

Reef Rescue Research & Development

Technical Report

Simulation of growth, development and
nitrogen balance of banana in APSIM
RRRD054



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Simulation of growth, development and nitrogen balance of banana in APSIM (Project RRRD054)

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Acronyms

APSIM	Agricultural Production Systems Simulator
DoE	Department of the Environment
CSIRO	Commonwealth Scientific and Industrial research Organization
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
NRM	Natural Resource Management
QDAFF	Queensland Department of Agriculture, Fisheries and Forestry
RRRC	Reef and Rainforest Research Centre Limited
RRRD	Reef Rescue Research & Development

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Executive Summary

The development of the Agricultural Production Systems Simulator (APSIM) model has enabled simulation of a large number of cropping systems, and investigation of a diverse range of management practices. Cropping system simulation is used to analyse cropping scenarios, giving an indication of productivity and environmental impacts without extensive in-field trials. Cropping simulation can be thought of as 'virtual experimentation'.

Currently, APSIM is used in the Reef Plan Paddock to Reef Program (P2R program) to determine the economic and water quality impacts of management practices in sugarcane. This information is used by economic and catchment modellers to develop Reef Plan report cards. APSIM is also used to inform NRM bodies on targeting of incentive funding. The development of a banana module for the APSIM modelling framework provides an ability for the P2R program to model the water quality and economic impact of management practices in the banana industry. The model was developed through a combination of using published and unpublished data, and field experimentation at South Johnstone Research Station. Data were used to calibrate the APSIM model for phenology, leaf area development, biomass accumulation and partitioning and for harvest. The model was validated against a dataset from a trial planted at South Johnstone Research Station, and closely predicted time to bunch emergence and time to harvest, biomass and nitrogen uptake. Dry matter allocation between plant parts overestimated fruit weight and underestimated stem weight.

The banana APSIM model does not predict nitrogen losses, but rather 'passes information to' the model processes that do simulate nitrogen losses (via denitrification, leaching and runoff). The banana model is able to closely simulate nitrogen uptake by banana plants, and therefore nitrogen losses would be able to be simulated.

The APSIM banana model is a research tool that can be incorporated to the P2R program over time to validate and improve reporting of pollutant generation from banana crops.

Introduction

The development of the Agricultural Production Systems Simulator (APSIM) model has enabled simulation of a large number of cropping systems, and investigation of a diverse range of management practices. Cropping system simulation is used to analyse cropping scenarios, giving an indication of productivity and environmental impacts without extensive in-field trials. Cropping simulation can be thought of as ‘virtual experimentation’.

The APSIM model has a strong track record within past Reef Plan and current Reef Rescue activities: It was used in development of the Douglas Shire, Tully and Burdekin Water Quality Improvement Plans, and is the modelling platform for nutrients in sugarcane in the Reef Rescue Monitoring and Evaluation Program. It has also been used in economic analyses in Water Quality Improvement Plans. By developing a banana module for the APSIM modeling framework, programs such as Reef Rescue can make more thorough analysis of the impact of banana cropping on water quality, and assess the impact of changed management practices in the banana industry on water quality.

Currently, APSIM is used in the Reef Rescue Monitoring and Evaluation Program to determine the economic and water quality impacts of ABCD management practices in sugarcane. This information is used by economic and catchment modellers to develop reef report cards. APSIM is also used to inform NRM bodies on incentive funding.

This project used existing data and new data from experiments (e.g. RRRD049) to develop and test a banana module for the APSIM modelling framework. Much of the development of the banana module was undertaken as a desktop activity, with trials used to fill gaps in the data required in the module development. Data on crop phenology (timing of crop stages based on radiation and temperature), biomass accumulation, leaf development, flowering, fruit growth and yield, water and nitrogen uptake, root growth and crop response to water and nutrient limitations will be sought from publications (including grey literature). Where data gaps exist, trial data was used to provide the required data.

The development of a banana module for the APSIM modelling framework will provide, for the first time, an ability for the Reef Rescue Monitoring and Evaluation Program to model the water quality and economic impact of ABCD management practices in the banana industry. This information will be available for catchment modelling to improve the validity of their reef card reporting and for regional NRM boards (particularly Terrain NRM) to better inform them on incentive funding decisions.

The project aligns with Reef Rescue Research and Development (RRRD) research priorities by: enabling validation of banana management practices that improve water quality outcomes, for both existing and proposed management practices; better enabling assessment over a wider range of climates the relative benefits/costs of various improved banana management practices, including the profitability and sustainability of farming systems utilising improved management techniques, changes in yield/productivity, reductions in farm inputs and off-farm impacts; and enabling assessment of water quality benefits from adoption of improved land management practices in the banana industry.

Project Objectives

To provide, for the first time, a modelling framework that is able to output the water quality (N and sediment) and economic impacts of ABCD management practices in the banana industry;

The key issue is that discharge of water pollutants (N and sediment) from banana farming systems is poorly understood, and modeling will allow more robust reporting of these pollutants from banana production systems under ABCD management practices. These are consistent with targets and Caring for our Country outcomes because having a mechanism for monitoring water pollutant discharge from banana production will allow better funding of management practices in the banana industry for improved water quality and better reporting of progress towards Reef Rescue goals through P2R.

Methods

Parameters and physiological relationships required to build functions used in the model were collated from published studies, and are reported in the results section. Parameters that could not be derived from the data were parameterized from an experimental study conducted by the authors.

Experimental study

An experimental study was established in December 2011 to derive parameters not available from published data and to confirm the applicability of previously published data.

Study design

The experimental program was located at South Johnstone Research Station, Queensland, Australia (17°36'S, 146°00'E) (location at South Johnstone Research Station is shown in Figure 1) on a Brown Dermasol (Isbell 1996). Daily climate data (minimum and maximum temperature, daily rainfall, daily radiation) for the duration of the experiment was downloaded from the Bureau of Meteorology web site for station number 032037, which is located on South Johnstone Research Station, approximately 350 m away from the experimental site (Figure 2).



Figure 1 Image of South Johnstone Research Station with arrow pointing to location of experimental study described in this report.



Figure 2 Bureau of Meteorology station at South Johnstone Research Station (station number 32037).

Thirty nine banana (*Musa* AAA Group, Cavendish Sub-group cv. Williams) suckers of consistent size and leaf number were chosen from planting stock with thirty six planted on day 345 of 2011 (Figure 3) and three sub sampled immediately for above ground component dry weight determination (Figure 4). Sub-surface components were not sampled due to the difficulty is extracting the entire below ground biomass of plants growing in the field. The suckers were planted in a double row configuration and fertilized fortnightly through under tree fertigation at a rate equal to 150 kg N/ha/crop. The plants were fully irrigated.



Figure 3 Thirty six banana sukurs on day of planting.



Figure 4 Above ground part of sucker typical of suckers planted in experimental study on day of planting.

Plant measurements

Leaf number of all plants in the study were counted on days 0, 33, 51, 67, 114, 129, 143, 158, 164, 171, 192 and 200 after planting. Three plants were destructively sampled each on days 0, 33, 67, 114, 143, 164, 248 and 306 (harvest) after planting. At destructive sampling all leaves were measured for length and width, plant height was measured to the throat (point where the final leaf is emerging from the stem), stem girth was measured at ground level and 0.5 m above ground, and the plant was sub sampled into above-ground components for dry weight determination (leaf, petiole, stem, flowering and fruiting organs) (Figure 5). On day 192 after planting flowering parts normally removed (the bell and bottom hands) from three plants were sampled for dry weight determination (Figure 6). Dry matter components were analysed for total nitrogen and total carbon, and some also analysed for total phosphorous, nitrate nitrogen and phosphate phosphorous to allow parameterization of residue breakdown.



Figure 5 Individual plant component parts were sampled for dry weight determination.



Figure 6 At bunch bagging stage (shown above) the bell (flower) and bottom two hands of fruit are removed.

Management data recorded included deleafing date and number of leaves removed, fertilizing date, type and amount, chemical application, bunch emergence date, debelling date, harvest date.

Soil measurements

Prior to the study the soil was sampled to 1.8 m (in increments 0-0.15, 0.15-0.3, 0.3-0.6, 0.6-0.9, 0.9-1.2, 1.2-1.5, 1.5-1.8, 1.8-2.1, 2.1-2.4 m) (Figure 7) and analysed for pH, nitrate nitrogen, phosphorous, potassium, sulphur, calcium, magnesium, boron, copper, iron, manganese, zinc, chloride, sodium, organic matter, electrical conductivity and exchangeable cations. Any detected deficiencies were corrected. At planting (from across the entire planted area) and at times of destructive sampling (from where the destructive sampling took place) soil was sampled to 0.6 m (in increments of 0-0.15, 0.15-0.3, 0.3-0.6 m) and analysed for nitrate nitrogen.

At 192 days after planting (post bunch emergence) an area of soil extending at least 1 m around six plants was covered in plastic to exclude water (both from rain and irrigation) from entering the soil where the banana plant could extract water from (Figure 8). The plants were visually monitored for signs of water stress, and 132 days later the soil was sampled to 2.4 m (in increments 0-0.15, 0.15-0.3, 0.3-0.6, 0.6-0.9, 0.9-1.2, 1.2-1.5, 1.5-1.8, 1.8-2.1, 2.1-2.4 m) to measure soil water. These values are referred to as 'crop lower limit' and represent the lower water holding capacity of the soil. At 192 days after planting an area adjacent to the crop lower limit study that did not have any plants growing was covered in plastic to prevent evaporation, and irrigation water was applied for the following 130 days to fill the profile with water (Figure 9). The irrigation water was turned off and the area allowed to drain freely. The soil was sampled to 2.4 m (in increments 0-0.15, 0.15-0.3, 0.3-0.6, 0.6-0.9, 0.9-1.2, 1.2-1.5, 1.5-1.8, 1.8-2.1, 2.1-2.4 m) to measure soil water. These values are referred to as 'drained upper limit' of the soil, and represents the upper water holding capacity of the soil. The difference between drained upper limit and crop lower limit is the plant available water holding capacity of the soil. At the same time the soil was sampled for drained upper limit, three undisturbed cores of soil (0.075 m x 0.05 m) were taken at depths 0.075, 0.225, 0.45, 0.75, 1.05, 1.35 and 1.65 m and dried at 105°C to determine soil bulk density.



Figure 7 Soils sampled from the experimental site. From the left the soils were sampled from increments at 0-0.15, 0.15-0.3, 0.3-0.6, 0.6-0.9, 0.9-1.2, 1.2-1.5, 1.5-1.8, 1.8-2.1, 2.1-2.4 m depth.



Figure 8 Excluding water from six plants for the purpose of drying the soil to the lowest soil water content bananas could extract water.



Figure 9 An area of soil was covered with plastic to prevent evaporation and ‘wet up’ for the purpose of determining the upper water holding capacity of the soil.

Results

Model description and parameterization

Phenology

Phenology parameters were derived from previously published studies. APSIM uses thermal time to drive phonological development, which is calculated from three cardinal temperatures: base, optimal and maximum. Banana development ceases below base (14) and above maximum (40) temperature, and development rate is greatest at optimal (30) temperature (Turner et al. 1983). Daily thermal time is calculated from interpolated three hourly air temperature derived from daily observed minimum and maximum air temperature (Jones et al. 1986), and is represented as degree days. Daily thermal time is summed, with the duration between each phonological crop stage determined by a parameterized thermal time sum. The model has 10 stages, *Germination*, *Emergence*, *EndDependence*, *FloralInitiaton*, *FinalLeaf*, *Flowering*, *StartFruitFill*, *EndFruitFill*, *Maturity*, and *Ripe*. Crops planted as suckers start at *EndDependence*, and rationing crops start at *Germination*. The rate of phonological development may also be changed through nitrogen or water stress. Banana shows a quantitative response to photoperiod (Fortescue et al.

2011) and in the model long photoperiod shortens the stages between *EndDependance* and *FinalLeaf*.

Leaf area development

Experimental data was used to derive functions for leaf appearance and expansion. Leaf appearance is limited by the maximum number of leaf nodes (40), and is driven by thermal time (72 degree days). The sucker starts with 14 leaf nodes, and leaf node appearance is also driven by thermal time (40 degree days). Photoperiods greater than 12 hours reduce the maximum leaf node number. When the actual leaf node number reaches the maximum leaf node number, the maximum number of leaves is set, and *FloralInitiation* is reached.

Leaf expansion (represented as leaf area) is driven by thermal time, leaf number and maximum potential leaf area, with maximum leaf area determined by leaf node number. Actual simulated leaf area is lower than maximum potential leaf area when carbon supply is insufficient to meet the maximum specific leaf area, calculated on a daily basis.

Leaf senescence in banana is driven by farmer management, whereby leaves are cut off regularly to reduce the incidence of banana leaf spot disease. In the model leaves senesce at the same thermal time rate they appear at (72 degree days), starting 11 leaves after the first leaf appears so as the plant always has 10 leaves. The biomass (carbon and nitrogen) from senesced leaves are added to the *Residue* pool.

Biomass accumulation and partitioning

Biomass is predicted daily from leaf area (which adsorbs carbon), radiation extinction coefficient (the rate radiation decreases as it filters through the canopy), and the crops set radiation use efficiency (Nyombi 2010). Radiation use efficiency is reduced at base and maximum temperatures. Actual daily biomass accumulation is limited by temperature, nitrogen or water stress. Biomass is partitioned to seven different plant parts, in ratios that are dependant of crop phase: *Stem*, *CormandRoot*, *Petiole*, *Leaf*, *Bell*, *FlowerStem*, and *Fruit*.

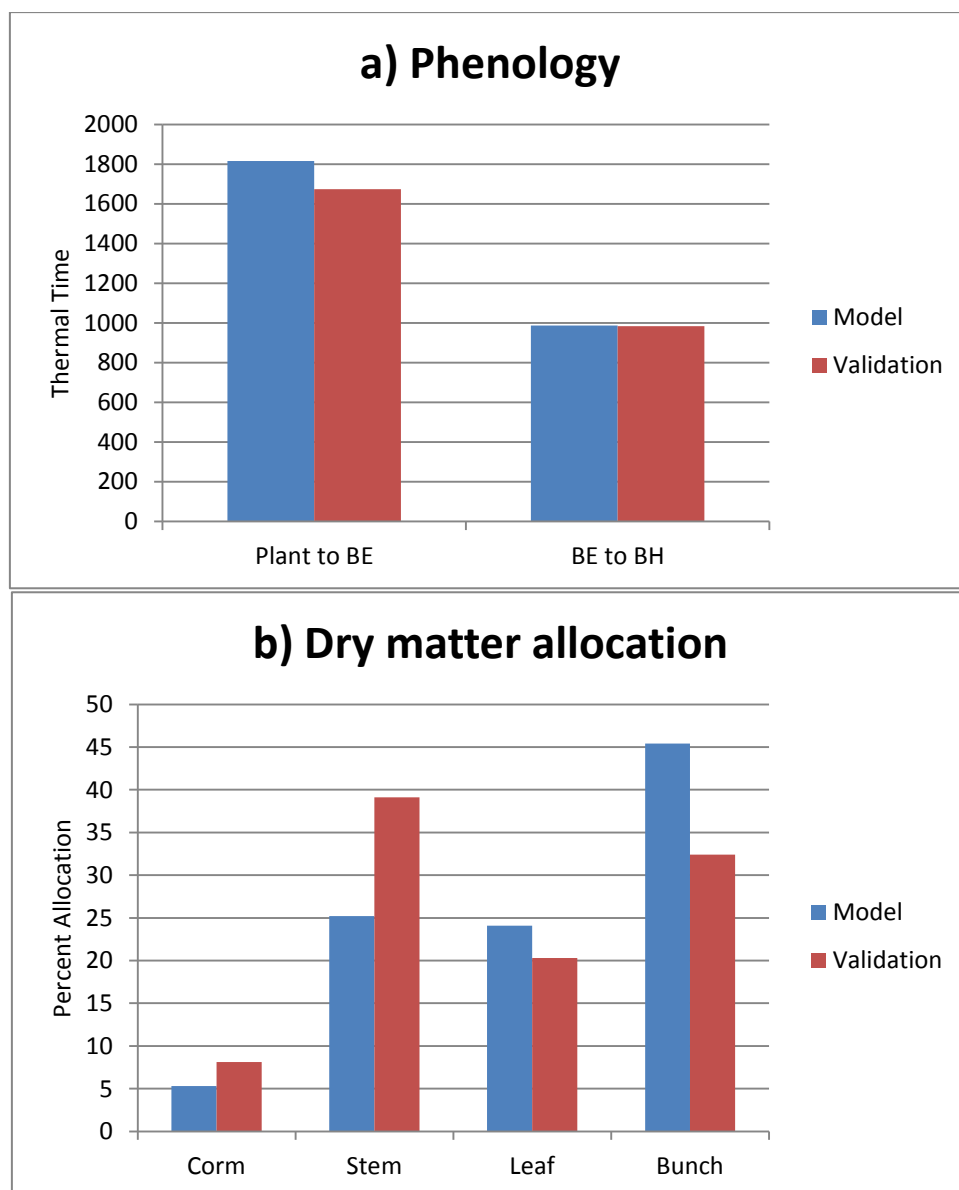
Harvesting

At *StartFruitFill* phase biomass accumulates in the *Bell*, *FlowerStem* and *Fruit*. The actual bell and lower two hands of bananas are cut off through on farm management, and the model represents this by removing all of *Bell* and a proportion of *FlowerStem* and *Fruit* biomass (and adds them to the *Residue* pool) with further biomass accumulation only reaching *FlowerStem* and *Fruit*. The model has phases *EndFruitFill*, *Maturity* and *Ripe*, however in practice the fruit is harvested before the *EndFruitFill* phase is reached. The thermal time sum between *EndFruitFill* and *Maturity* and between *Maturity* and *Ripe* is set to 0. At harvest the *FlowerStem* and *Fruit* partitions are removed, and the leaves and a proportion of the *Stem* and *CormandRoot* parts are added to the *Residue* pool.

Model validation

Experimental data from an earlier trial at South Johnstone Research Station was used as a validation data set for the developed model. As there was only one planting date tested, the

validity of photoperiod is not fully tested, however, given the planting date of the validation dataset is different to the data used in model calibration, time to *Flowering* is a test of photoperiod response. Figure 10 shows that the model is representing phonological time to *Flowering* well, reported as time from planting to bunch emergence (BE) in the field trial. Total biomass accumulation was well represented by the model, however the model overestimated bunch weight and underestimated stem weight (Figure 10). In these figures bunch weight (as reported from the field) is represented by removed *Fruit* and *FruitStem*. Nitrogen uptake by the plant is also well represented by the model (Figure 10). Nitrogen uptake validation is a surrogate for nitrogen losses. Nitrogen loss processes in APSIM are soil based processes, and APSIM has been proven to be able to account for nitrogen losses through denitrification, leaching and surface runoff. For the banana model to be able to accurately represent nitrogen losses, the banana model has to validate for nitrogen uptake, as the nitrogen loss processes are not driven by the banana model.



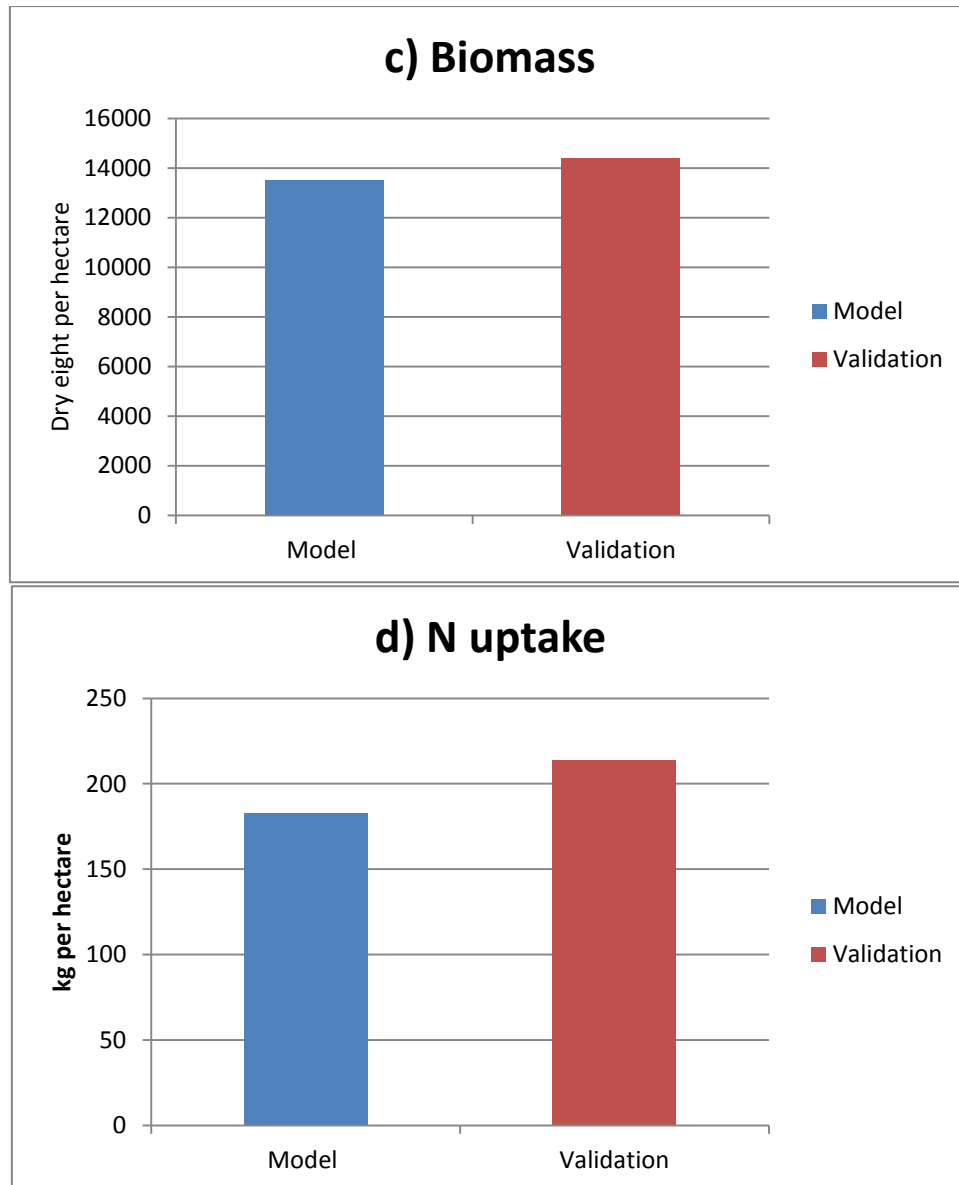


Figure 10 Validation of a) phenology, b) biomass, c) dry matter partitioning and d) nitrogen uptake of a South Johnstone Research Station banana trial and the model.

Discussion

This report has shown it is possible to represent phenology, biomass accumulation and nitrogen uptake in bananas through simulation with APSIM. Biomass partitioning to fruit (and hence fruit yield) validated satisfactorily, and may require further calibration to accurately simulate possible economic returns. Estimating economic return from bananas is always going to pose a challenge given the diverse range of fruit wastage in packing sheds and short term price fluctuations. The model is able to closely simulate nitrogen uptake by a banana crop, which means nitrogen loss estimations should simulate accurately (nitrogen loss processes happen outside of the crop module in the APSIM framework).

Having a functioning banana model in the APSIM framework will allow better estimates of the water quality impact of current, and proposed management practices. Banana production is a major landuse in the Wet Tropics region, and nitrogen application rates can be high (100+ kg/ha above crop removal – unpublished data). The use of simulation modeling will allow ‘virtual experimentation’ whereby different nitrogen management options can be tested with the model under different climates and on different soils.

The end users of a banana model will be Paddock2Reef researchers. There is a steep learning curve for using the APSIM model, and it is not something farmers or the general community use. Within the Reef Reporting structures APSIM modeling is used extensively for reporting on sugarcane management practices. This reporting structure can now also use APSIM to report on banana management practices.

Conclusions

The APSIM modeling framework has a history of being used in Paddock 2 Reef monitoring for sugarcane. Now, with the development of a banana model in APSIM, it will be possible for bananas to be included in the modeling of water quality impacts of ABCD management practices. This will allow better reporting of water quality impacts in the wet tropics from current and proposed management practices.

Future Directions

To better allow the banana model to capture nitrogen dynamics within a paddock it is necessary to understand the breakdown of crop residue. Currently the banana model uses general terms described from other crops to simulate residue breakdown. An experimental study is underway to better understand banana residue breakdown, and cycling of carbon and nitrogen from residue into the soil. Banana is a large biomass crop, and leaves are constantly being added to the soil, so understanding how they contribute to soil nitrogen is important.

The APSIM model simulates banana phenology for a point (equivalent of a single plant). Banana plantations have a spread of flowering time, which can be over a number of months. It was necessary in the model to model the ‘average’ phenology. Further development may be sought at a later time to allow APSIM to better simulate the spread of phenology through the use of crop cohorts.

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