



1 The APSIM Sorghum 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.

1.1 The APSIM NextGen Sorghum Model – Structure and Function

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The APSIM-sorghum model is based on a framework of the physiological determinants of crop growth and development [Charles-Edwards, 1982](#), is focused at organ scale, and has been detailed in [Hammer et al., 2010](#) and [Hammer et al., 2019](#). It generates the phenotype of a crop as a consequence of underlying physiological processes (Fig. 1) by using the concept of supply and demand balances for light, carbon, water, and nitrogen [Hammer et al., 2001](#). The approach is focused around quantifying capture and use of radiation, water, and nitrogen within a framework that predicts the dynamics of crop development and the realized growth of major organs based on their potential growth and whether the supply of carbohydrate and nitrogen can satisfy this potential. Demand for resources is defined by potential organ growth and potential supply by resource capture ([Monteith et al., 1977](#); [Passioura, 1983](#); [Monteith et al., 1986](#)) (Figure. 1). Arbitration rules and organ level responses are invoked when resource capture cannot satisfy demand. The APSIM-sorghum model retains some features and concepts of earlier models: [Sinclair, 1986](#); [Rosenthal, 1989](#); [Birch et al., 1990](#); [Sinclair et al., 1992](#); [Chapman et al., 1993](#); [Hammer et al., 1994](#), but has been adapted and redesigned to generate a more explanatory approach to the modelling of the underlying physiology [Hammer et al., 2006](#).

APSIM-sorghum operates via the dynamic interaction of crop development, crop growth, and crop nitrogen with soil and weather attributes (Fig. 1). Predictive schemas can be separated into crop growth and development dynamics (Fig. 1a) and crop nitrogen dynamics (Fig. 1b) for purposes of description, but the interactions between these major components are critical.

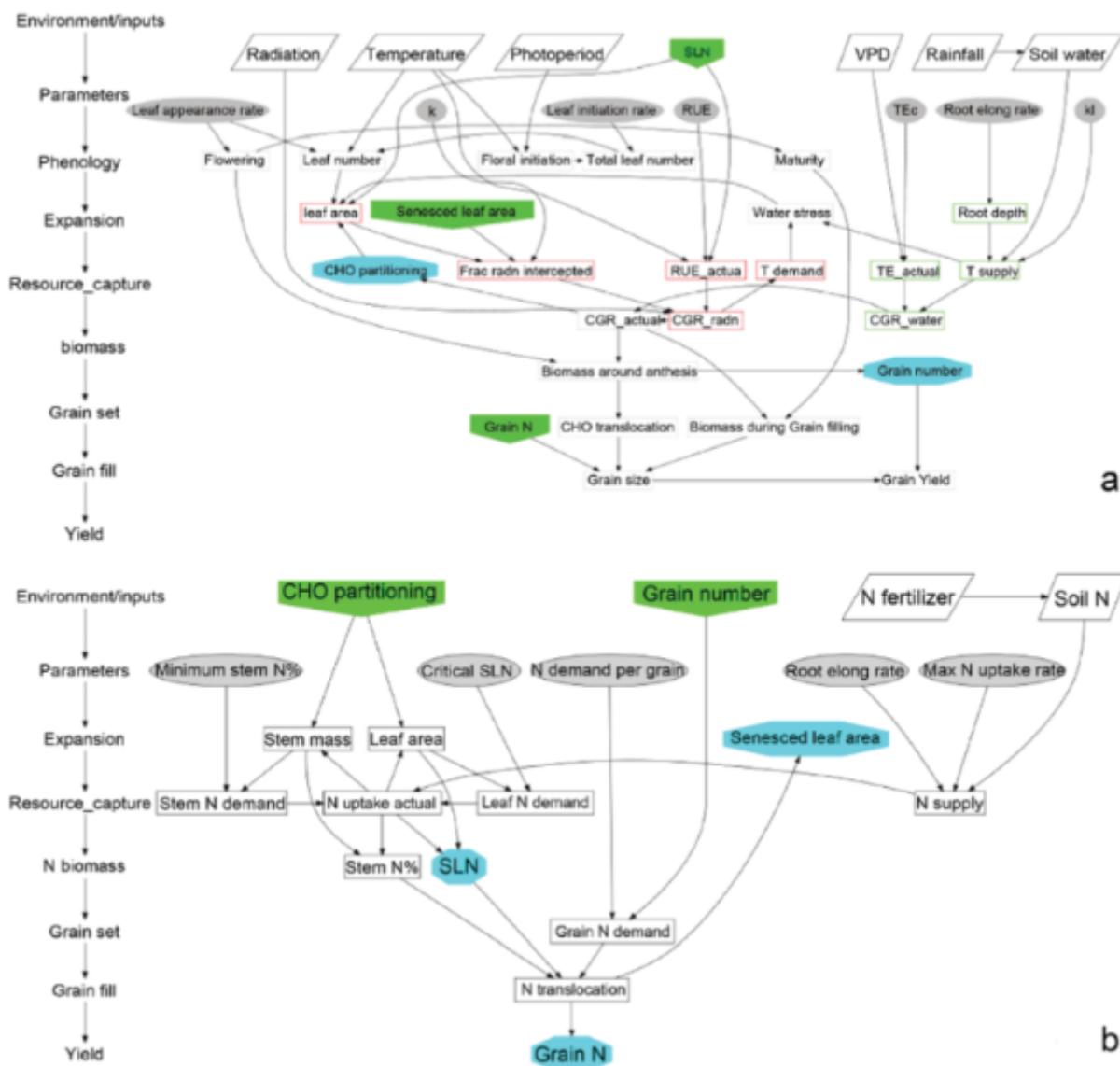


Figure 1: Schematic representation of crop growth and development dynamics (a) and crop nitrogen dynamics (b) in Agricultural Production System simulator (APSIM)-sorghum model. Connection points between the two schematics are shown by the shaded boxes.

Image Reference: [Hammer et al., 2010](#)

1.2 Crop Growth and Development Dynamics

Phenology is simulated through a number of development stages by using a thermal time approach [Muchow et al., 1990](#); [Hammer et al., 1994](#), with the temperature response characterized by a base (T_b), optimum (T_{opt}), and maximum (T_m) temperature. [Hammer et al., 1993](#) and [Carberry et al., 1993](#) reported values of T_b , T_{opt} , and T_m for sorghum of 11, 32, and 42°C, respectively. The thermal time target for the phase between emergence and panicle initiation is also a function of day length ([Hammer et al., 1989](#); [Ravi Kumar et al., 2009](#)), and its duration, when divided by the plastochron (°C per leaf), determines total leaf number once an allowance for leaf initials in the embryo has been included. Total leaf number multiplied by the phyllochron (°C per leaf) determines the thermal time to reach flag leaf stage, which is thus an emergent property of the model. Timing of the stages anthesis, and start and end of grain filling are also simulated through thermal time targets ([Muchow et al., 1990](#); [Hammer et al., 1994](#); [Ravi Kumar et al., 2009](#)). Drought stress and N stress can both reduce the leaf appearance rate and hence delay phenology during the vegetative stages ([Craufurd et al., 1993](#); [van Oosterom et al., 2010](#)).

Canopy development is simulated on a whole plant basis given the fertile tiller number and leaf size-leaf number distribution ([Carberry et al., 1993](#); [van Oosterom et al., 2001](#)). Expected fertile tiller number can be input or predicted using a dynamic tillering prediction routine. The total plant leaf area at any time is calculated as the sum of main culm and tiller leaf area. Main culm leaf area is determined from the number of fully expanded leaves on the main culm and their size, plus an adjustment for the area of expanding leaves in the whorl ([Hammer et al., 1993](#)). The area of leaves on tillers is determined from the number of fertile tillers and the size of their leaves, which is determined via the allometric association of leaf size distribution on each tiller with that on the main culm. The dynamic tillering routine predicts the total number of tillers produced from a relationship combining the genetic propensity to tiller (input) with availability of surplus assimilate at the time of tiller outgrowth early in crop development ([Alam et al., 2014](#)). Plant assimilate status is estimated

from the balance between radiation-driven supply and main culm leaf expansion-driven demand. Hence, tillering is favoured in high radiation-low temperature conditions as found by [Kim et al., 2010](#). The number of tillers surviving to produce grain is then dependent on internal plant competition for available assimilate, which will be influenced by the rate of leaf expansion for the entire plant and the plant density. The trajectory of specific leaf area (SLA $\text{cm}^2 \text{g}^{-1}$) is a good indicator of extent of internal plant competition and is used to drive tiller outgrowth cessation until a balance is reached ([LAFARGE et al., 2002](#)). It is also used to reduce potential leaf size on the main culm in situations of reduced assimilate availability per plant (eg under high density) where SLA will reach boundary conditions.

The number of fully expanded leaves at any time is the product of thermal time elapsed since emergence and the leaf appearance rate (phyllochron). This enables calculation of leaf area per plant at any time as outlined above. Actual crop leaf area is the product of plant density and leaf area per plant. Green leaf area index (LAI) is the difference between the total plant leaf area and the senesced leaf area. Under drought stress, the crop will initially cease expanding new leaves, thus reducing transpiration demand, and then commence senescing leaves until demand for transpiration no longer exceeds supply from uptake ([Hammer et al., 2001](#)).

Aboveground biomass accumulation is simulated as the minimum of light-limited or water-limited growth. In the absence of water limitation, biomass accumulation is the product of the amount of intercepted radiation (IR) and its conversion efficiency, the radiation use efficiency (RUE). The fraction of incident radiation intercepted is a function of the LAI and the canopy extinction coefficient (k), which is a measure of canopy structure ([LAFARGE et al., 2002](#)). The effects of N supply on crop growth are implicitly incorporated in this approach. Nitrogen limitation will reduce leaf area growth and hence LAI and IR. It can also reduce RUE, which is a function of the N status of the leaves ([Muchow et al., 1994](#); [Sinclair et al., 1992](#)). [Sinclair and Muchow Sinclair et al., 1999](#) reviewed studies that had measured RUE in many crops and noted a consistent value of 1.25 g MJ^{-1} for triple-dwarf sorghum under optimum growing conditions. The flexibility of the object-oriented template also allows simulation of crop biomass accumulation via diurnal canopy photosynthesis models where this is required, as in the studies of [Sinclair et al., 2005](#), [Hammer et al., 2009](#), and [Wu et al., 2019](#).

Under water limitation, aboveground biomass accumulation is the product of realized transpiration and its conversion efficiency, biomass produced per unit of water transpired, or transpiration efficiency (TE). It is necessary to adjust TE to allow for the prevailing vapor pressure deficit (vpd) ([Tanner et al., 1983](#); [Kemanian et al., 2005](#)). Numerous studies in sorghum ([Tanner et al., 1983](#); [Hammer et al., 1997](#)) have found a standard value of 9 Pa for the TE coefficient in sorghum, so that at a vpd of 2 kPa a TE of $4.5 \text{ gm}^{-2} \text{ mm}^{-1}$ results. The water supply accessible to the plant depends on the effective rooting depth and the rate at which soil water can be extracted from the soil by the roots. The potential extraction rate is related to the soil water content via an exponential function, parameterized via an extraction decay constant (k_l) that incorporates effects of both soil hydraulic conductivity and root length density on water uptake ([Passioura, 1983](#); [Monteith et al., 1986](#); [Robertson et al., 1993](#); [Hammer et al., 2001](#)). Water extraction occurs from multiple layers, and the total extraction is the sum of that calculated for individual layers. As RUE and TE are based on aboveground biomass only, root mass is not explicitly modelled, but is added to the aboveground biomass accumulation according to a root/shoot ratio that declines with successive growth stages of the crop.

Daily aboveground biomass accumulation is partitioned to plant parts in allometric ratios that depend on the growth stage of the crop via functions that have been found to describe these ratios well ([Jones et al., 1986](#)). Before the flag leaf stage, new biomass is allocated to stem and leaves. Leaves are partitioned a fraction that decreases with increasing node number up to a maximum absolute allocation to leaf that is set by the ratio of the new leaf area to be grown (described above) and a minimum specific leaf area ($\text{cm}^2 \text{g}^{-1}$). The remaining biomass is partitioned to stem and rachis. The stem fraction incorporates leaf sheaths, but a distinct allocation to rachis commences after panicle initiation. Between flag leaf and anthesis, accumulated biomass is allocated to the stem and rachis in a fixed ratio.

Grain yield is simulated as the product of grain number and grain size. Maximum grain number is a function of the change in plant biomass between panicle initiation and start grain filling ([Rosenthal, 1989](#)), while grain size is determined by grain growth rate, effective grain filling period, and redistribution of assimilates postanthesis ([Heiniger et al., 1997](#)). If grain mass demand for a day exceeds the daily increase in biomass, the shortfall will first be met through translocation from stem and, if that is insufficient to meet demand of the grain, through translocation from leaves, accelerating their senescence. Conversely, if the daily increase in biomass exceeds the grain mass demand, the excess biomass production is allocated to the stem.

1.3 Crop Nitrogen Dynamics

Crop N dynamics are modelled based on a physiological approach that accounts for the fact that the bulk of reduced N present in leaves is associated with photosynthesis structures and enzymes ([GRINDLAY, 1997](#)) (Fig. 1b). The rate of light-saturated net photosynthesis has been shown to be a linear function of the amount of leaf N per unit leaf area (specific leaf nitrogen [SLN]), until a species-specific maximum rate of photosynthesis has been reached ([Sinclair et al., 1989](#); [Anten et al., 1995](#); [GRINDLAY, 1997](#)). Expressing crop N demand relative to canopy expansion thus provides a physiological link between crop N status, light interception, and dry matter accumulation. In addition, the cardinal SLN values for new leaf growth and for leaf death in response to N deficiency are independent of growth stage ([van Oosterom et al., 2010](#)).

During the preanthesis period, only stems (including rachis) and leaves are expanding, and their N demand is met in a hierarchical fashion ([van Oosterom et al., 2010](#)). First, structural N demand of the stem (and rachis) is met, as structural stem mass is required to support leaf growth. Structural stem N demand is represented by the minimum stem N

concentration. If insufficient N has been taken up to meet structural stem N requirement, N can be translocated from leaves by dilution or, in extreme cases of early season N deficiency, by leaf senescence. Second, the N demand of expanding new leaves will be met, and this is determined from their critical SLN. Any additional N uptake will first be allocated to leaves to meet their target SLN and then to stem. For leaves, this N uptake represents "luxury" uptake that can occur after full expansion of a leaf, and which does not affect growth and development (van Oosterom et al., 2010). This hierarchical allocation of N is consistent with observations that under N stress a relatively larger proportion of N is allocated to the leaves (van Oosterom et al., 2010). Hence, preanthesis N allocation ratios are a consequence of model dynamics, rather than a model input.

After anthesis, grain becomes the major sink for N, and grain N demand is determined as the product of grain number and N demand per grain. During the first part of grain filling, N demand per grain is constant and independent of grain growth rate and N status of the crop (van Oosterom et al., 2010). At this time embryonic and endosperm cells are dividing, so that the accumulation of structural (metabolic) proteins in the grain is the key driver. During the second half of grain filling, grain N demand is linked with grain growth rate as cell division and simultaneous storage of carbohydrate and proteins assumes a greater role (Martre et al., 2006). Grain protein content can thus vary depending on the N supply–demand balance and the carbohydrate supply to the grain. Grain N demand is initially met through stem (plus rachis) N translocation, and if this becomes insufficient, then N translocation from leaf can occur. Maximum N translocation rates from stem and per unit leaf area are a function of the N status of these organs, so that sink demand determines the amount of leaf area that is senescing at any one time (van Oosterom et al., 2010). The source regulation of N translocation follows a first-order kinetic relationship that is representative of enzyme activity. Leaf SLN thus declines to its structural (minimum) level, and the amount of leaf area senesced, in the absence of other factors that can affect senescence, such as water limitation and shading, depends on the N supply–demand balance.

The daily rate of crop N uptake is the minimum of demand for N by the crop and potential supply of N from the soil and senescing leaves, capped at a maximum N uptake rate (van Oosterom et al., 2010). Potential N supply from the soil depends on the available soil N through the profile and on the extent to which roots have explored the soil. N supply from the soil is calculated from the combination of passive uptake, through mass flow of N taken up with the transpiration, and active uptake if there is a deficiency (Van Keulen et al., 1987). Soil N transformations and their modelling in APSIM have been detailed by Probert et al., 1998.

1.4 Crop Model Applications

The APSIM sorghum model has been tested (Hammer et al., 2010) and used extensively to support research and decision-making in agronomy (Meinke et al., 2000; Nelson et al., 2002; Whish et al., 2005) and plant breeding (Chapman et al., 2000, Chapman et al., 2000, Chapman et al., 2003; Hammer et al., 2005, Hammer et al., 2016). Comprehensive in silico adaptation (GxExM) studies have been reported for current Hammer et al., 2014 and future Hammer et al., 2020 climates. Sorghum crop modelling has evolved in capability and reached a credible level of acceptance in agronomy. This has been associated with strong connections between crop physiological experimentation, model development, and agronomists.

While advances in knowledge, model improvements, and enhanced interactions with decision-makers will undoubtedly further advance the utility of modelling in agronomy, it is the potential to add significant value to the revolution in plant breeding associated with genomic technologies that is the new modelling frontier (Hammer et al., 2019). This will require models where capturing biological understanding in a crop growth and development context is as important as the predictive capability of the model—the right answer for the right reason. Models developed for agronomic application will likely not be sufficient. Models with more robust biological underpinning and the ability to link parameters with the genetic architecture of adaptive traits in a stable manner will come to the fore (Cooper et al., 2014; Messina et al., 2018).

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

1.5 Plant Model Components

Component Name	Component Type
Arbitrator	Models.PMF.OrganArbitrator
Phenology	Models.PMF.Phen.Phenology
Grain	Models.PMF.Organs.ReproductiveOrgan
Root	Models.PMF.Organs.Root
Leaf	Models.PMF.Organs.SorghumLeaf
Rachis	Models.PMF.Organs.GenericOrgan
Stem	Models.PMF.Organs.GenericOrgan

Component Name	Component Type
TotalPlantDemand	Models.Functions.AddFunction
MortalityRate	Models.Functions.Constant
SeedMortalityRate	Models.Functions.Constant

1.6 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

1.7 Cultivars

Cultivar Name	Alternative Name(s)
Buster	Buster
early	early
medium	medium
late	late
ATX623xRTX430	ATX623xRTX430
A35xQL36	A35xQL36
QL41xQL36	QL41xQL36
QL39xQL36	QL39xQL36
M35-1	M35-1
CSH13R	CSH13R
dekalb_DK55	dekalb_DK55
texas_RS610	texas_RS610
pioneer_s34	pioneer_s34
texas_671	texas_671
Scorpio	Scorpio
Apollo	Apollo
Bazley	Bazley
Taurus	Taurus
P85G33	P85G33
P84G22	P84G22

Cultivar Name	Alternative Name(s)
P84G99	P84G99
P86G56	P86G56
MR43	MR43
N_14NUS01	N_14NUS01
N_14NUS02	N_14NUS02
N_14NUS03	N_14NUS03
N_14NUS04	N_14NUS04

1.8 Child Components

1.8.1 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 DoPotentialDMAAllocation() 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, DoActualDMAAllocation 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.

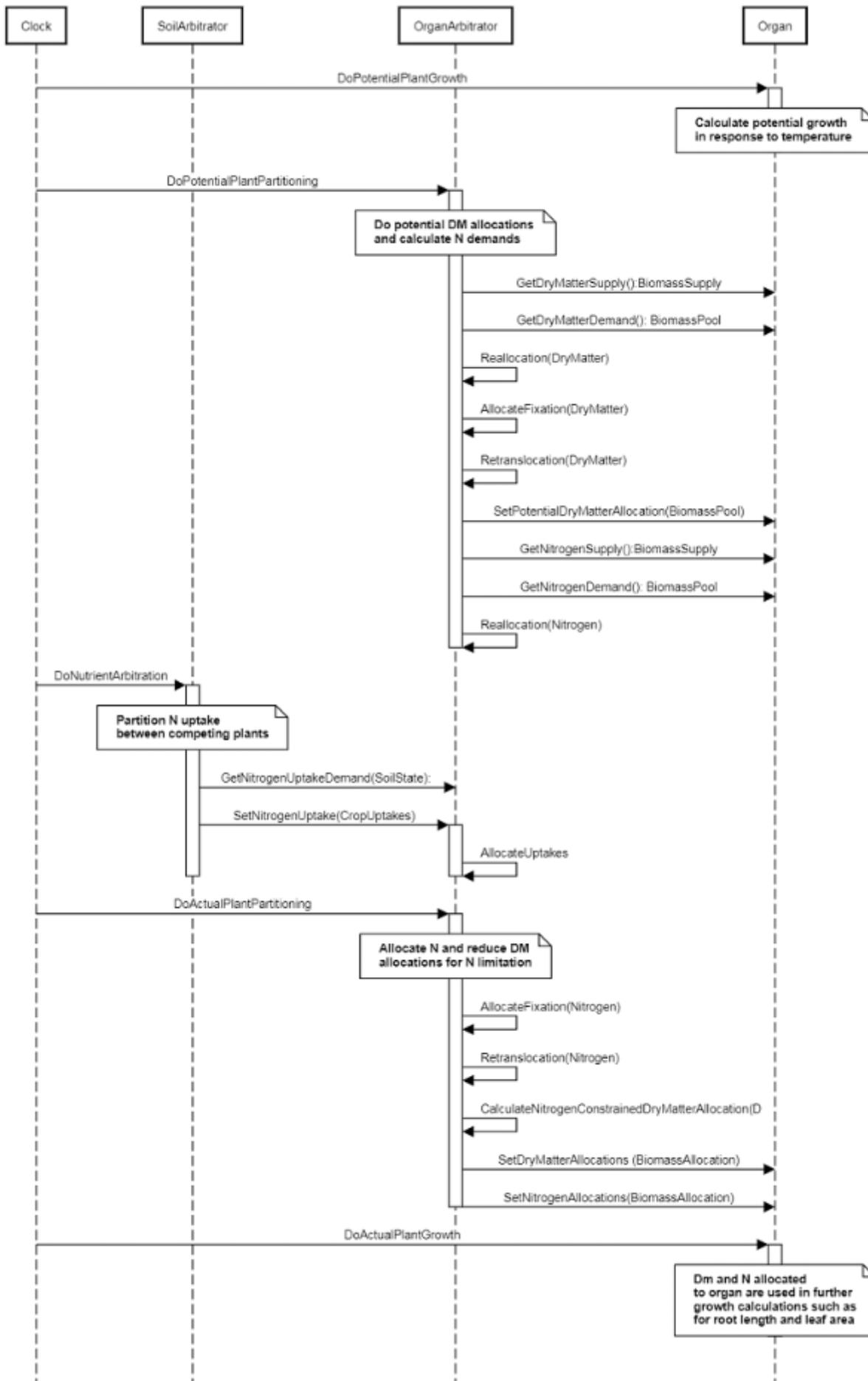


Figure 2: Schematic showing the procedure for arbitration of biomass partitioning. Pink boxes represent events that occur every day and their numbering shows the order of calculations. Blue boxes represent the methods that are called when these events occur. Orange boxes contain properties that make up the organ/arbitrator interface. Green boxes are organ specific properties.

1.8.2 Phenology

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

1.8.3 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).

1.8.4 Root

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

1.8.5 Leaf

SorghumLeaf reproduces the functionality provided by the sorghum and maize models in Apsim Classic. It provides the core functions of intercepting radiation, producing biomass through photosynthesis, and determining the plant's transpiration demand.

1.8.6 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.

1.8.7 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.

1.8.8 TotalPlantDemand

A class that returns the sum of its child functions.

1.8.9 MortalityRate

A constant function (name=value)

1.8.10 SeedMortalityRate

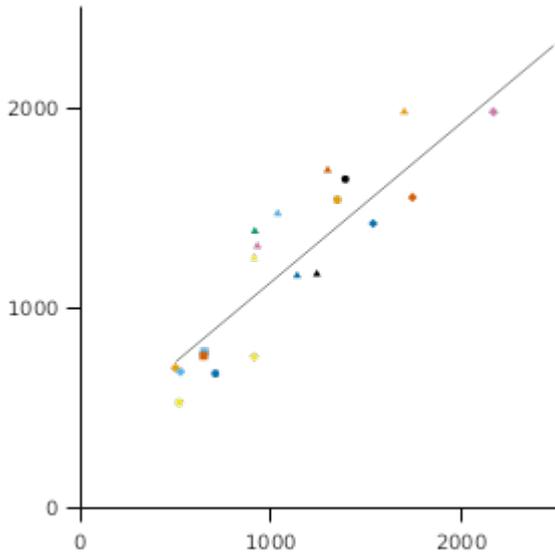
A constant function (name=value)

2 Validation

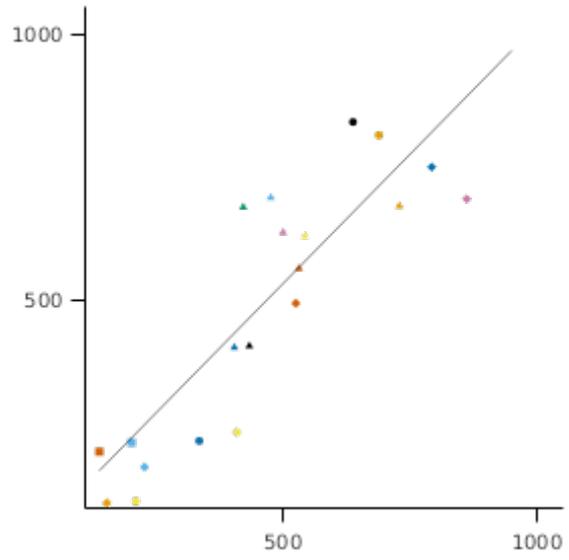
2.1 Combined Results

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).

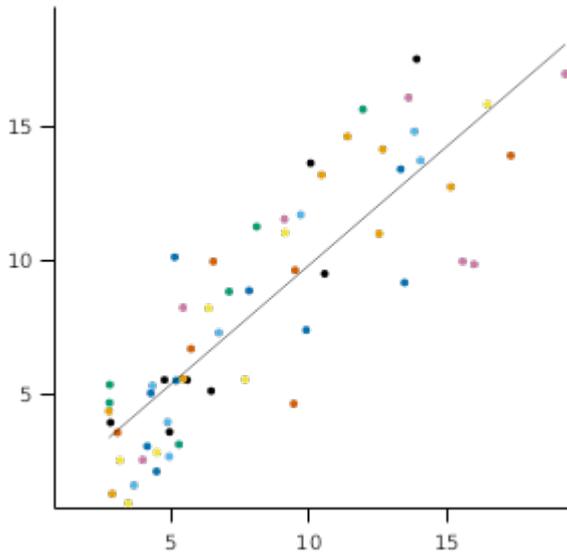
Harvest Biomass



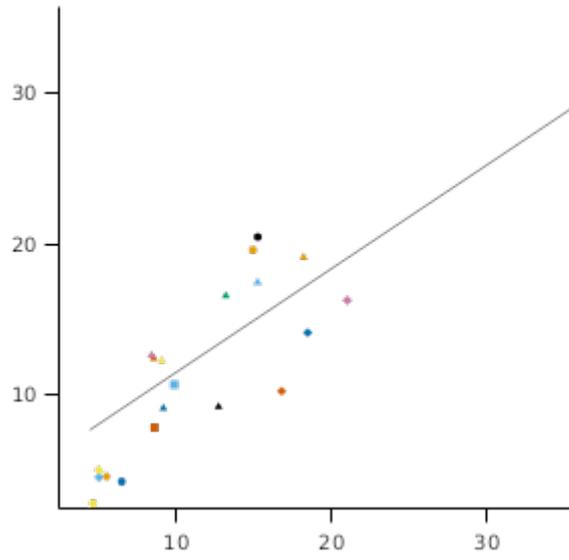
Yield

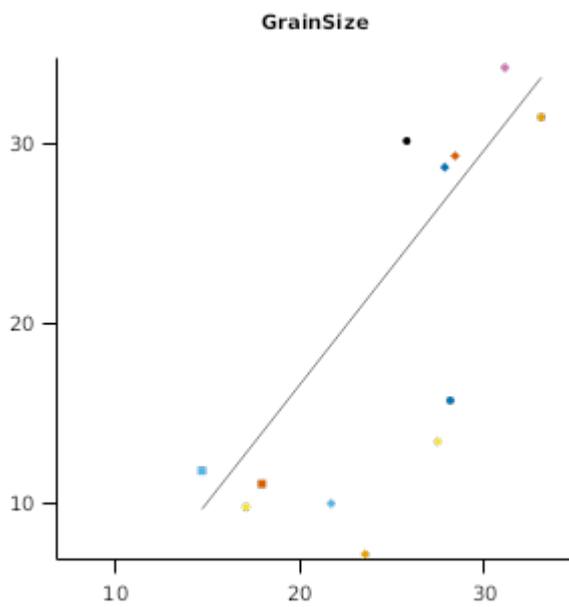
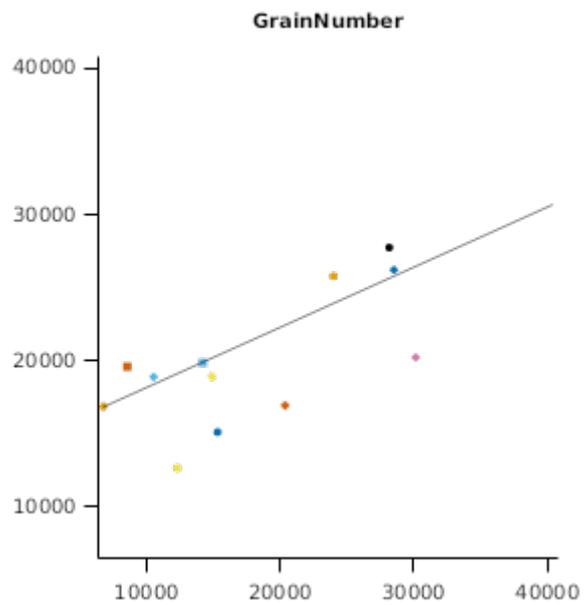
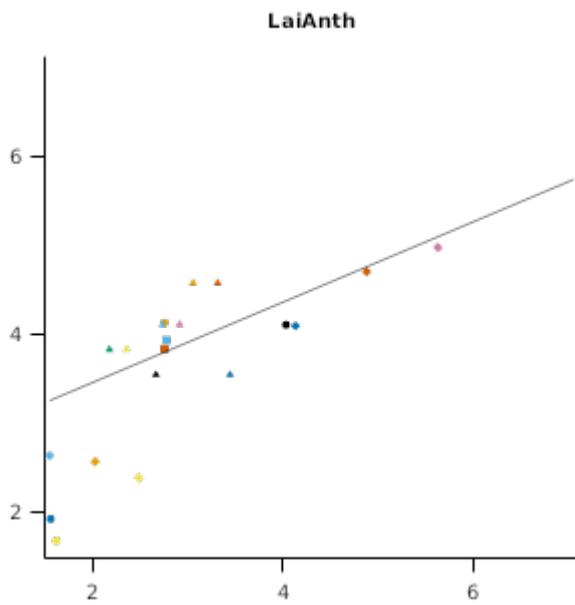


GrainN



BiomassN





2.2 Hermitage

2.2.1 List of experiments

Experiment Name	Design (Number of Treatments)
HE1	Cultivar (3)
HE2	Cultivar (3)
HE3	Cultivar (3)
HE4	Cultivar (3)
HE5	Cultivar (3)
HE6	Cultivar (3)
HE7	Cultivar (3)
HE8	Cultivar (3)

2.2.2 HE1

Experiment: HE1

Description: HE1 - High N/Irrig. - 3 Indian/Aust. Cultivars

Start Date: 1/12/1996

End Date: 30/06/1997

SimulationName	Cultivar
Sorghum_HE1_T1	QL41xQL36
Sorghum_HE1_T2	Buster
Sorghum_HE1_T3	M35-1

2.2.3 HE2

Experiment: HE2

Description: HE2 - Low N/Irrig. - 3 Indian/Aust. Cultivars

Start Date: 1/12/1996

End Date: 30/06/1997

SimulationName	Cultivar
Sorghum_HE1_T1	QL41xQL36
Sorghum_HE1_T2	Buster
Sorghum_HE1_T3	M35-1

2.2.4 HE3

Experiment: HE3

Description: HE3 - High N/No Irrig. - 3 Indian/Aust. Cultivars

Start Date: 1/12/1996

End Date: 30/06/1997

SimulationName	Cultivar
Sorghum_HE3_T1	QL41xQL36
Sorghum_HE3_T2	Buster
Sorghum_HE3_T3	M35-1

2.2.5 HE4

Experiment: HE4

Description: HE4 - Low N/No Irrig. - 3 Indian/Aust. Cultivars

Start Date: 1/12/1996

End Date: 30/06/1997

SimulationName	Cultivar
Sorghum_HE4_T1	QL41xQL36
Sorghum_HE4_T2	Buster
Sorghum_HE4_T3	M35-1

2.2.6 HE5

Experiment: HE5

Description: HE5 - High N/Irrig. - 3 Indian/Aust. Cultivars

Start Date: 18/11/1997

End Date: 15/04/1998

SimulationName	Cultivar
Sorghum_HE5_T1	Buster
Sorghum_HE5_T2	M35-1
Sorghum_HE5_T3	CSH13R

2.2.7 HE6

Experiment: HE6

Description: HE6 - Low N/Irrig. - 3 Indian/Aust. Cultivars

Start Date: 18/11/1997

End Date: 15/04/1998

SimulationName	Cultivar
Sorghum_HE6_T1	Buster
Sorghum_HE6_T2	M35-1
Sorghum_HE6_T3	CSH13R

2.2.8 HE7

Experiment: HE7

Description: HE7 - High N/No Irrig. - 3 Indian/Aust. Cultivars

Start Date: 18/11/1997

End Date: 15/04/1998

SimulationName	Cultivar
Sorghum_HE7_T1	Buster
Sorghum_HE7_T2	M35-1
Sorghum_HE7_T3	CSH13R

2.2.9 HE8

Experiment: HE8

Description: HE8 - Low N/No Irrig - 3 Indian/Aust. Cultivars

Start Date: 17/11/1997

End Date: 15/04/1998

SimulationName	Cultivar
Sorghum_HE8_T1	Buster
Sorghum_HE8_T2	M35-1
Sorghum_HE8_T3	CSH13R

2.3 Icrisat

2.3.1 List of experiments

Experiment Name	Design (Number of Treatments)
BW5	Cv x Fert x Irrig (12)
BW8	Cv x Fert x Irrig (12)

2.3.2 BW5

Experiment: BW5_GxE

Description: Genotype x Management Environment (Rabi Sorghum)

Start Date: 26/09/1996

End Date: 20/02/1997

Treatment	Cultivar	N Rates	Irrigation
Sorghum_BW5_GxE_T1	M35-1	240	Irrigated
Sorghum_BW5_GxE_T2	CSH13R	240	Irrigated
Sorghum_BW5_GxE_T3	ATx623/RTx430	240	Irrigated
Sorghum_BW5_GxE_T4	QL41/QL36	240	Irrigated
Sorghum_BW5_GxE_T5	M35-1	120	Dryland
Sorghum_BW5_GxE_T6	CSH13R	120	Dryland
Sorghum_BW5_GxE_T7	ATx623/RTx430	120	Dryland
Sorghum_BW5_GxE_T8	QL41/QL36	120	Dryland
Sorghum_BW5_GxE_T9	M35-1	10	Dryland
Sorghum_BW5_GxE_T10	CSH13R	10	Dryland
Sorghum_BW5_GxE_T11	ATx623/RTx430	10	Dryland
Sorghum_BW5_GxE_T12	QL41/QL36	10	Dryland

2.3.3 BW8

Experiment: BW8_GxE

Description: BW8 - GENO x ENVIRON (RABI SORGHUM)

Start Date: 26/09/1996

End Date: 20/02/1997

Treatment	Cultivar	N Rates	Irrigation
Sorghum_BW8_GxE_T1	M35-1	240	Irrigated
Sorghum_BW8_GxE_T2	CSH13R	240	Irrigated
Sorghum_BW8_GxE_T3	ATx623/RTx430	240	Irrigated
Sorghum_BW8_GxE_T4	QL41/QL36	240	Irrigated
Sorghum_BW8_GxE_T5	M35-1	120	Dryland
Sorghum_BW8_GxE_T6	CSH13R	120	Dryland
Sorghum_BW8_GxE_T7	ATx623/RTx430	120	Dryland
Sorghum_BW8_GxE_T8	QL41/QL36	120	Dryland

Treatment	Cultivar	N Rates	Irrigation
Sorghum_BW8_GxE_T9	M35-1	20	Dryland
Sorghum_BW8_GxE_T10	CSH13R	20	Dryland
Sorghum_BW8_GxE_T11	ATx623/RTx430	20	Dryland
Sorghum_BW8_GxE_T12	QL41/QL36	20	Dryland

2.4 Lawes

2.4.1 List of experiments

Experiment Name	Design (Number of Treatments)
LE13	(6)
LE14	Cv (3)
LE15	Cv (3)
LE17	Cv (3)
LE19	(8)
LE21	Cv x Fert (9)

2.4.2 LE13

Experiment: LE13

Description: 2 Cultivars x 2 Water regimes x 2 N Potential Yield

Start Date: 28/11/1995

End Date: 1/05/1996

SimulationName	Irrigation	N Rates	Cultivar
Lawes1995FertLowirrigOffCvBuster	Irrigation to establish & fert inco	10 N	Buster
Lawes1995FertHighIrrigOffCvBuster	Irrigation to establish & fert inco	240 N	Buster
Lawes1995FertHighIrrigOnCvBuster	Irrigated	240 N	Buster
Lawes1995FertLowIrrigOffCvM351	Irrigation to establish & fert inco	10 N	M35-1
Lawes1995FertHighIrrigOffCvM351	Irrigation to establish & fert inco	240 N	M35-1
Lawes1995FertHighIrrigOnCvM351	Irrigated	240 N	M35-1

2.4.3 LE14

Experiment: LE14

Description: Early Sow - 3 Indian/Aust Cultivars

Start Date: 5/09/1996

End Date: 19/02/1997

SimulationName	Cultivar
Lawes1996EarlyCvBuster	Buster
Lawes1996EarlyCvM351	M35-1
Lawes1996EarlyCvQL41xQL36	QL41xQL36

2.4.4 LE15

Experiment: LE15

Description: Late Sow - 3 Indian/Aust Cultivars

Start Date: 5/09/1996

End Date: 8/05/1997

SimulationName	Cultivar
Lawes1996LateCvBuster	Buster
Lawes1996LateCvM351	M35-1
Lawes1996LateCvQL41xQL36	QL41xQL36

2.4.5 LE17

Experiment: LE17

Description: LE17 Growth Analysis- Late Sow - 2 Indian/ 1 Aust. Cultivars

Start Date: 27/11/1997

End Date: 27/04/1998

SimulationName	Cultivar
Lawes1997LateCvBuster	Buster
Lawes1997LateCvM351	M35-1
Lawes1997LateCvCSH13R	CSH13R

2.4.6 LE19

Experiment: LE19

Description: LE19 - Genotypic variation in Radiation Use Efficiency

Start Date: 9/11/1998

End Date: 7/03/1999

SimulationName	N Rates	Cultivar
Lawes1998FertOffBuster	0 kg/ha	Buster
Lawes1998FertLowBuster	120 kg/ha	Buster
Lawes1998FertMedBuster	240 kg/ha	Buster
Lawes1998FertHighBuster	360 kg/ha	Buster
Lawes1998FertOffCSH13R	0 kg/ha	CSH13R
Lawes1998FertLowCSH13R	120 kg/ha	CSH13R
Lawes1998FertMedCSH13R	240 kg/ha	CSH13R
Lawes1998FertHighCSH13R	360 kg/ha	CSH13R

2.4.7 LE21

Experiment: Gatton_RUE

Description: N Rates x Genotype LE21

Start Date: 22/11/1999

End Date: 3/04/2000

SimulationName	Cultivar	N Rates
Lawes1999FertLowCvCSH13R	CSH13R	0kg/ha
Lawes1999FertLowCvA35xQL36	A35xQL36	0kg/ha
Lawes1999FertLowCvQL39xQL36	QL39xQL36	0kg/ha
Lawes1999FertMedCvCSH13R	CSH13R	45kg/ha
Lawes1999FertMedCvA35xQL36	A35xQL36	45kg/ha
Lawes1999FertMedCvQL39xQL36	QL39xQL36	45kg/ha
Lawes1999FertHighCvCSH13R	CSH13R	360kg/ha
Lawes1999FertHighCvA35xQL36	A35xQL36	360kg/ha
Lawes1999FertHighCvQL39xQL36	QL39xQL36	360kg/ha

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