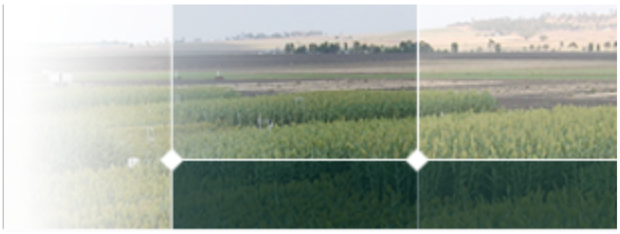


1 The APSIM Maize Model

The APSIM Maize model has been tested on a range of datasets from around the world to provide tests across a range of environmental conditions. Tests include ranges in plant population, nitrogen management and irrigation levels, as well as including historical datasets from africa using cultivars developed during the 1960's, through to modern varieties grown in the American mid-West.

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., Teixeira, E.I., Huth, N.I. and Holzworth, D.P.

#Future Development requirements

* Phenology not responding to stress events. Requires better data sets for quantifying the effects of water and nitrogen on leaf apperance and the timing of development stages.
* Phosphorus response
* Improved parameterisation of supply and demand for N and DM from organs and arbitration of these resources.
* Heat Stress responses in grain number
* More validation under a wider range of environments with more detailed datasets
* Seedling mortality
* Water demand (MicroClimate) needs validation

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
Husk	Models.PMF.Organs.GenericOrgan
Rachis	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
BelowGround	Models.PMF.CompositeBiomass
Total	Models.PMF.CompositeBiomass
TotalLive	Models.PMF.CompositeBiomass
TotalDead	Models.PMF.CompositeBiomass
EarLive	Models.PMF.CompositeBiomass
AboveGroundLive	Models.PMF.CompositeBiomass
AboveGroundDead	Models.PMF.CompositeBiomass
Spike	Models.PMF.CompositeBiomass

1.3 Cultivars

Cultivar Name	Alternative Name(s)
Hycorn_53	Hycorn_53
Pioneer_33M54	Pioneer_33M54
Pioneer_38H20	Pioneer_38H20
Pioneer_34K77	Pioneer_34K77
Pioneer_39V43	Pioneer_39V43
Atrium	Atrium
Laila	Laila
GH_5019WX	GH_5019WX
Hycorn_40	Hycorn_40
GH_5009	GH_5009
Dekalb_XL82	Dekalb_XL82
malawi_local	malawi_local
mh19	mh19
mh17	mh17
mh16	mh16
mh12	mh12
sc623	sc623
sc625	sc625
sc601	sc601
CG4141	CG4141
mh18	mh18
r215	r215
Melkassa	Melkassa

Cultivar Name	Alternative Name(s)
sr52	sr52
sc501	sc501
r201	r201
sc401	sc401
NSCM_41	NSCM_41
Makueni	Makueni
Katumani	Katumani
Pioneer_3153	Pioneer_3153
Pioneer_39G12	Pioneer_39G12
B_80	B_80
B_90	B_90
B_95	B_95
B_100	B_100
B_103	B_103
B_105	B_105
B_108	B_108
B_110	B_110
B_112	B_112
B_115	B_115
B_120	B_120
B_130	B_130
A_80	A_80
A_90	A_90
A_95	A_95
A_100	A_100
A_103	A_103
A_105	A_105
A_108	A_108
A_110	A_110
A_112	A_112
A_115	A_115
A_120	A_120
A_130	A_130
HY_110	HY_110

Cultivar Name	Alternative Name(s)
LY_110	LY_110
P1197	P1197

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.

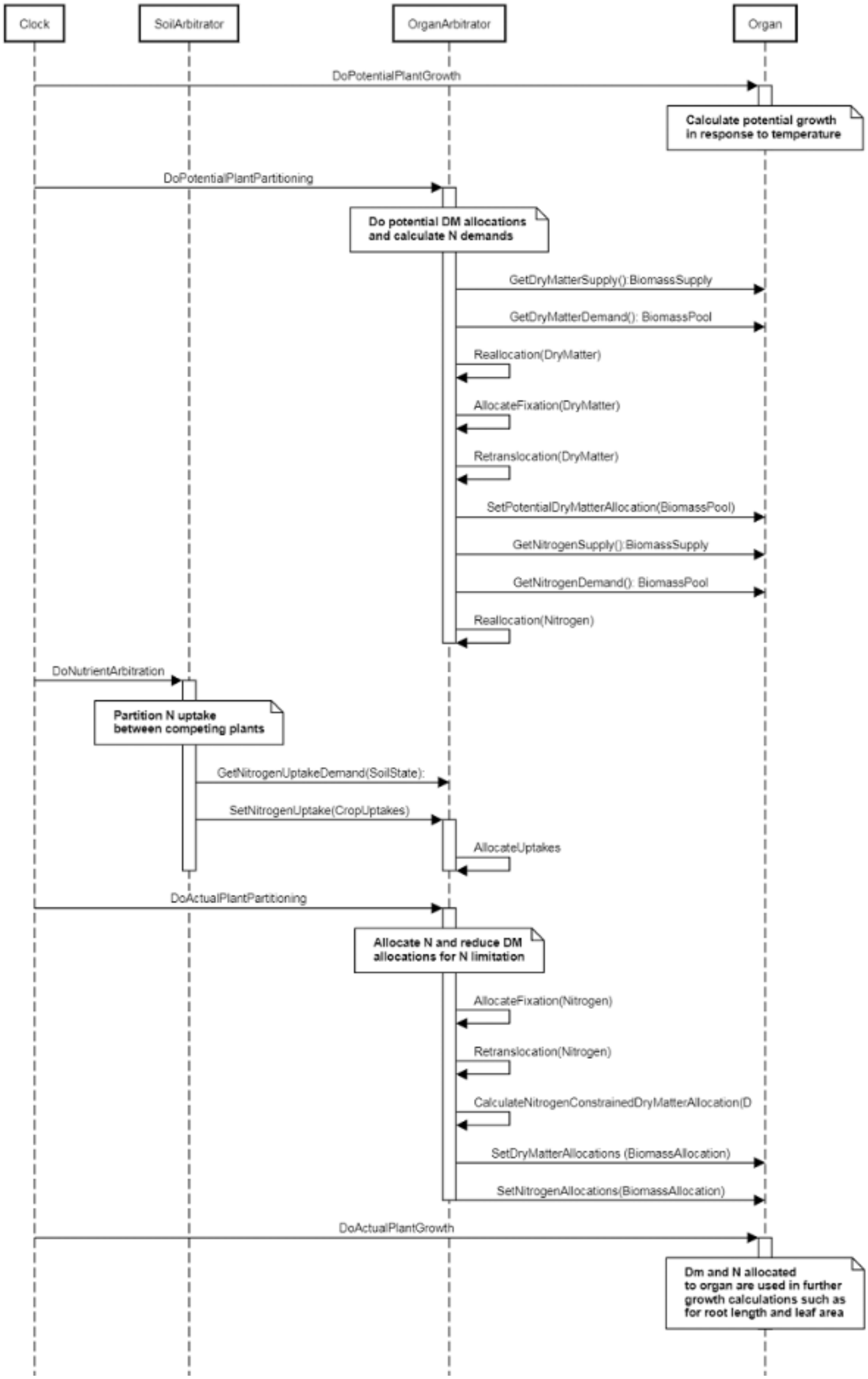


Figure 1: Schematic showing the procedure for arbitration of biomass partitioning. Pink boxes represent events that occur every day and their numbering shows the order of calculations. Blue boxes represent the methods that are called when these events occur. Orange boxes contain properties that make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

1.4.2 Phenology

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

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.

Though tillering is common in some maize varieties under certain agronomic conditions, no tillering is accounted for within this model. Therefore all branching has been parameterised out of the current maize model.

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 Husk

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 Rachis

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 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.

1.4.10 MortalityRate

A constant function (name=value)

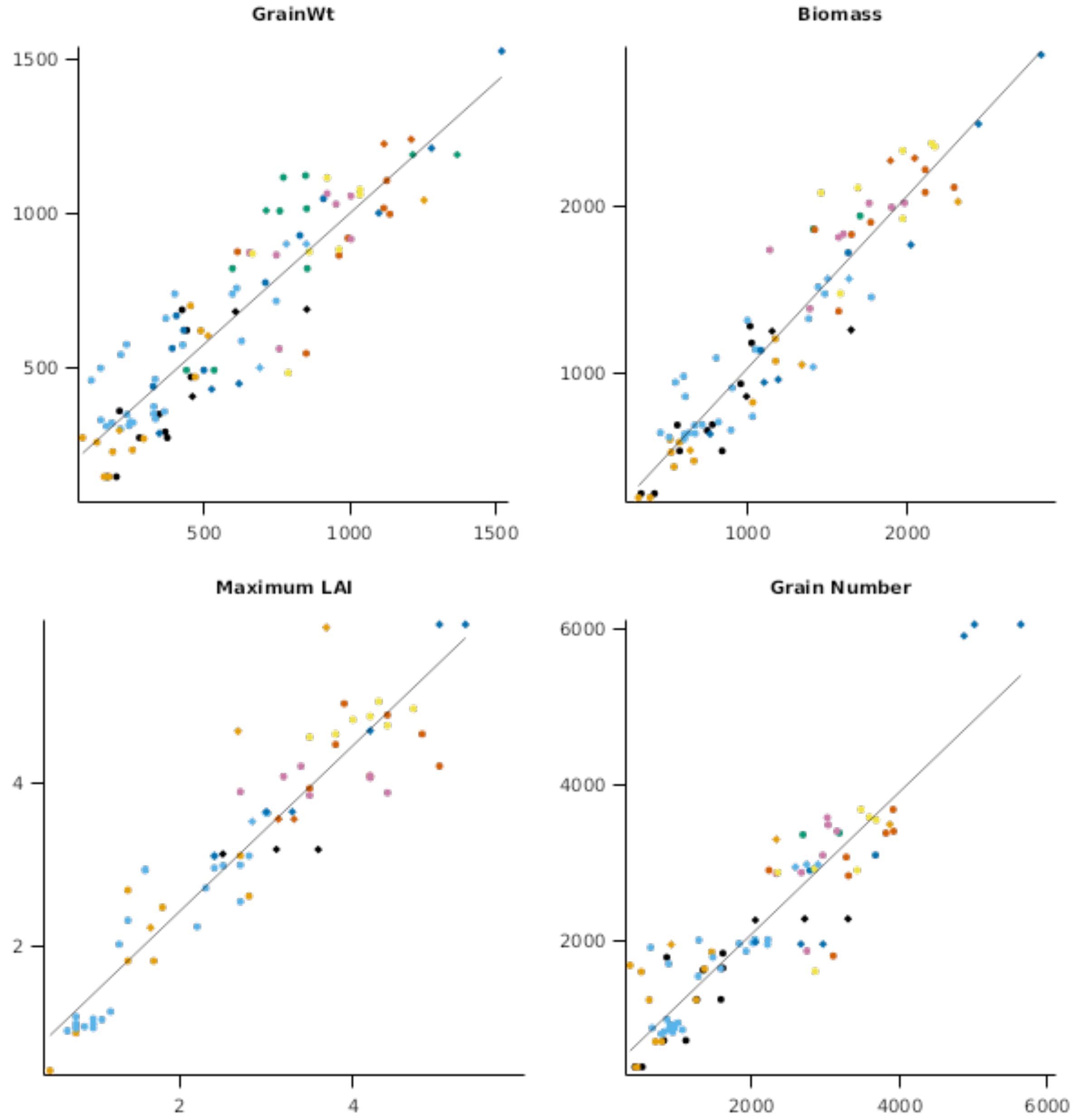
1.4.11 SeedMortalityRate

A constant function (name=value)

2 Validation

2.1 Combined Results

Simulation results for the combined datasets from the various countries are shown in the following graphs. The model is able to adequately capture the influence of growing conditions (soil, climate) and management (population, Nitrogen, irrigation, sowing date).



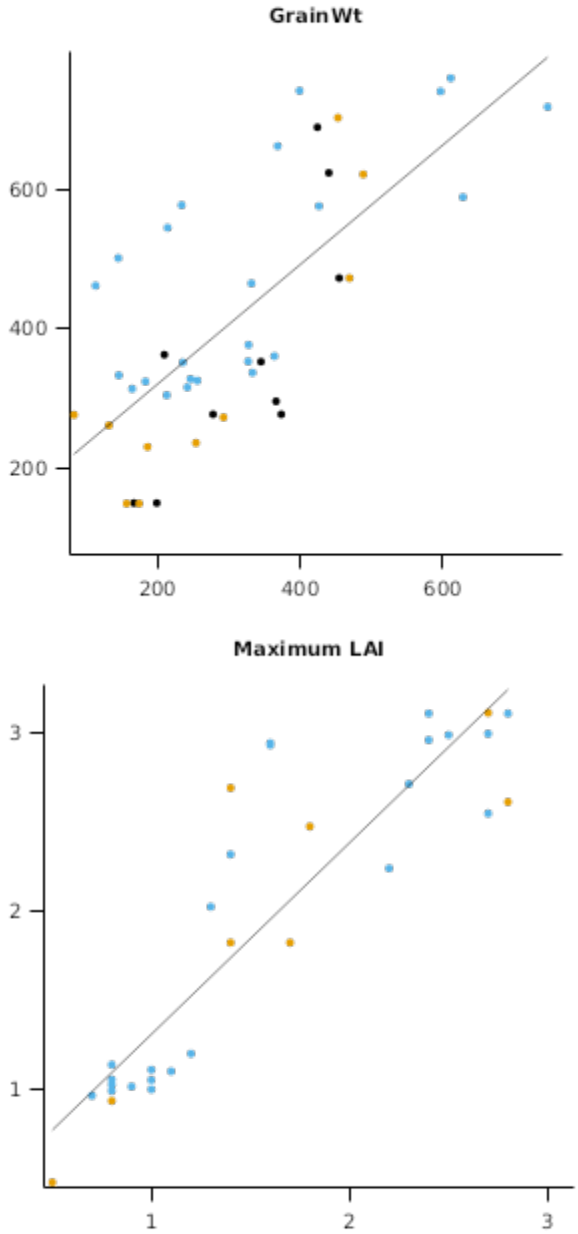
2.2 Africa

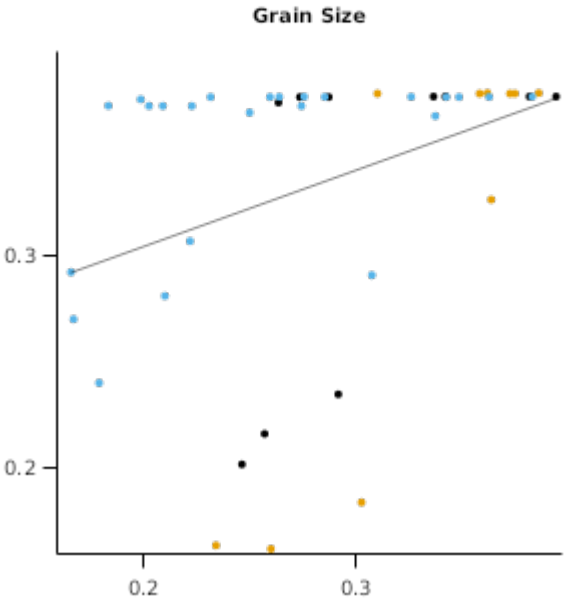
A selection of data from Kenya has been included from the work of KEATING et al., 1992. These include the trial originally labelled JMW2 by the original authors and was labelled Experiment 6 in KEATING et al., 1992. This trial includes maize (cultivar Katumani Composite B) sown at 5 populations (1.1, 2.2, 4.4, 6.6 and 8.8 plants/m2) under low (0 kg N/ha applied) and high (120 kgN/ha) fertiliser conditions during the Long Rains of 1988. This same experimental design was conducted at two locations, Katumani (1o 35' S, 37o 14' E) and Kiboko (2o 13' S, 37o 43' E). The trial was rainfed at Katumani but fully irrigated at Kiboko. Yields ranged from 2000 to 5400 kg/ha at Katumani and 1000 to 6000 kg/ha at Kiboko. There were strong population x nitrogen interactions at both sites. A second trial refered to as BMW1 or Experiment 1 in KEATING et al., 1992. A range of populations (2.0-6.5 plants/m2) and irrigation treatments (6-176 mm) where planted under high (80 kgN/ha) and low (0kgN/ha) fertiliser conditions at Katumani. Individual replicates are modelled separately due to variability in soil (depth to rock), establishment and irrigation application. Grain yields varied from 1600 to 8000 kg/ha.

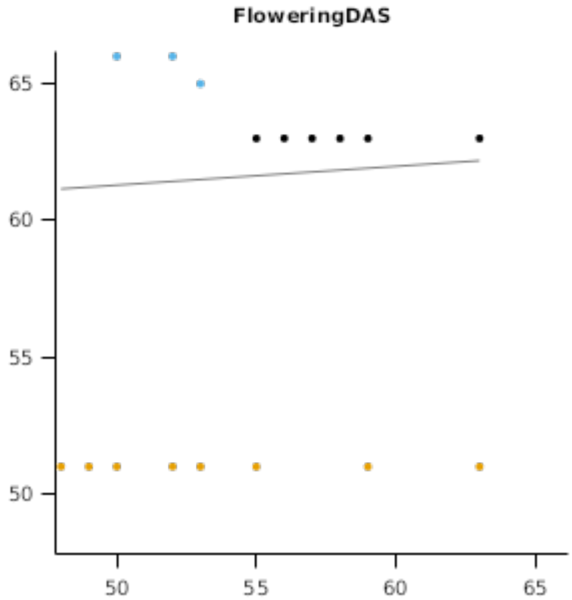
Note. The BMW1 trail consists of data from unreplicated plots.

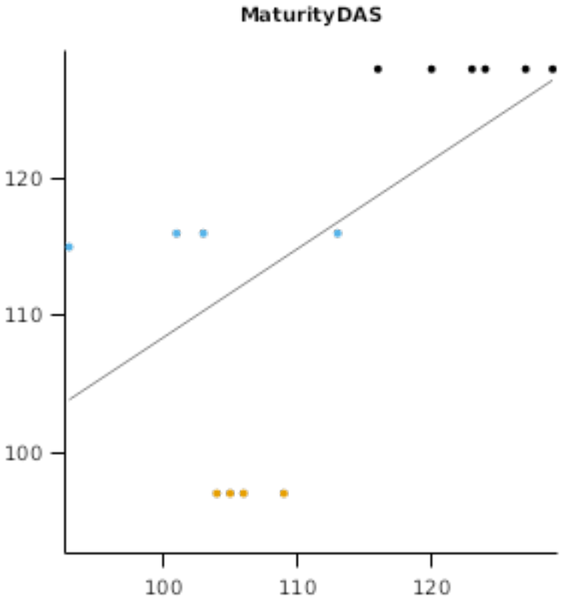
2.2.1 List of experiments

Experiment Name	Design (Number of Treatments)
JMW2Katumani	Popn x Fert (10)
JMW2Kiboko	Popn x Fert (10)
BMW1	Site (24)

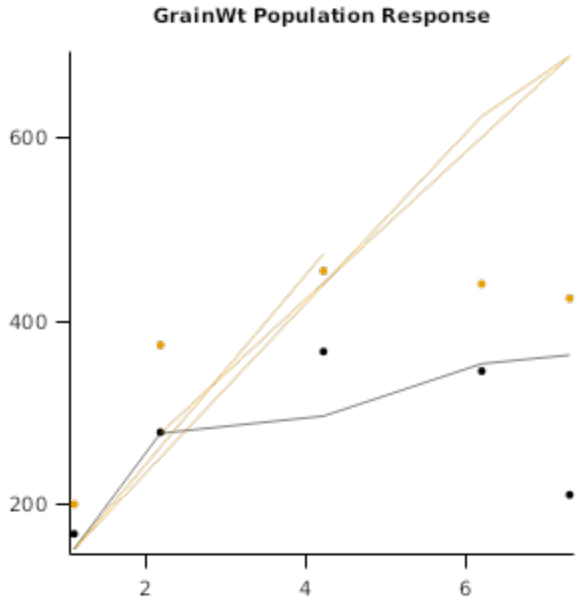

GrainWt
600
400
200
200
400
600
Biomass
1500
1000
500
500
1000
1500
Maximum LAI
3
2
1
1
2
3
Grain Number
2000
1500
1000
500
500
1000
1500
2000

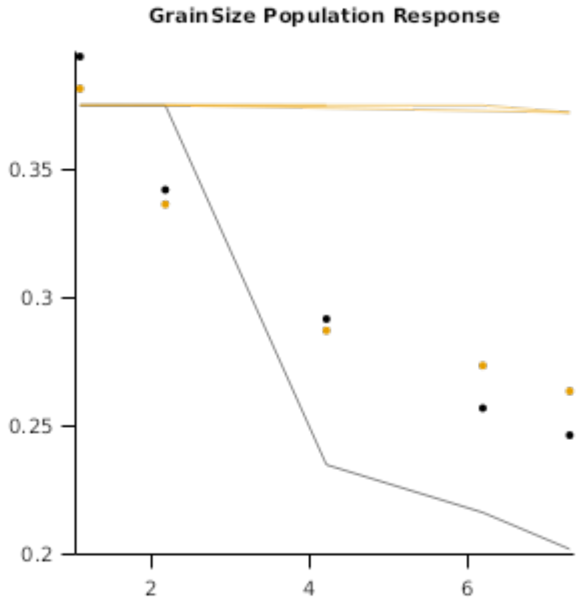


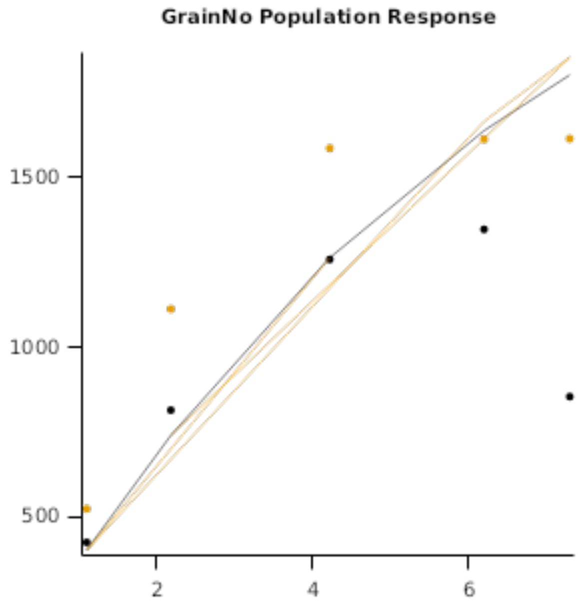




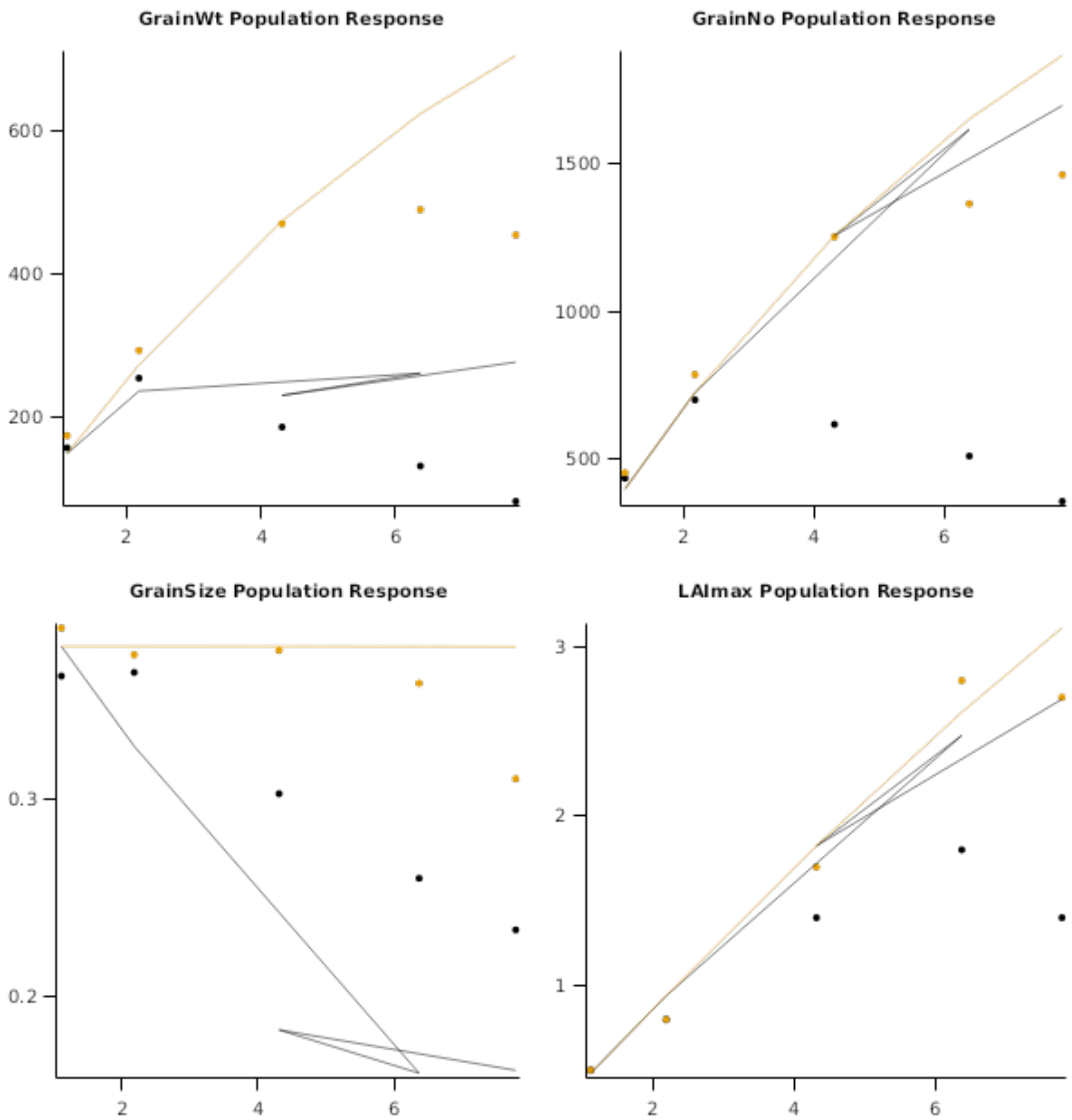
2.2.2 JMW2Katumani







2.2.3 JMW2Kiboko



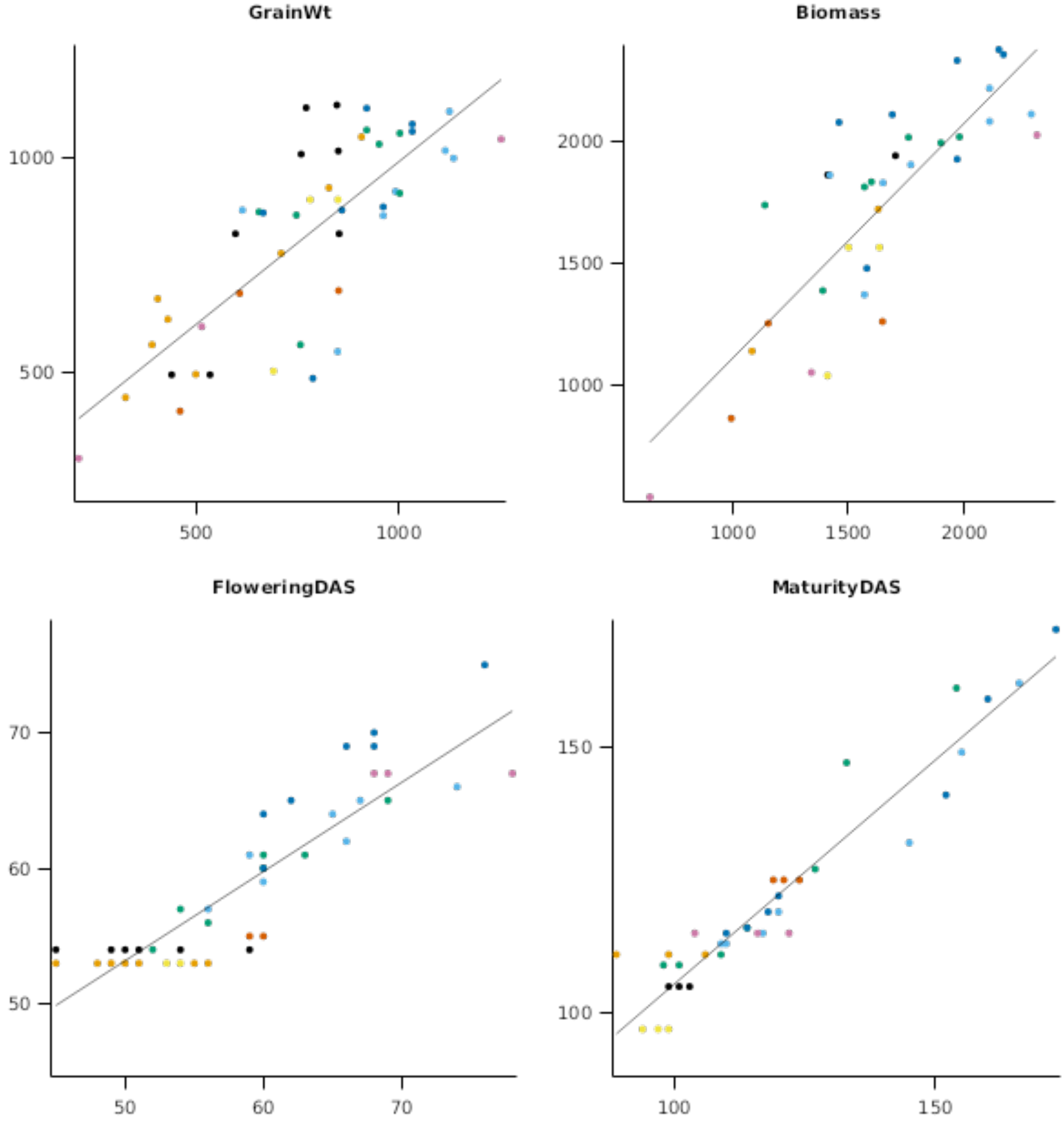
2.3 Australia

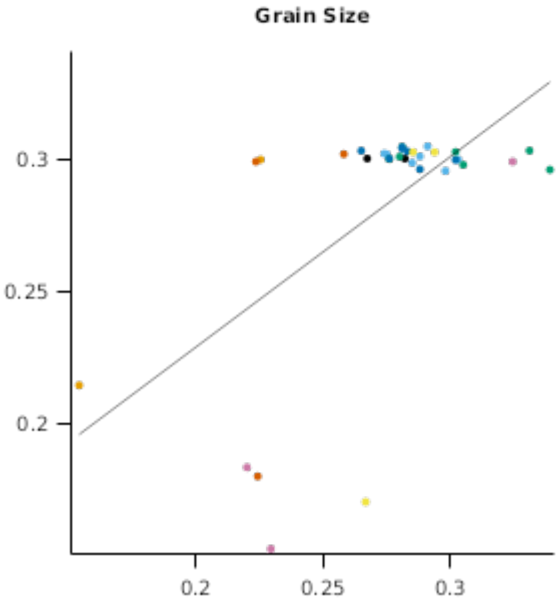
The data for two trials from near Katherine, Northern Territory, Australia, have been included from CARBERRY et al., 1989 and CARBERRY et al., 1991. These include two planting dates for the summer of 1983/1984 (labelled as K841, K842). At each planting date, cultivar Dekalb XL82 was sown at 4 populations (3, 5, 7, 9 plants/m^2) under low and high irrigation conditions. The low irrigation treatments only included preliminary applications to ensure crop establishment.

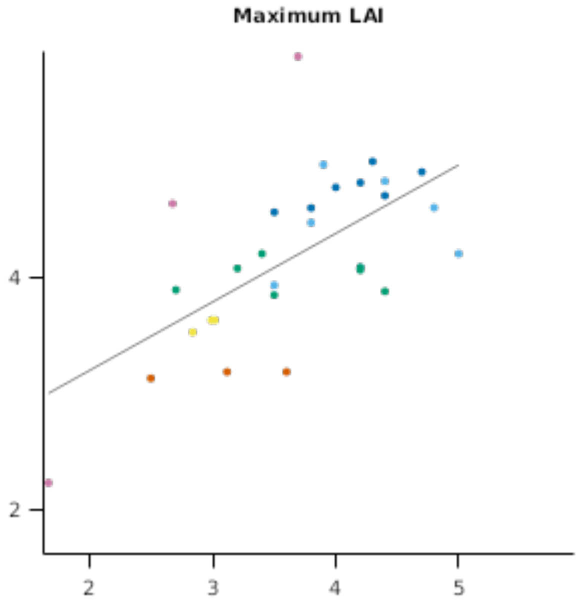
2.3.1 List of experiments

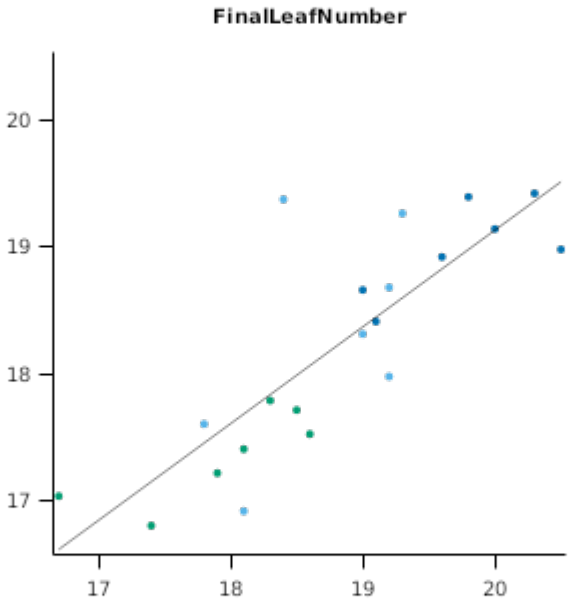
Experiment Name	Design (Number of Treatments)
K841	Popn x Irrigation (8)
K842	Popn x Irrigation (8)
DRK1	Sowing (7)
DRK2	Sowing (7)
DRK3	Sowing (7)
Angelo98	Fert (3)
Angelo99	Fert (3)

Experiment Name	Design (Number of Treatments)
Angelo00	Fert (3)

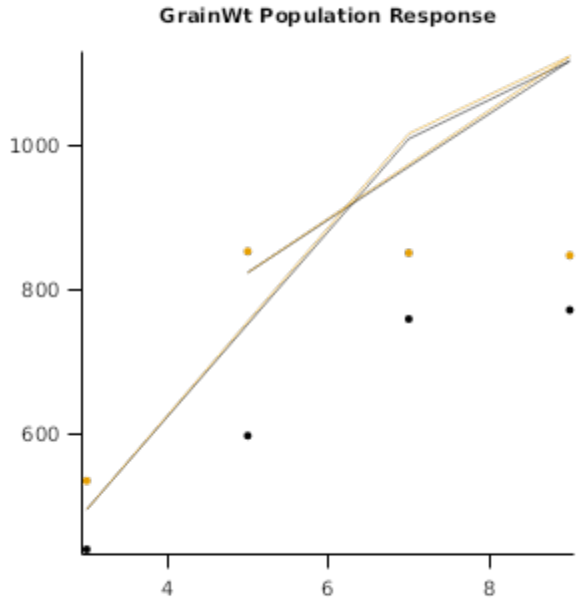


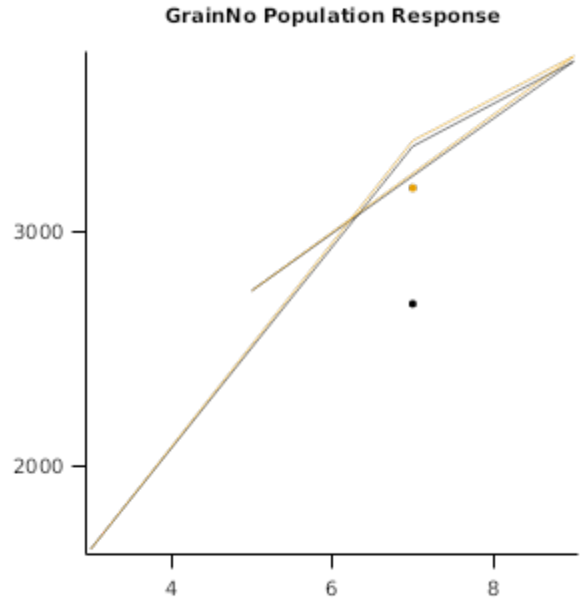

Grain Size
0.3
0.25
0.2
0.2
0.25
0.3

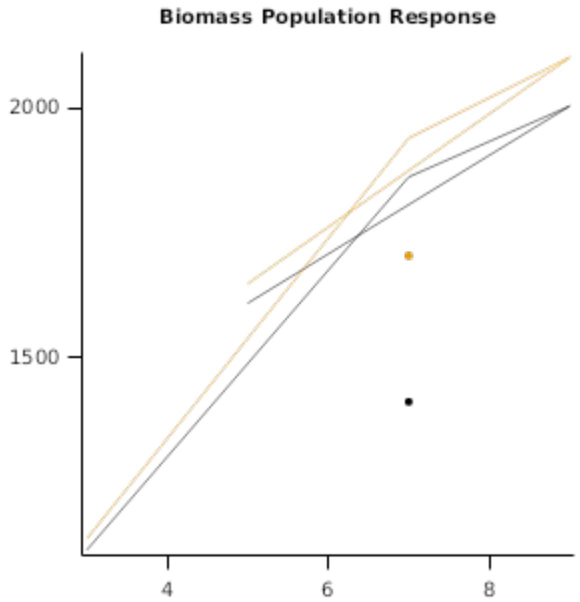

Maximum LAI
4
2
2
3
4
5


FinalLeafNumber
20
19
18
17
17
18
19
20

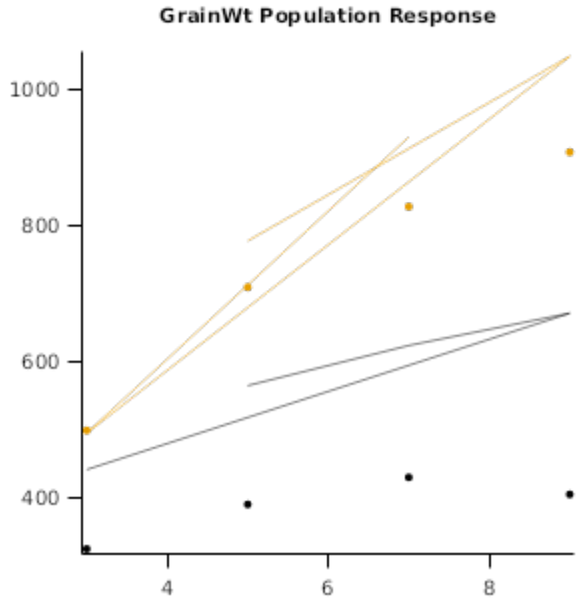
2.3.2 K841

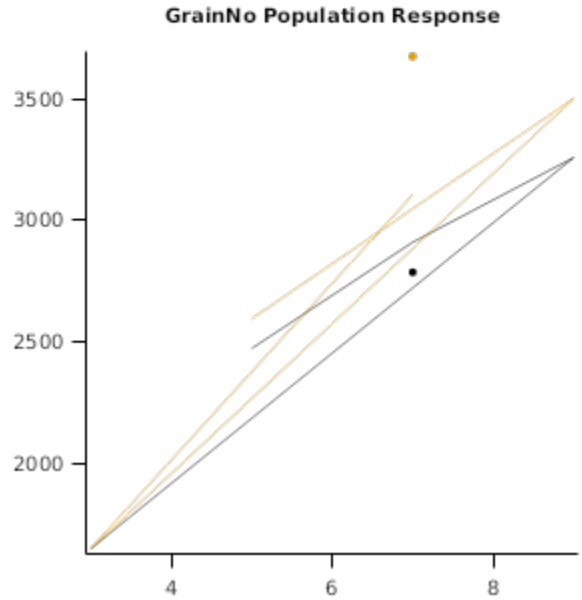

GrainWt Population Response
1000
800
600
4
6
8

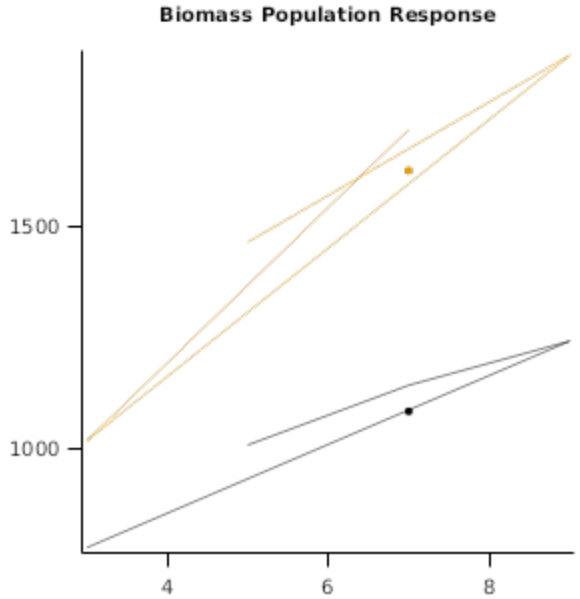

GrainNo Population Response
3000
2000
4
6
8

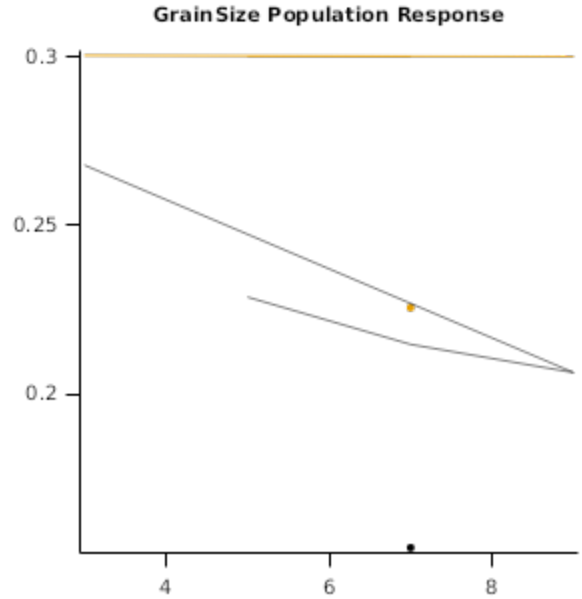

Biomass Population Response
2000
1500
4
6
8

2.3.3 K842



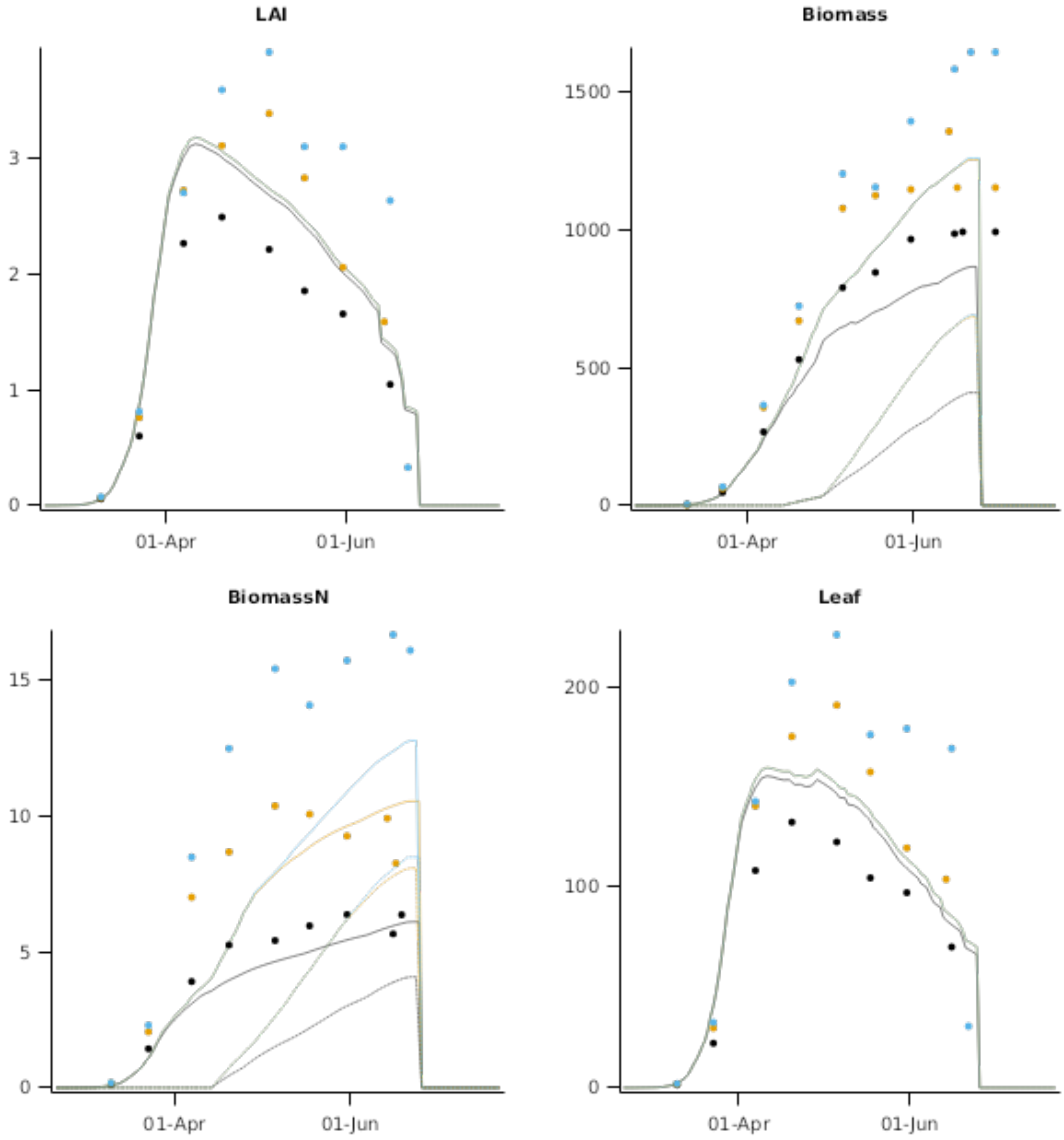


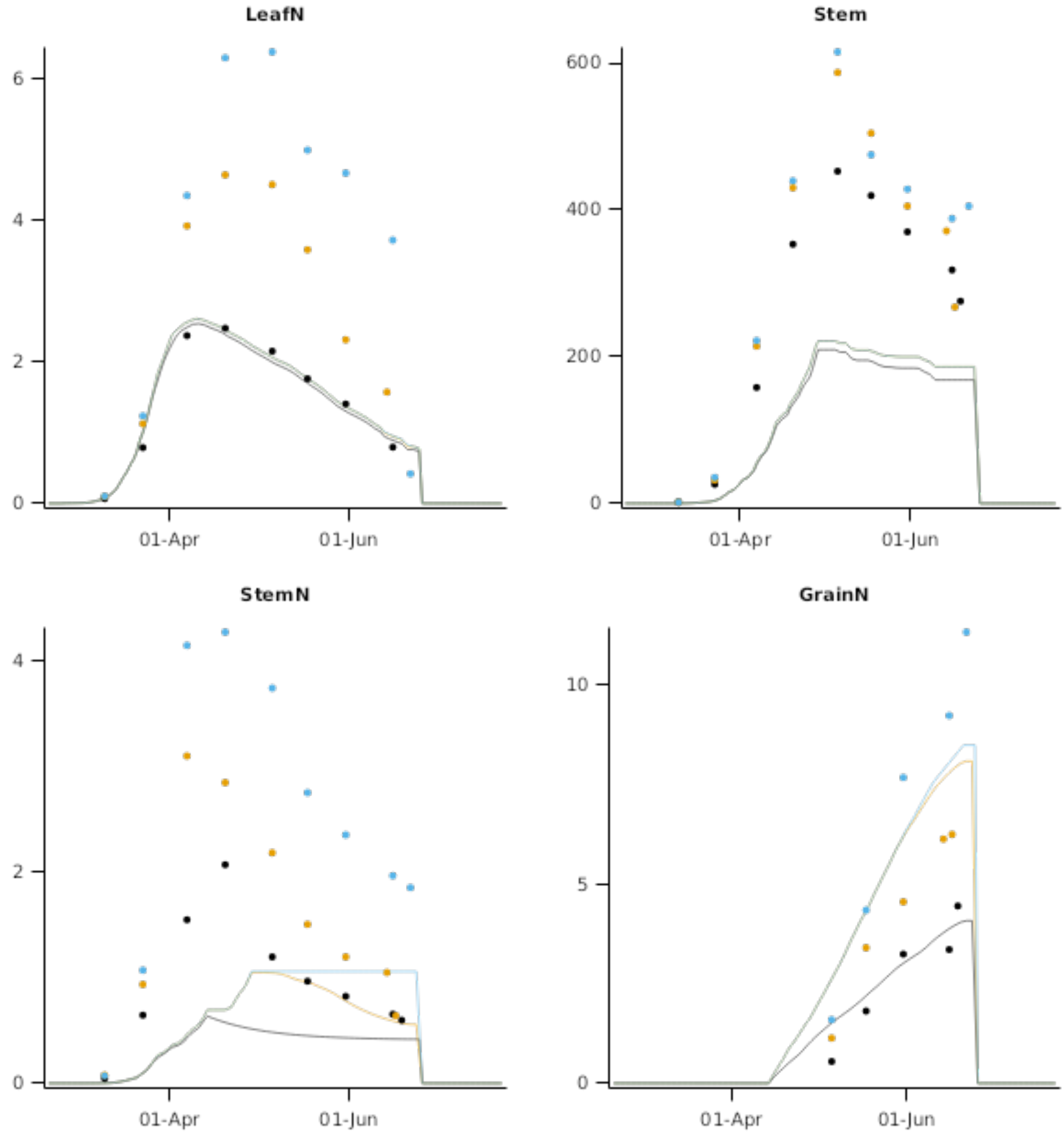




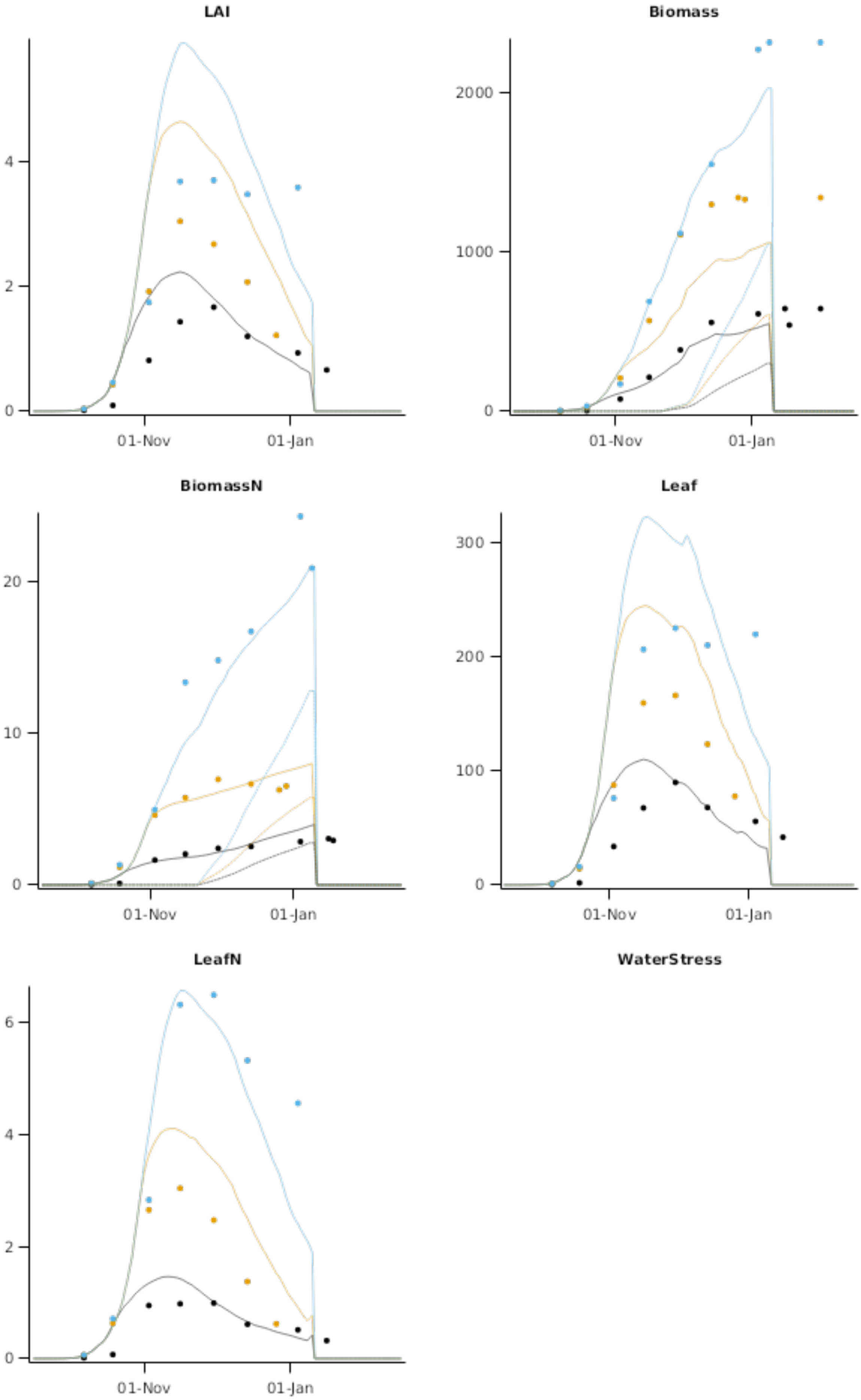
2.3.4 Angelo98

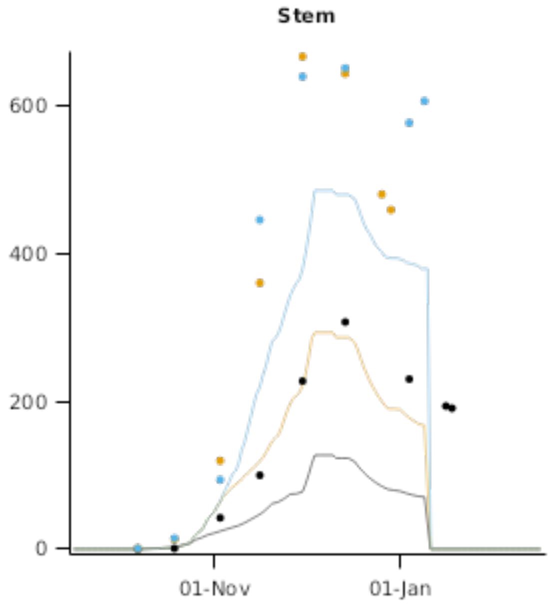
This data set has been published by Massignam et al., 2009. Three sowings were conducted at the CSIRO Cooper field station (27o34'S, 152o20'E), Gatton, Australia. The soil was a Lockyer clay loam for sowing 1 and 2 and a Hooper clay loam for sowing 3. Maize (Hycorn53) was sown on three dates to provide a range of growing environments. Each sowing was provided with 3 rates of nitrogen. To ensure moisture was non-limiting, the plots were irrigated weekly by trickle irrigation, except when rainfall occurred. Plots were weeded regularly and insect pests and foliar diseases controlled as required.

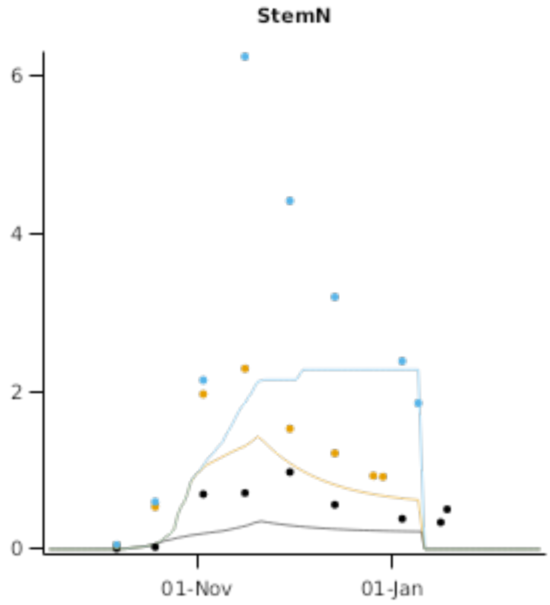

LAI
3
2
1
0
01-Apr
01-Jun
Biomass
1500
1000
500
0
01-Apr
01-Jun
BiomassN
15
10
5
0
01-Apr
01-Jun
Leaf
200
100
0
01-Apr
01-Jun

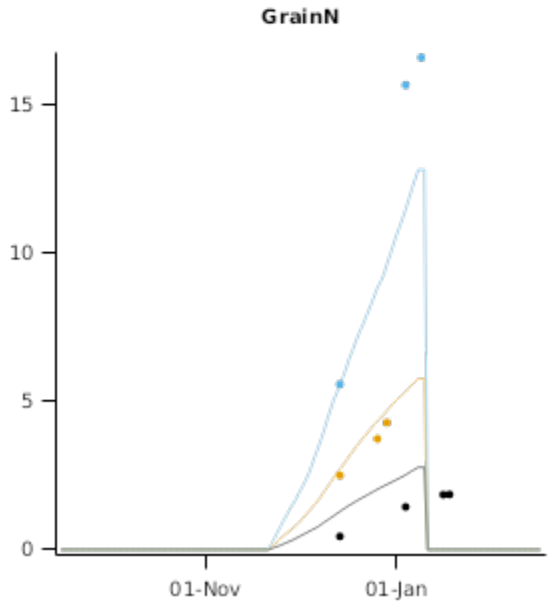


2.3.5 Angelo99

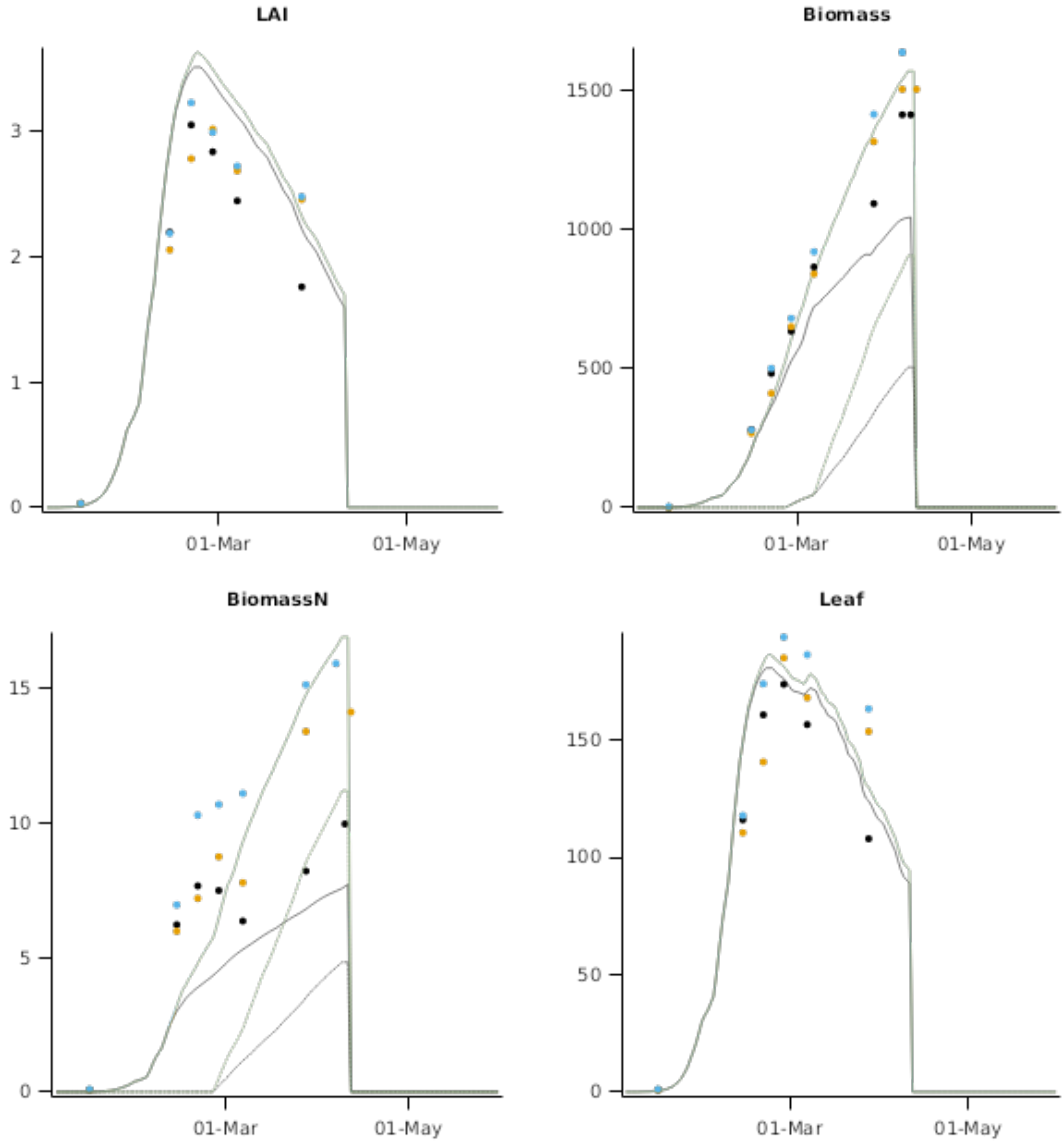

LAI
0
2
4
01-Nov
01-Jan
Biomass
0
1000
2000
01-Nov
01-Jan
BiomassN
0
10
20
01-Nov
01-Jan
Leaf
0
100
200
300
01-Nov
01-Jan
LeafN
0
2
4
6
01-Nov
01-Jan
WaterStress

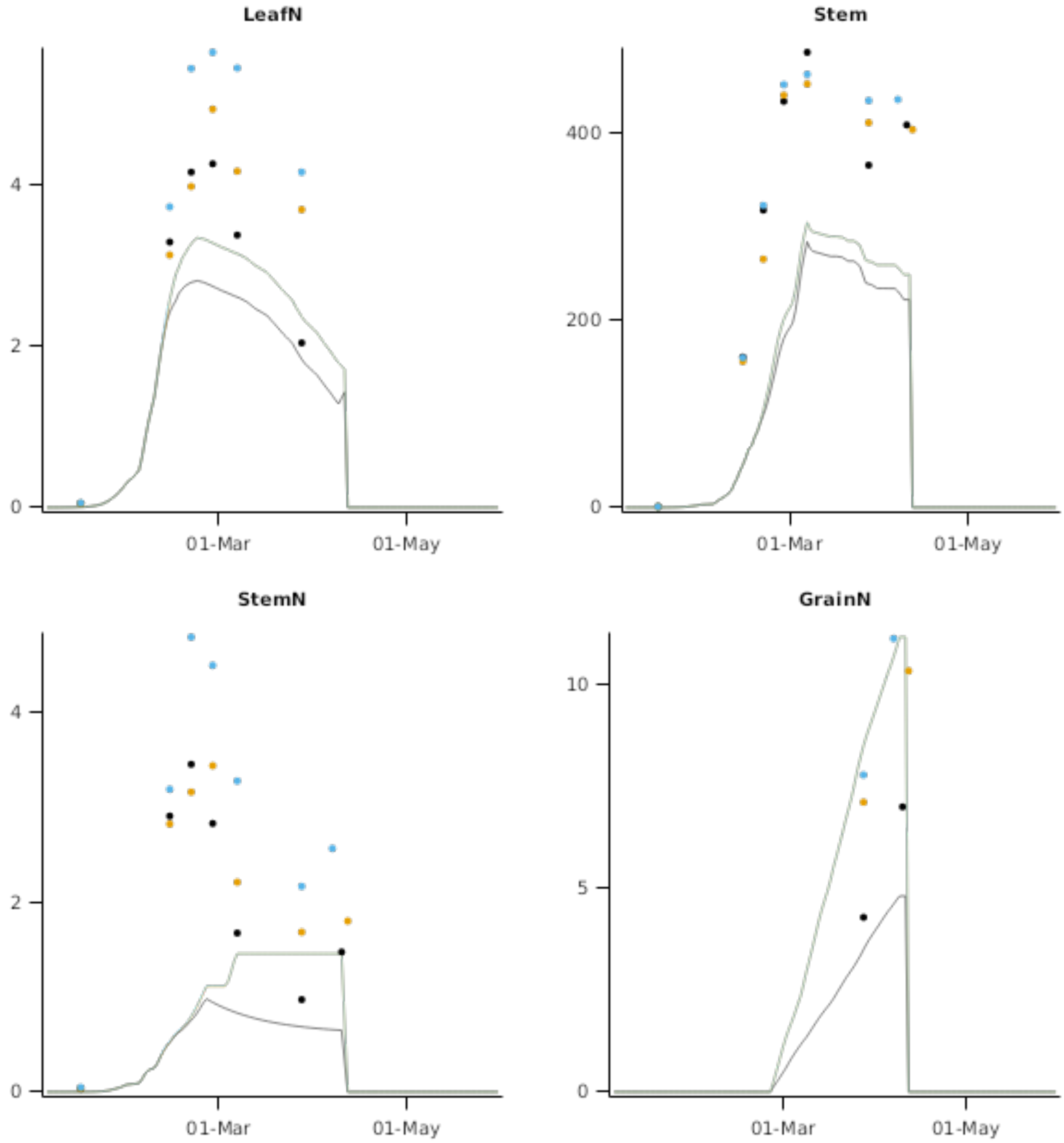






2.3.6 Angelo00


LAI
Biomass
BiomassN
Leaf
0
1
2
3
500
1000
1500
5
10
15
50
100
150
01-Mar
01-May



2.4 USA

Testing of APSIM Maize, Soil Water, Soil Nitrogen, Manure, and Soil Temperature Modules in the Midwestern United States was undertaken by [Archontoulis_etal_2014] using APSIM version 7.4. A subset of these data has been chosen for testing of the maize model. Datasets involving application of compost have not been included so as to concentrate on tests of maize model performance, rather than overall soil organic matter dynamics.

2.4.1 List of experiments

Experiment Name	Design (Number of Treatments)
Ames2011	NRate (3)

2.5 New Zealand

Testing of APSIM Maize under New Zealand conditions to determine the perormance of the model under temperate conditions with cool springs and mild summers. A range of trials have been conducted and are detailed below

2.5.1 List of experiments

Experiment Name	Design (Number of Treatments)
Lincoln2012	Nit x Irr (6)
Lincoln2010	Nitrogen (2)

Experiment Name	Design (Number of Treatments)
Lincoln2008	Sow x Cover (8)
HawksBay2010	Sow x Cv (9)

2.5.2 Lincoln2012

2.5.2.1 Lincoln2012 (Rain-Shelter Trail)

Testing of APSIM Maize under New Zealand conditions was undertaken using the data of Teixeira et al., 2014. This dataset includes the impact of three N (0 to 250 kg/ha N) and two water regimes (dryland and fully irrigated) using a rain-shelter structure. Observations include biomass growth and nitrogen content of individual organs, soil water contents, leaf area index, phenology and yield components. Total biomass ranged from 8000 kg/ha for dryland nil N crops to up to 28000kg/ha for fully irrigated and N fertilised crops. Dryland crops recovered 25 percent less N from applied fertilizer than irrigated crops.

2.5.3 Lincoln2010

2.5.3.1 Lincoln2010 (Leaf properties trial)

This trial was conducted to provide data for parametersising the Leaf Area model and is described in detail by Teixeira et al., 2011. Detailed measurements were conducted on leaf apperance and expansion with some measurements of biomass accumulation. Treatments of plus and minus Nitrogen were applied but there was sufficient N in the soil than N responses were very small.

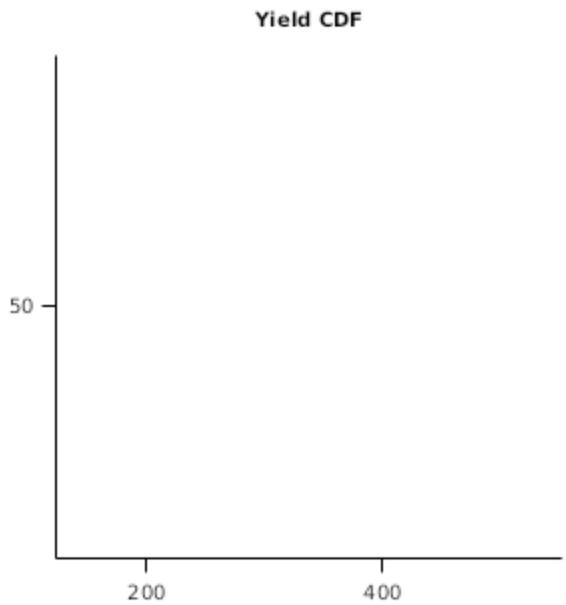
3 Sensibility Tests

3.1 List of experiments

Experiment Name	Design (Number of Treatments)
Bugesera	NRate (2)

3.2 Bugesera

Maize is grown in the Bugesera region of southern Rwanda in Central Africa. The region has a bimodal rainfall distribution which allows two plantings per year. For low input situations the maize yields should vary between 1 and 3 t/ha per crop. Under fertilised conditions the yield should increase up to 5 t/ha per crop.



4 References

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