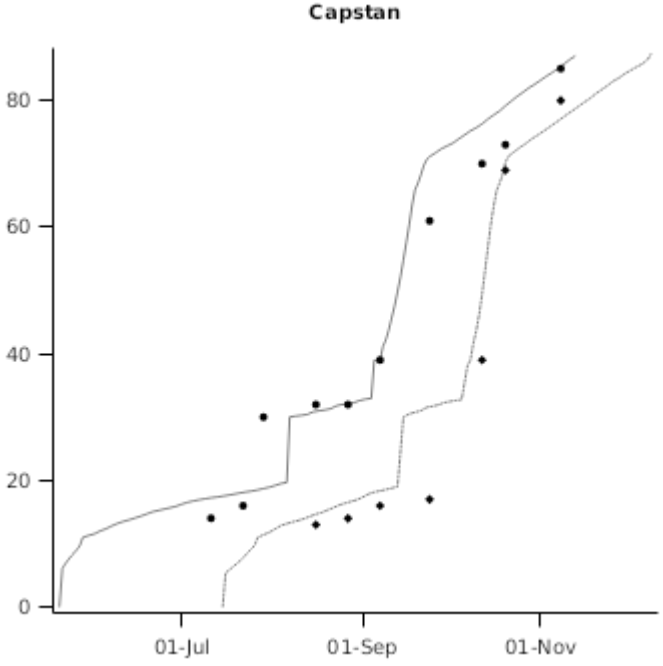
2.4.1.4 Tarlee2011

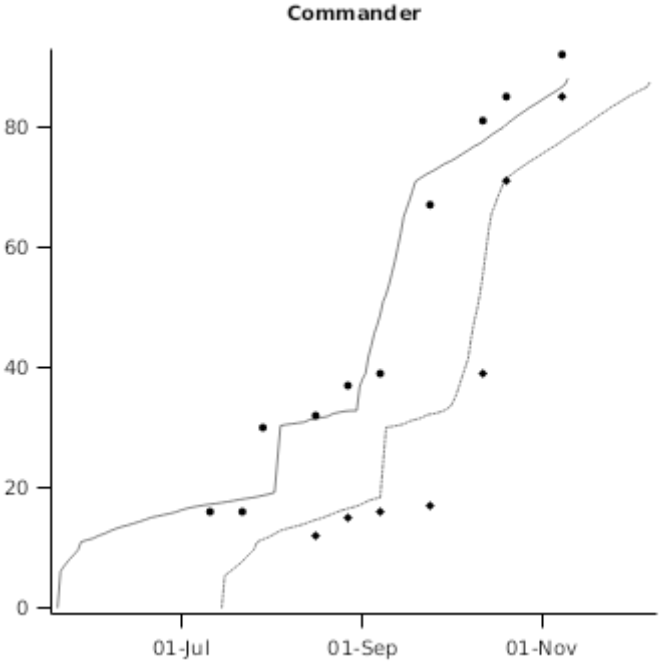

LeafNumberTimeSeries
Predicted
0
5
10
01-Jul
01-Sep
01-Nov
Observed

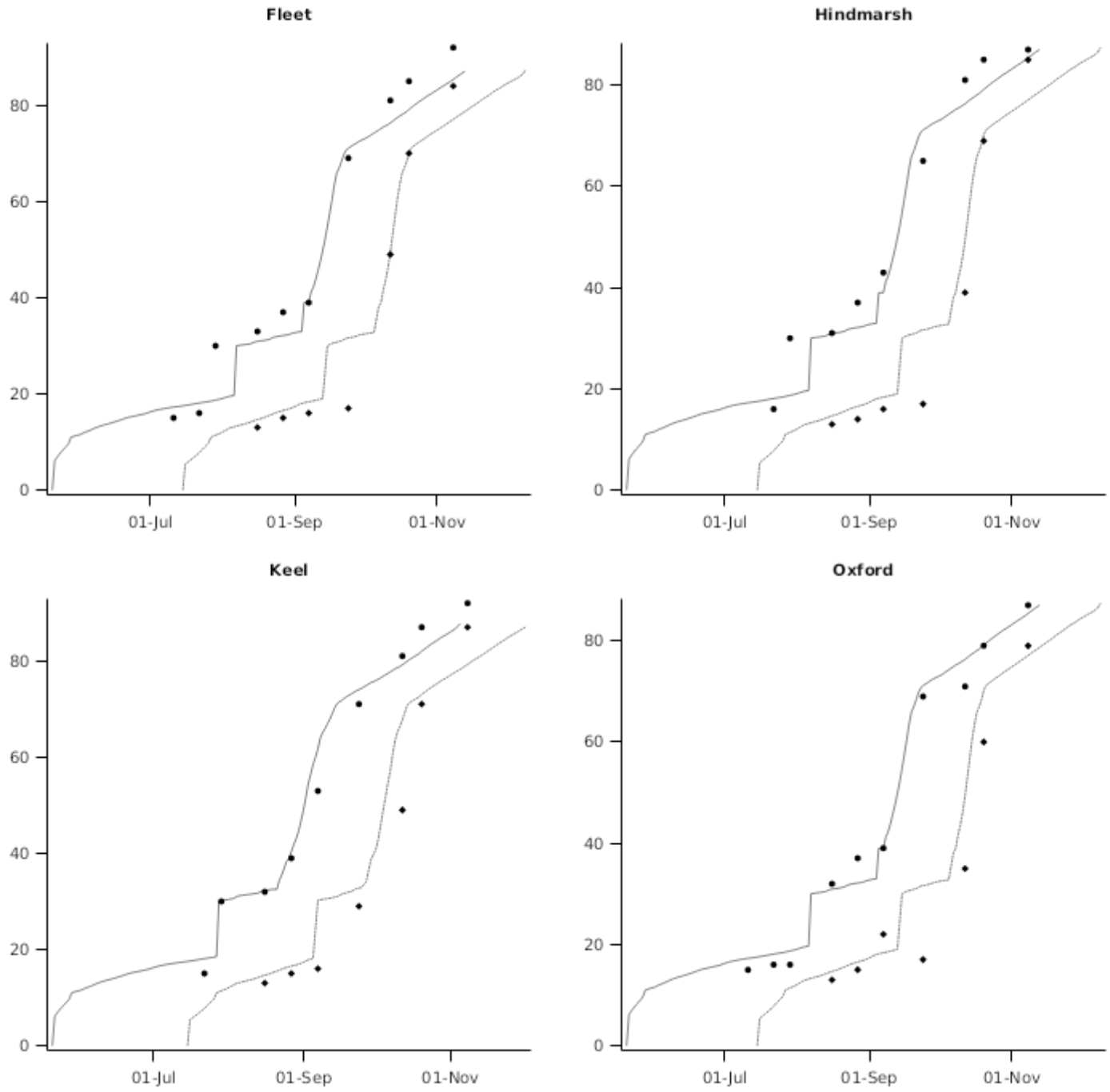

ZadokTimeSeries
Predicted
0
50
01-Jul
01-Sep
01-Nov
Observed


Baudin
0
20
40
60
80
01-Jul
01-Sep
01-Nov


Buloke
0
20
40
60
80
01-Jul
01-Sep
01-Nov


Capstan
0
20
40
60
80
01-Jul
01-Sep
01-Nov


Commander
0
20
40
60
80
01-Jul
01-Sep
01-Nov



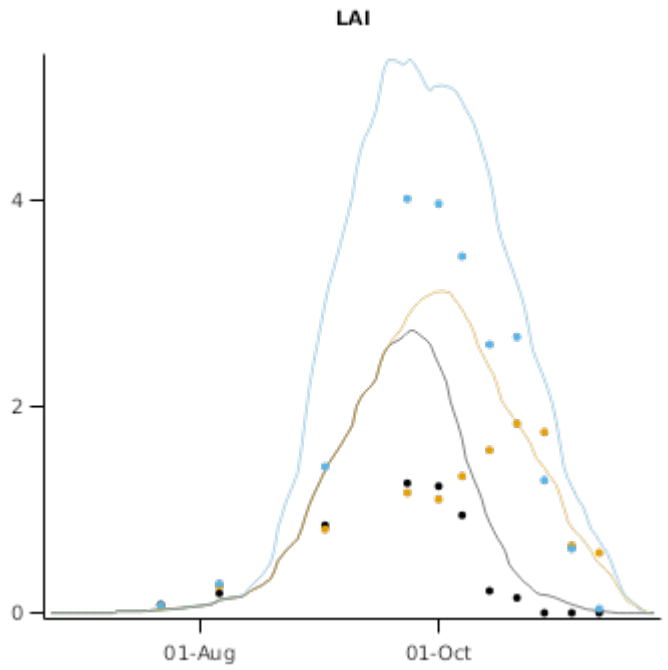
2.4.2 HermitageRS

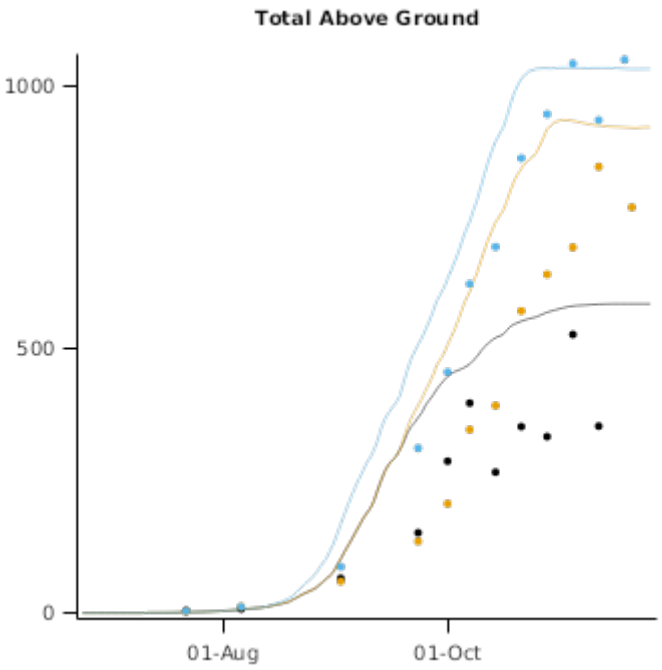
This rain-out shelter experiment was undertaken at the Hermitage Research Station near Warwick, Queensland. Treatments included 3 irrigation experiments to provide combinations of early and later water stress. The experiment was described by Goyne et al., 1996.

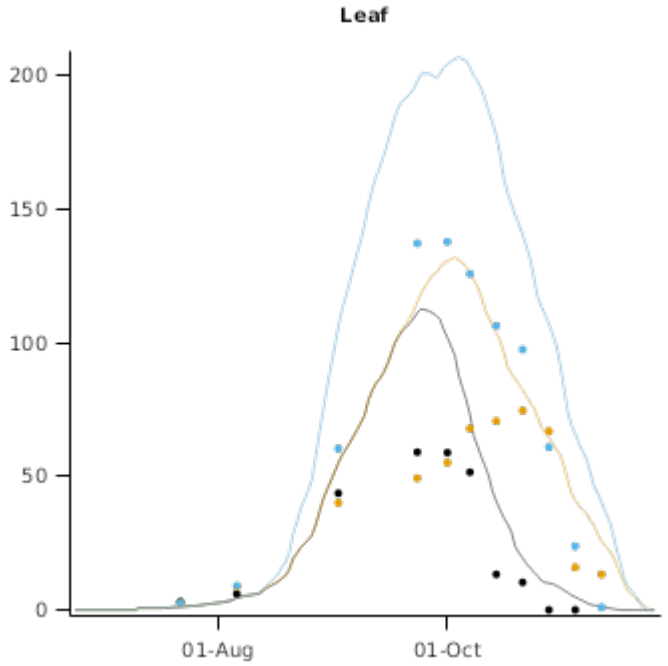
2.4.2.1 List of experiments

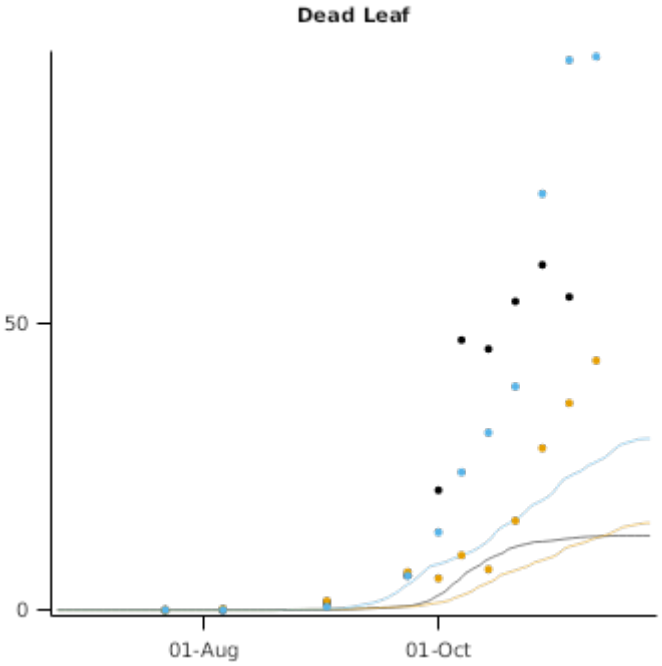
Experiment Name	Design (Number of Treatments)
HermitageRS	Irr (3)

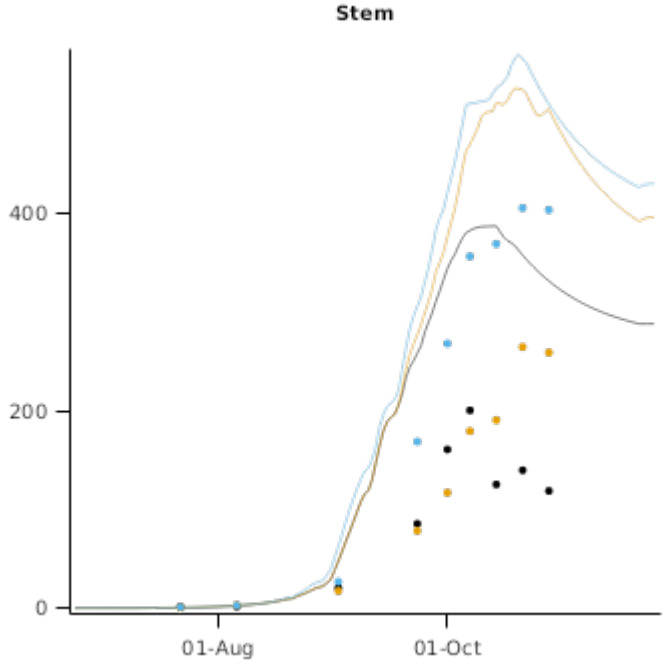
2.4.2.2 HermitageRS

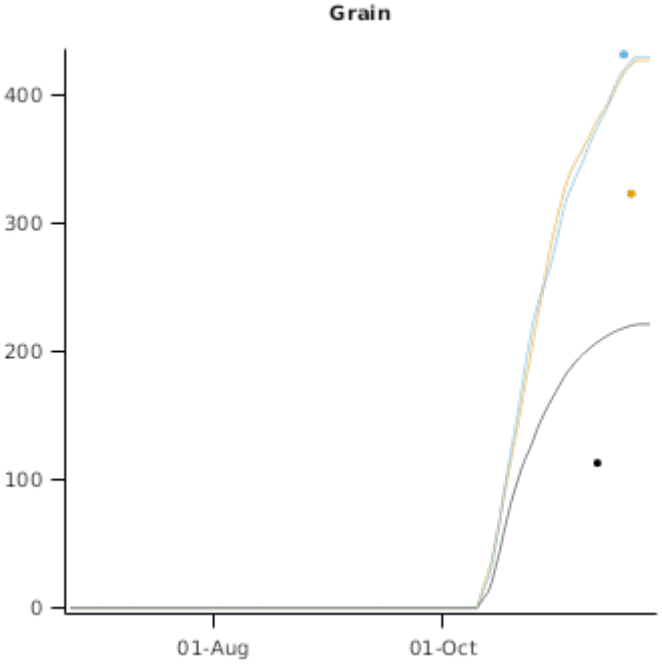

LAI
4
2
0
01-Aug
01-Oct

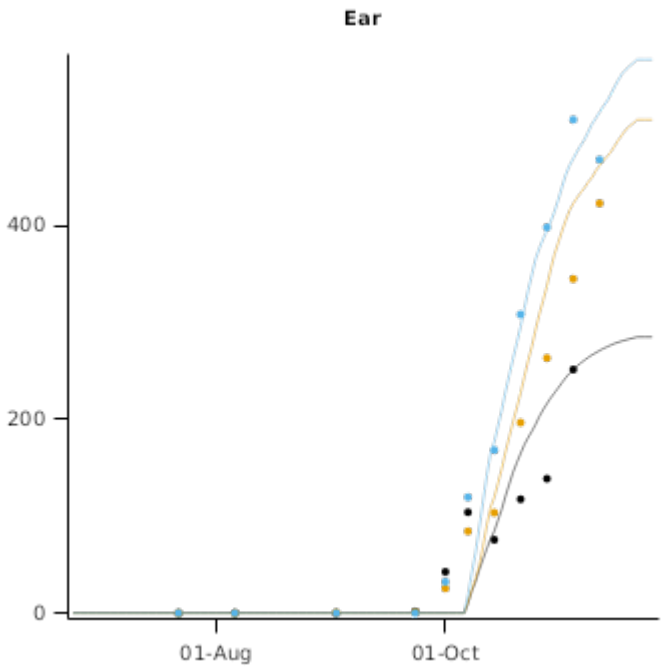

Total Above Ground
1000
500
0
01-Aug
01-Oct

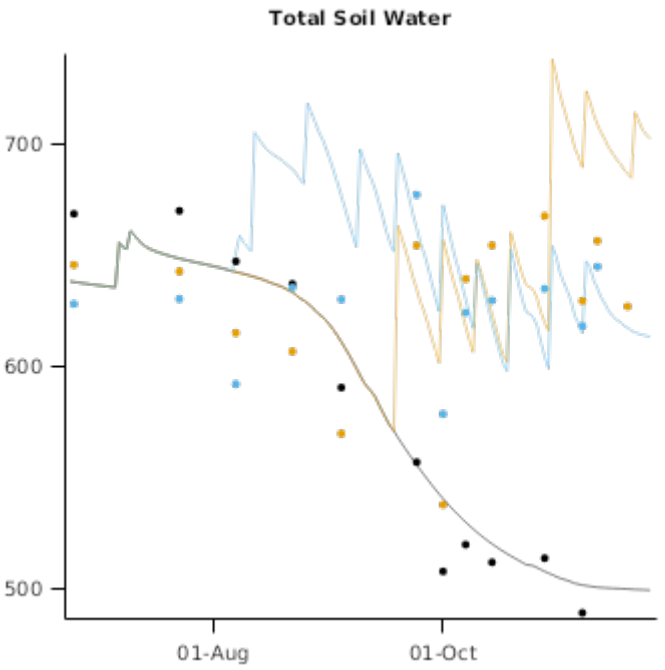

Leaf
200
150
100
50
0
01-Aug
01-Oct

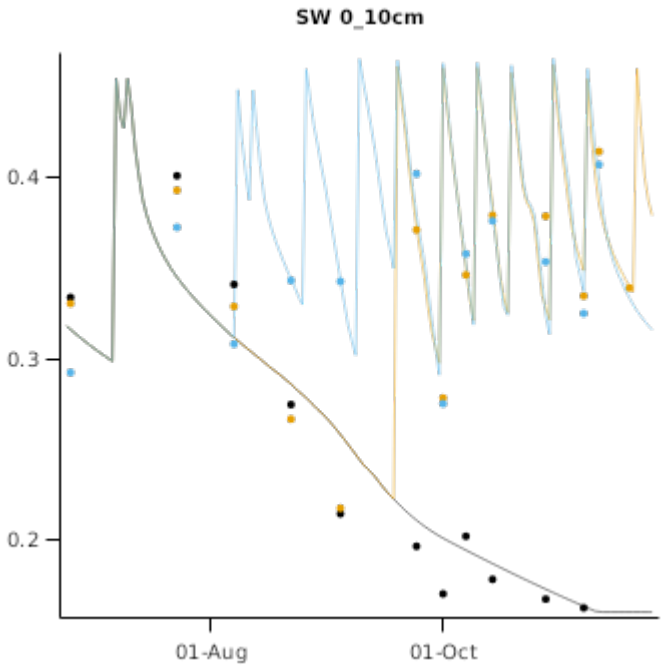

Dead Leaf
50
0
01-Aug
01-Oct

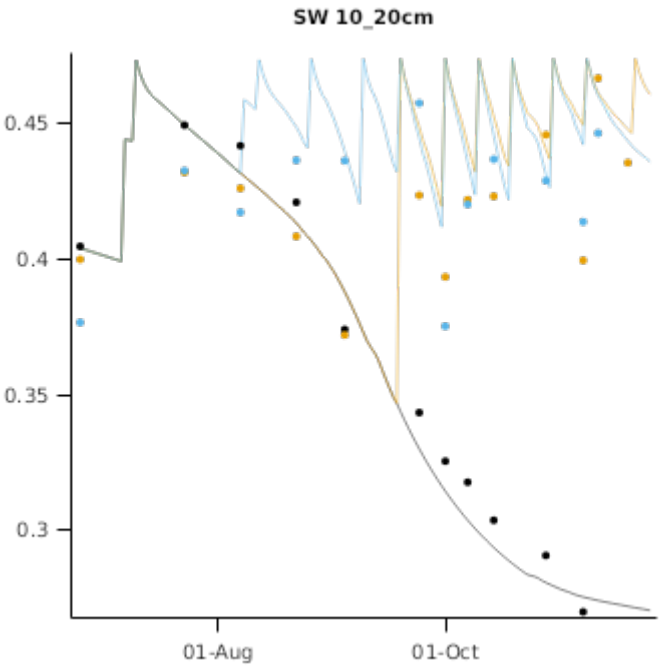

Stem
400
200
0
01-Aug
01-Oct

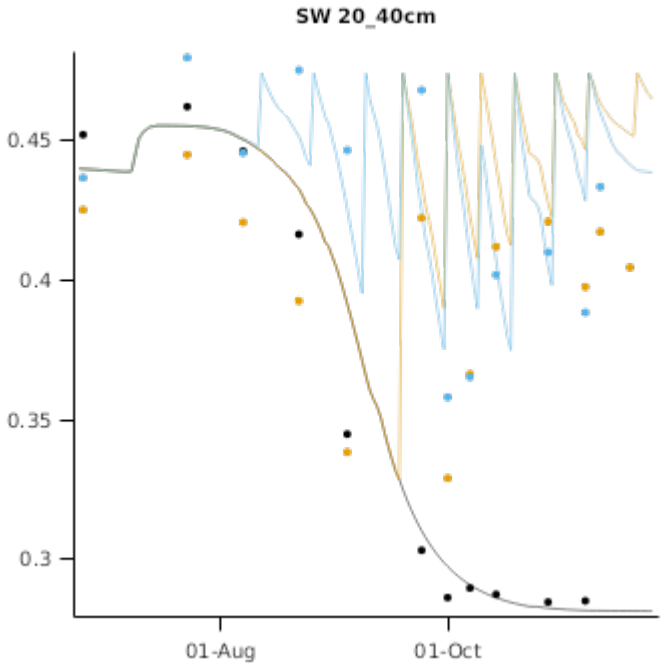

Grain
400
300
200
100
0
01-Aug
01-Oct

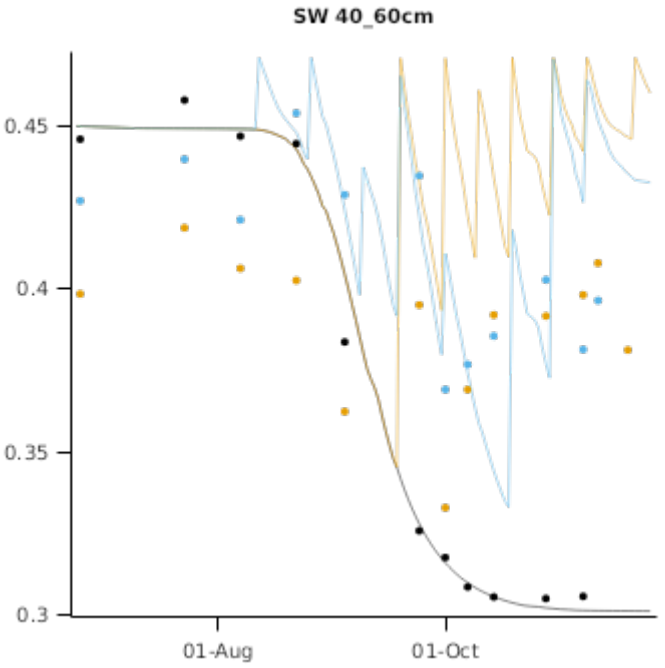

Ear
400
200
0
01-Aug
01-Oct

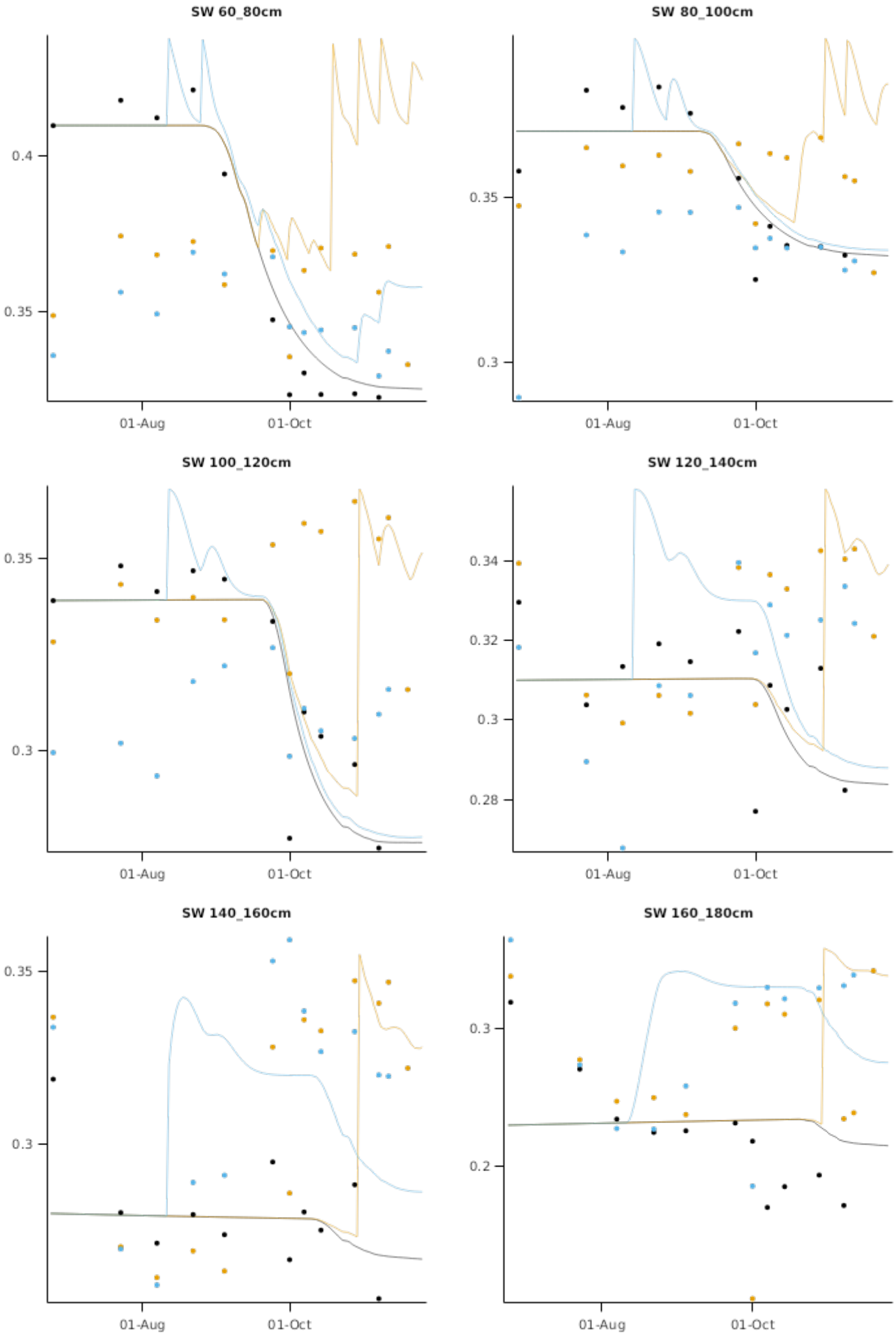

Total Soil Water
700
600
500
01-Aug
01-Oct


SW 0_10cm
0.4
0.3
0.2
01-Aug
01-Oct


SW 10_20cm
0.45
0.4
0.35
0.3
01-Aug
01-Oct


SW 20_40cm
0.45
0.4
0.35
0.3
01-Aug
01-Oct


SW 40_60cm
0.45
0.4
0.35
0.3
01-Aug
01-Oct


SW 60_80cm
0.4
0.35
01-Aug
01-Oct
SW 80_100cm
0.35
0.3
01-Aug
01-Oct
SW 100_120cm
0.35
0.3
01-Aug
01-Oct
SW 120_140cm
0.34
0.32
0.3
0.28
01-Aug
01-Oct
SW 140_160cm
0.35
0.3
01-Aug
01-Oct
SW 160_180cm
0.3
0.2
01-Aug
01-Oct

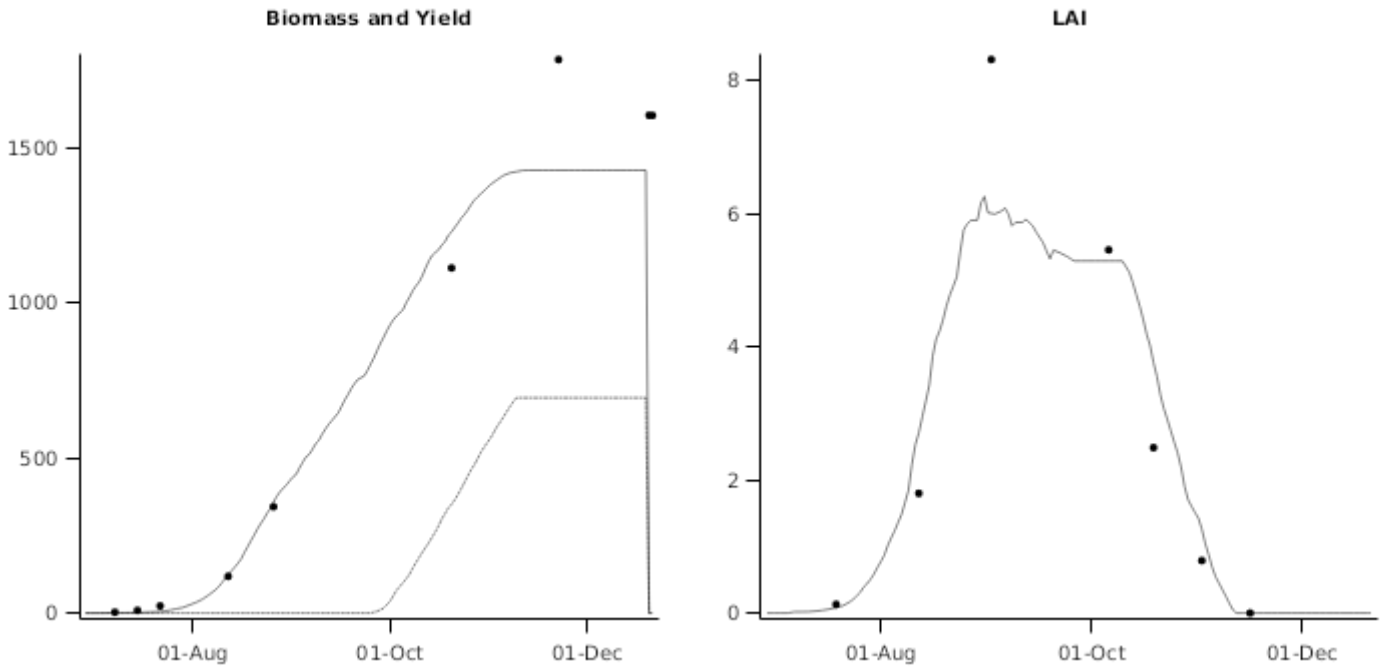
2.4.3 Wellcamp

This experiment provides information on biomass accumulation, canopy development and final yield for Barley sown on the eastern Darling Downs. The experiment is explained in Goyne et al., 1996.

2.4.3.1 List of experiments

Experiment Name	Design (Number of Treatments)
Wellcamp	1993 (1)

2.4.3.2 Wellcamp



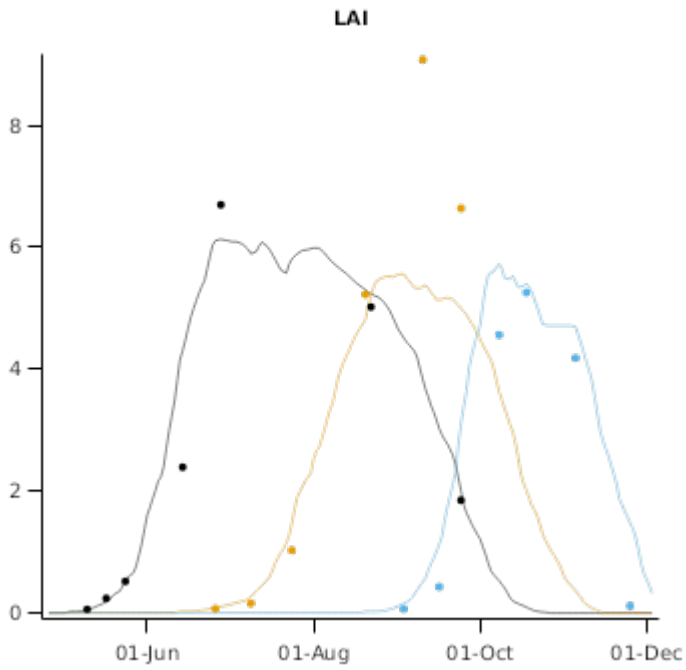
2.4.4 Hermitage1990

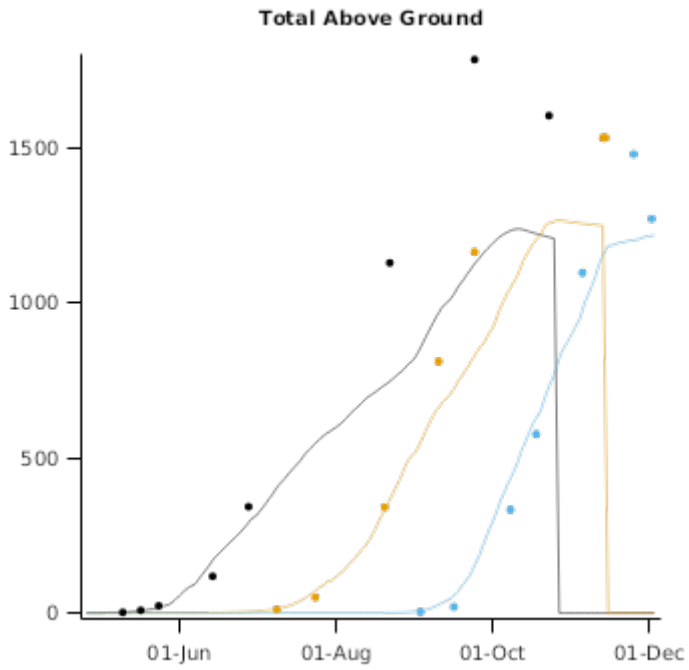
This experiment was conducted at Hermitage Research Station near Warwick, Queensland. Three sowing dates were used to study changes in phenology, biomass accumulation and canopy development. The experiment is explained in Goyne et al., 1993.

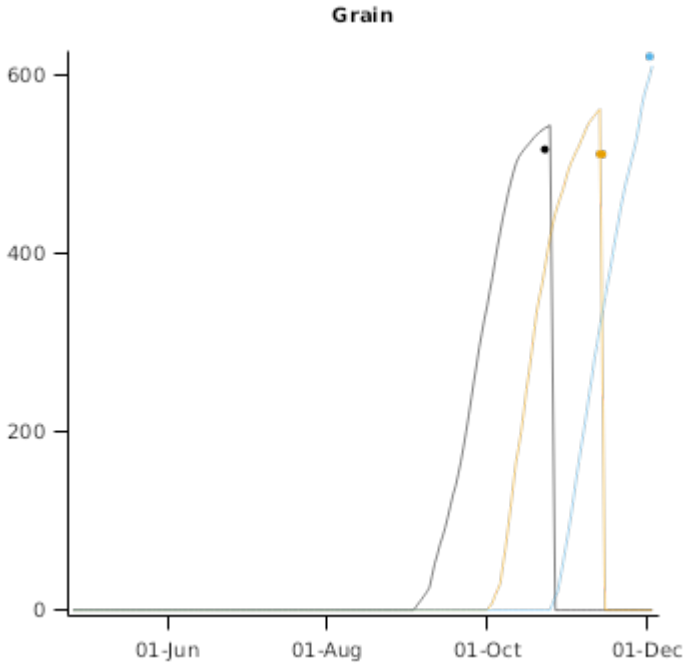
2.4.4.1 List of experiments

Experiment Name	Design (Number of Treatments)
Hermitage1990	TOS (3)

2.4.4.2 Hermitage1990







2.4.5 Roma1988

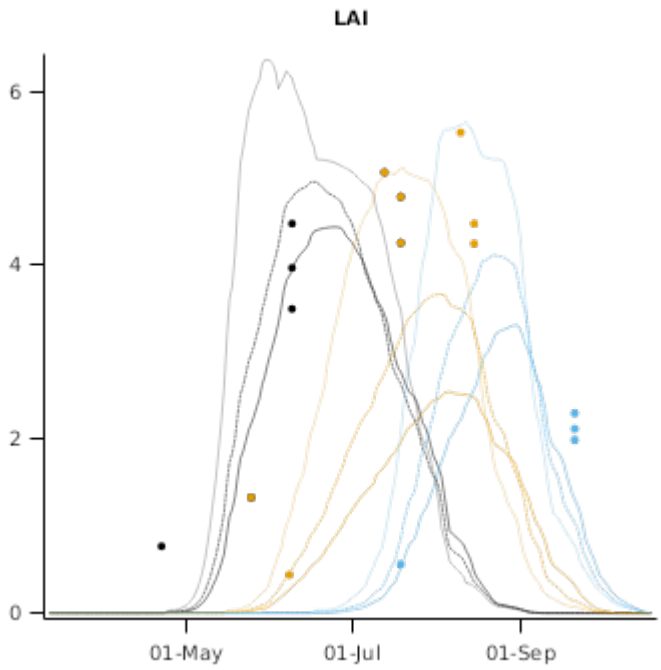
This sowing date x plant population experiment was undertaken near Roma, Queensland. Measurements include biomass accumulation, leaf area development and final grain yield. The experiment is explained in Goyne et al., 1996.

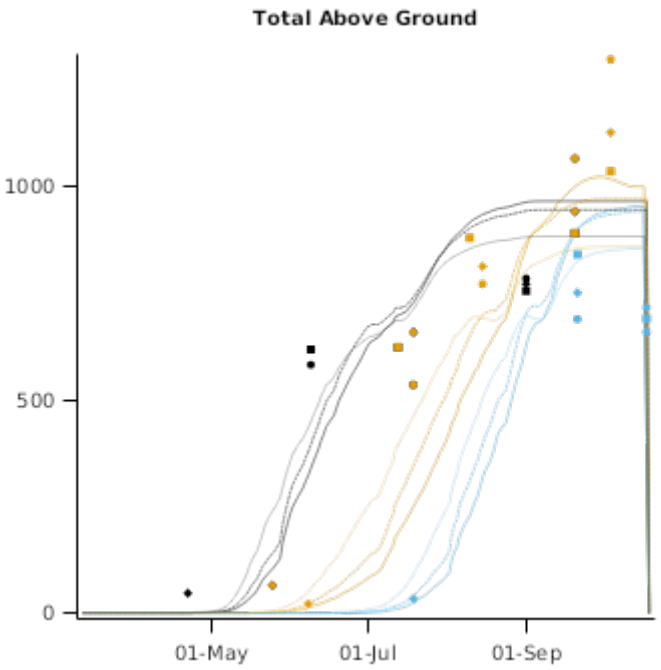
2.4.5.1 List of experiments

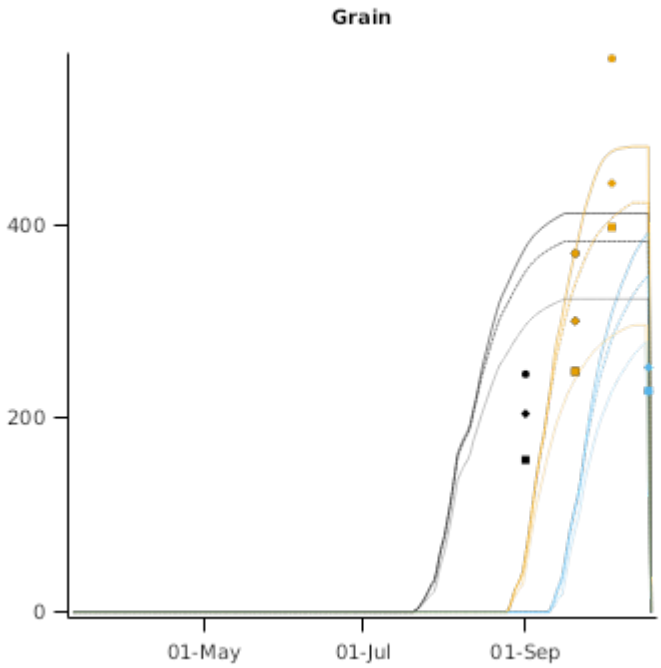
Experiment Name	Design (Number of Treatments)
Roma1988	Sow x Pop (9)

2.4.5.2 Roma1988

NOTE: Sowing was 12-Mar but simulations are sown on 30 March to capture delayed germination until following rainfall event







2.4.6 Gatton1984

This nitrogen rate (0 to 200 kg N/ha) experiment was conducted in 1984 at Gatton, Queensland. The experiment is explained in Birch et al., 1990.

2.4.6.1 List of experiments

Experiment Name	Design (Number of Treatments)
Gatton1984	NRate (5)

2.4.6.2 Gatton1984

NOTE: High N treatment logdged. Final grain sizes were less than expected.

2.4.7 NPIField2019

2.4.7.1 List of experiments

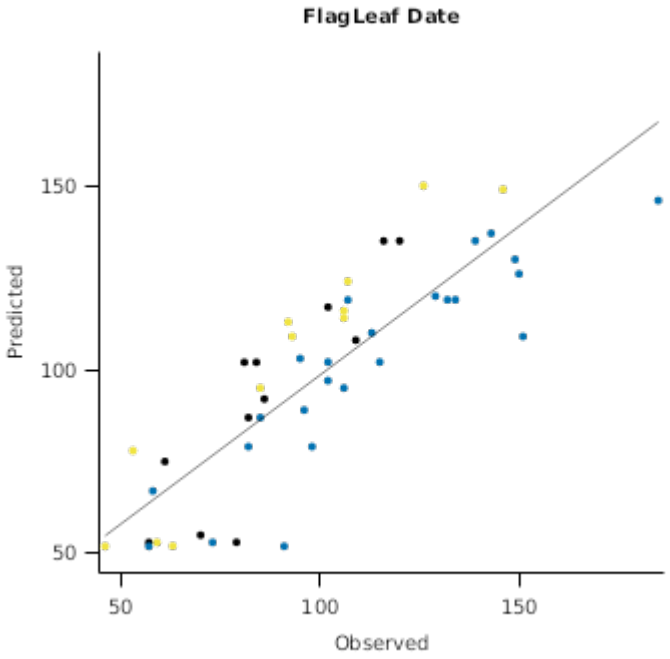
Experiment Name	Design (Number of Treatments)
WaggaWagga2019	TOS x Cv (240)

Experiment Name	Design (Number of Treatments)
Callington2019	TOS x Cv (240)
Dale2019	TOS x Cv (240)
YanYean2019	TOS x Cv (240)

2.4.8 NPIField2020

2.4.8.1 List of experiments

Experiment Name	Design (Number of Treatments)
WaggaWagga2020	TOS x Cv (240)
Urrbrae2020	TOS x Cv (240)
Dale2020	TOS x Cv (240)
YanYean2020	TOS x Cv (210)



2.4.9 ControlledEnvironment

2.4.9.1 List of experiments

Experiment Name	Design (Number of Treatments)
LaTrobeCE	Treat x Cv x Durat (140)

3 Sensibility tests

3.1 List of experiments

Experiment Name	Design (Number of Treatments)
WaterByNFactorial	Irrigation x Nitrogen (10)

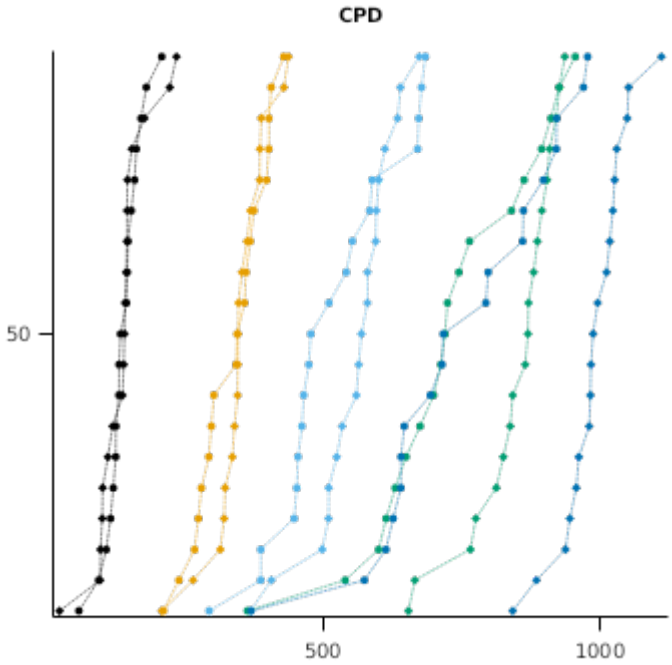
3.2 WaterByNFactorial

This is a hypothetical experiment with Barley sown on the 15th of October every year for 20 years at Lincoln, New Zealand. The treatments applied are as follows:

- Two water treatments; Dry (nil irrigation) and Wet, with irrigation applied when soil water deficit reaches 60% to return water content to 100% of capacity.

- five fertiliser N treatments; 0, 50, 100, 200 and 400 kg N/ha with half of the N applied at sowing and the other half applied at growth stage 32.

The results for irrigted, High N treatments the range of yields are inline with expectations for the location of the simulations. There is no sensitivity to irrigation with zero nitrogen as N supply is the factor limiting production. As N inputs increase the crop becomes increasingly sensitive to water application and the crop is more responsive to nitrogen with irrigation. These results show the model is giving sensible predictions



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