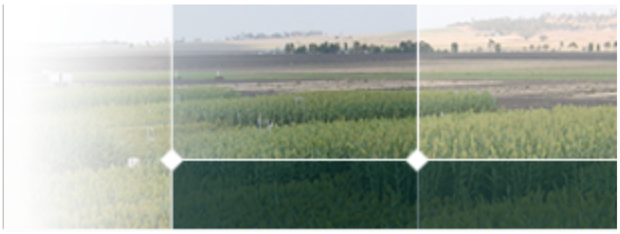


1 The APSIM Oil Palm Model

Neil I. Huth, Murom Banabas, Paul N. Nelson, Michael Webb

The base configuration of the oil palm model has been configured to match commercial dura x pisifera palms developed in Dami, West New Britain in Papua New Guinea. Other varieties are specified in terms of how they differ from this base variety.

1.1 SuperFamily

SuperFamily overrides the following properties:

[FrondMaxArea].XYPairs.X = 0,2,4.5,8.5,14

[FrondMaxArea].XYPairs.Y = 0.1,0.9,0.63,10.8,12.6

1.2 Nigeria_IRHO

Nigeria_IRHO overrides the following properties:

[BunchSizeMax].XYPairs.X = 0, 1,3,7,11,15

[BunchSizeMax].XYPairs.Y = 0, 53,265,7000,11600,12750

[FrondAppearanceRate].XYPairs.X = 0, 2, 5, 10, 15

[FrondAppearanceRate].XYPairs.Y = 10.1, 7.7, 10.1, 11, 11

1.3 Nigeria_SOCFINDO

Nigeria_SOCFINDO overrides the following properties:

[BunchSizeMax].XYPairs.X = 0, 1,3,7,11,15

[BunchSizeMax].XYPairs.Y = 0, 53,265,7000,11600,12750

[FrondAppearanceRate].XYPairs.X = 0, 2, 5, 8, 15

[FrondAppearanceRate].XYPairs.Y = 10.1, 7.7, 10.1, 11, 11

KNO3 = 0.02

The proportion of plant growth partitioned to roots has been set to 10% as this value lies between estimates used by Henson and Dolmat (2003) and van Kraalingen et al. (1989).

RootFraction = 0.1

Root nitrogen concentration is set at 0.39% (Goh, 2005)

RootNConcentration = 0.39

A constant root turnover rate of 0.001 d-1 is used for all soil layers. This value is larger than the value of 0.00065 which can be calculated from the root turnover functions given by Henson and Dolmat (2003), reflecting the slightly higher fraction of growth partitioned to roots in this model.

RootSenescenceRate = 0.001

InitialFrondNumber = 5

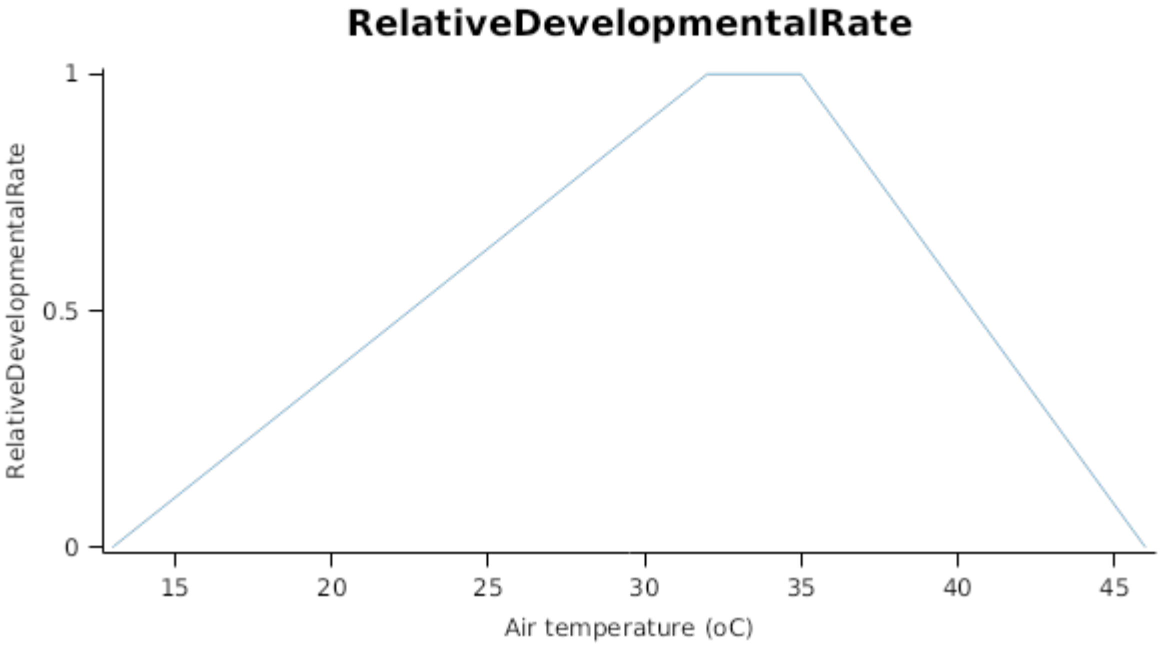
1.4 RelativeDevelopmentalRate

RelativeDevelopmentalRate is the average of sub-daily values from a XYPairs.

Firstly 3-hourly estimates of air temperature (Ta) are interpolated using the method of Jones et al., 1986 which assumes a sinusoidal temperature pattern between Tmax and Tmin.

Each of the interpolated air temperatures are then passed into the following Response and the Average taken to give daily RelativeDevelopmentalRate

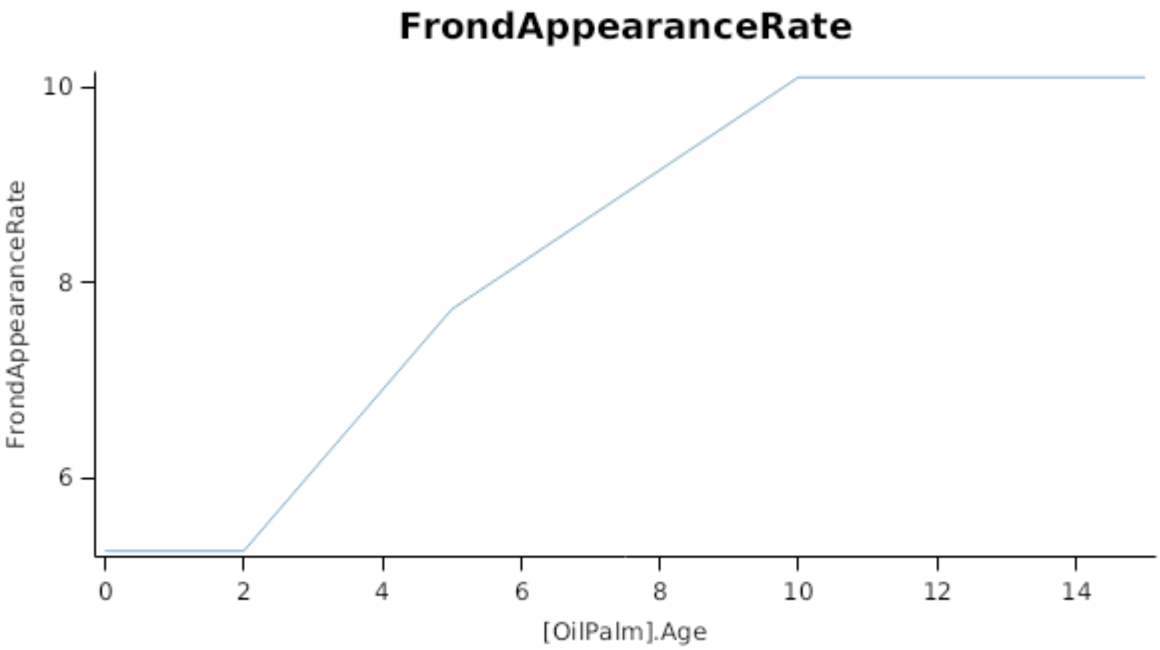
Air temperature (oC)	RelativeDevelopmentalRate
13.0	0.0
32.0	1.0
35.0	1.0
46.0	0.0



1.5 FrondAppearanceRate

FrondAppearanceRate is calculated using linear interpolation

[OilPalm].Age	FrondAppearanceRate
0.0	5.25
2.0	5.25
5.0	7.725
10.0	10.1
15.0	10.1



ExpandingFronds = 5

FrondMaximumNConcentration = 1.15

FrondCriticalNConcentration = 1.1

FrondMinimumNConcentration = 0.5

1.6 FrondMaxArea

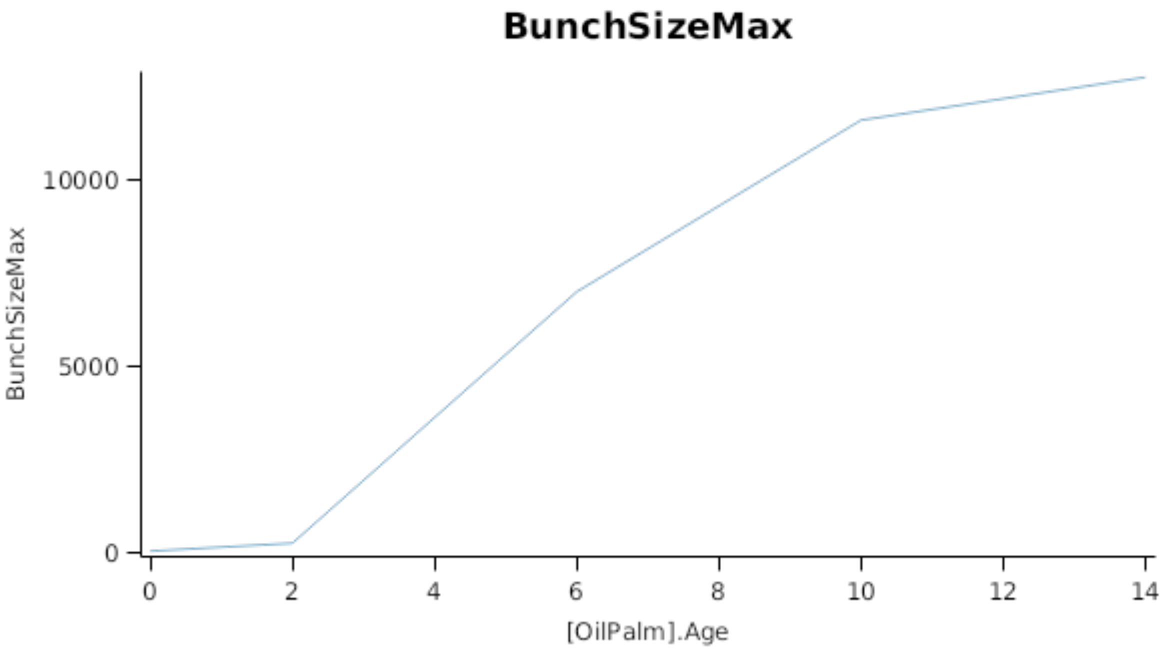
1.6.1 FrondMaxArea

A value is returned via Akima spline interpolation of a given set of XY pairs

1.7 BunchSizeMax

BunchSizeMax is calculated using linear interpolation

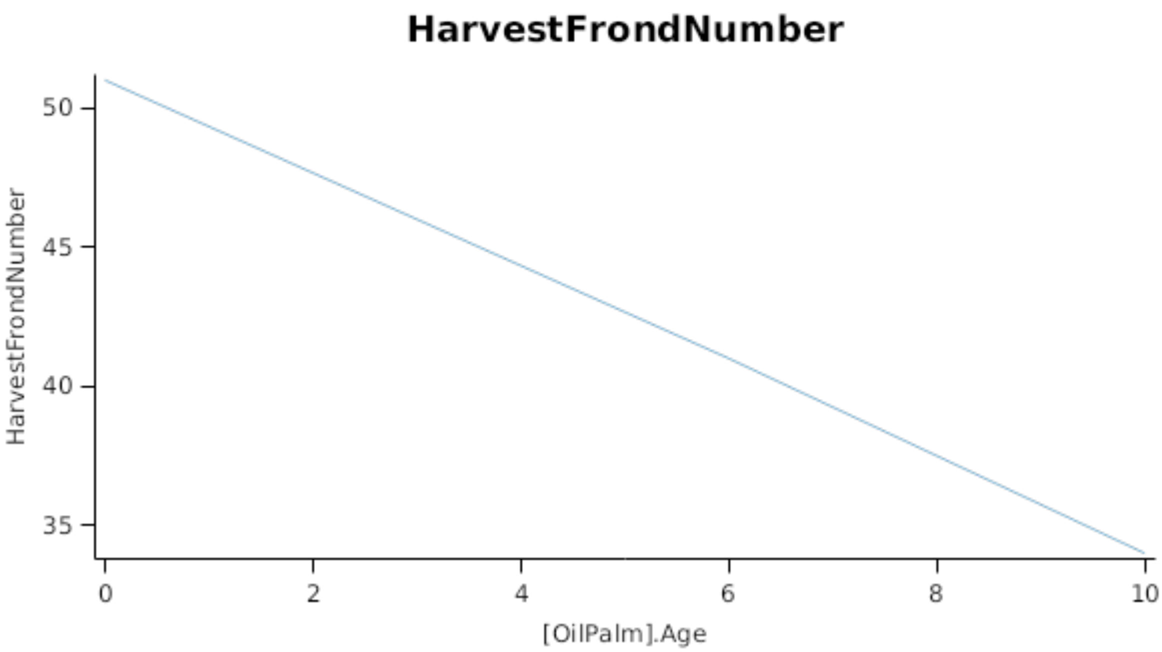
[OilPalm].Age	BunchSizeMax
0.0	53.0
2.0	265.0
6.0	7000.0
10.0	11600.0
14.0	12750.0



1.8 HarvestFrondNumber

HarvestFrondNumber is calculated using linear interpolation

[OilPalm].Age	HarvestFrondNumber
0.0	51.0
6.0	41.0
10.0	34.0



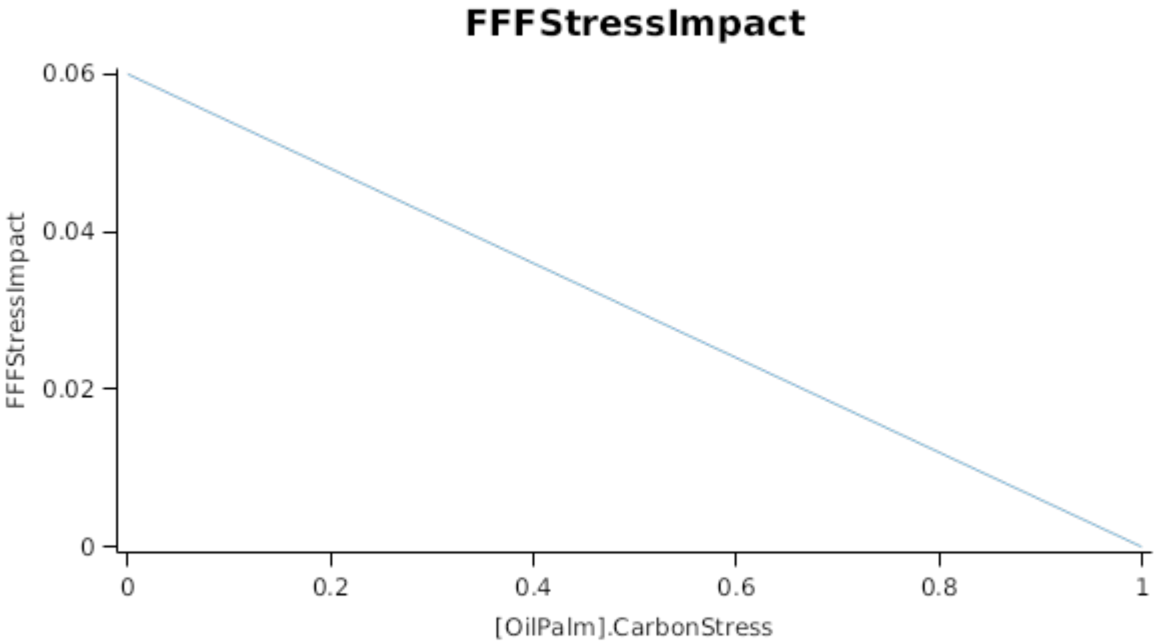
Sex determination is calculated during a phase occurring 49 to 57 fronds before bunch maturity. A constant value is assumed for Female Flower Fraction at the beginning of this phase. This represents the fraction of female flowers in the absence of any further stress effect.

FemaleFlowerFraction = 0.8

1.9 FFFStressImpact

FFFStressImpact is calculated using linear interpolation

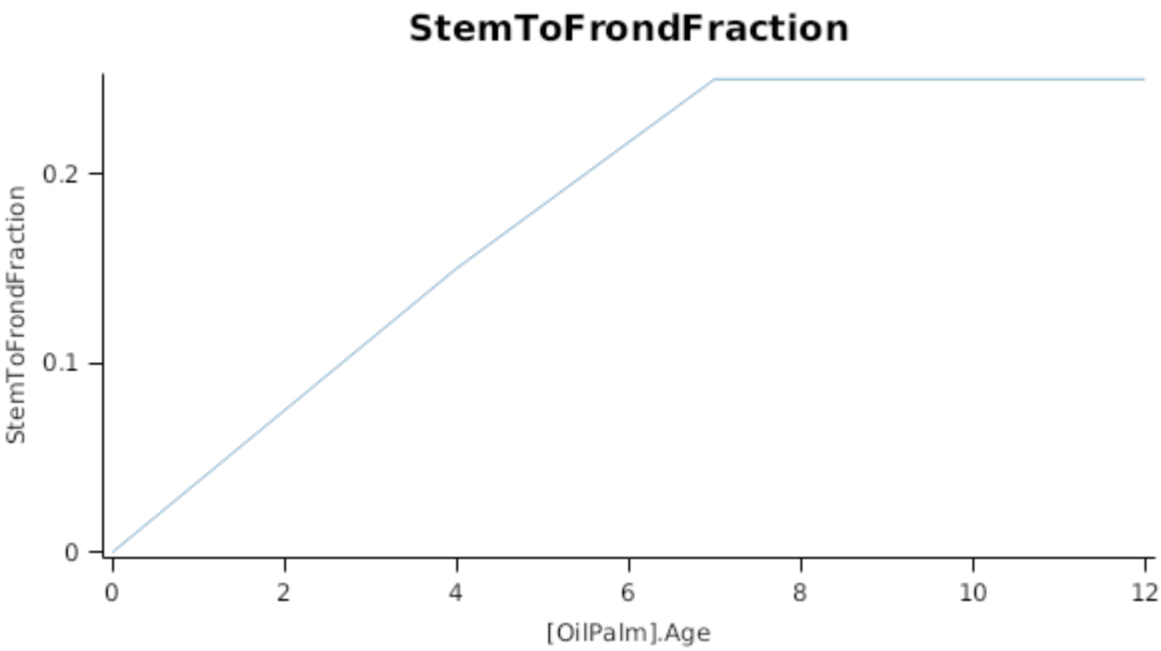
[OilPalm].CarbonStress	FFFStressImpact
0.0	0.06
1.0	0.0



1.10 StemToFrondFraction

StemToFrondFraction is calculated using linear interpolation

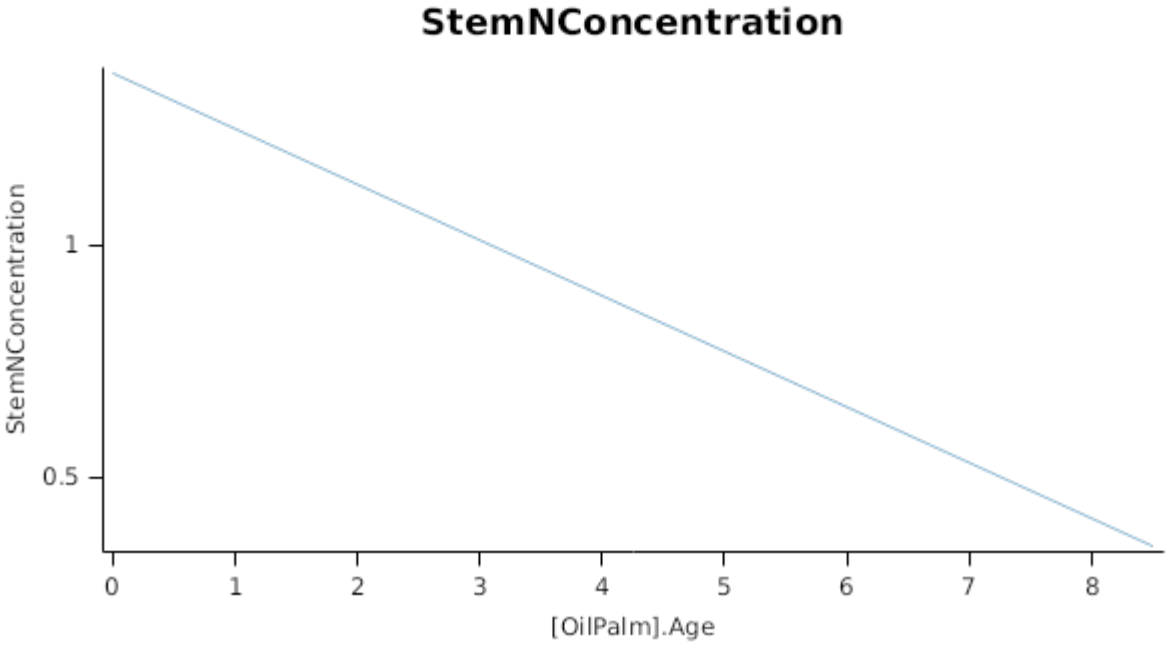
[OilPalm].Age	StemToFrondFraction
0.0	0.0
4.0	0.15
7.0	0.25
12.0	0.25



1.11 StemNConcentration

StemNConcentration is calculated using linear interpolation

[OilPalm].Age	StemNConcentration
0.0	1.37
8.5	0.351



BunchOilConversionFactor = 1.55

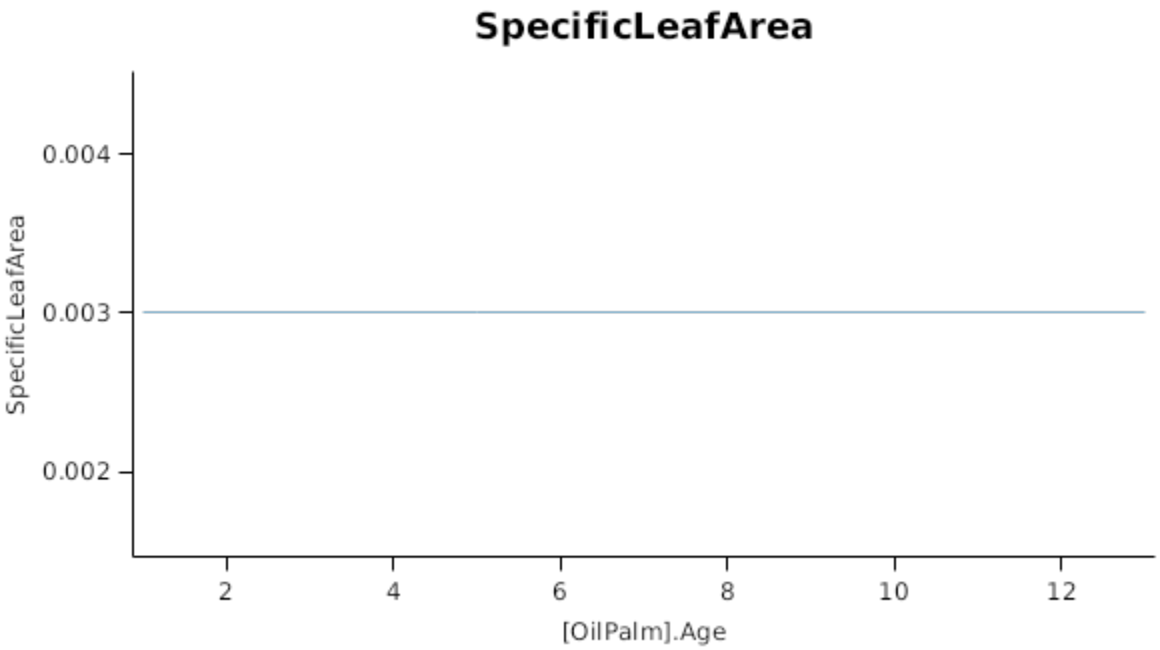
RipeBunchWaterContent = 0.47

BunchNConcentration = 0.603

1.12 SpecificLeafArea

SpecificLeafArea is calculated using linear interpolation

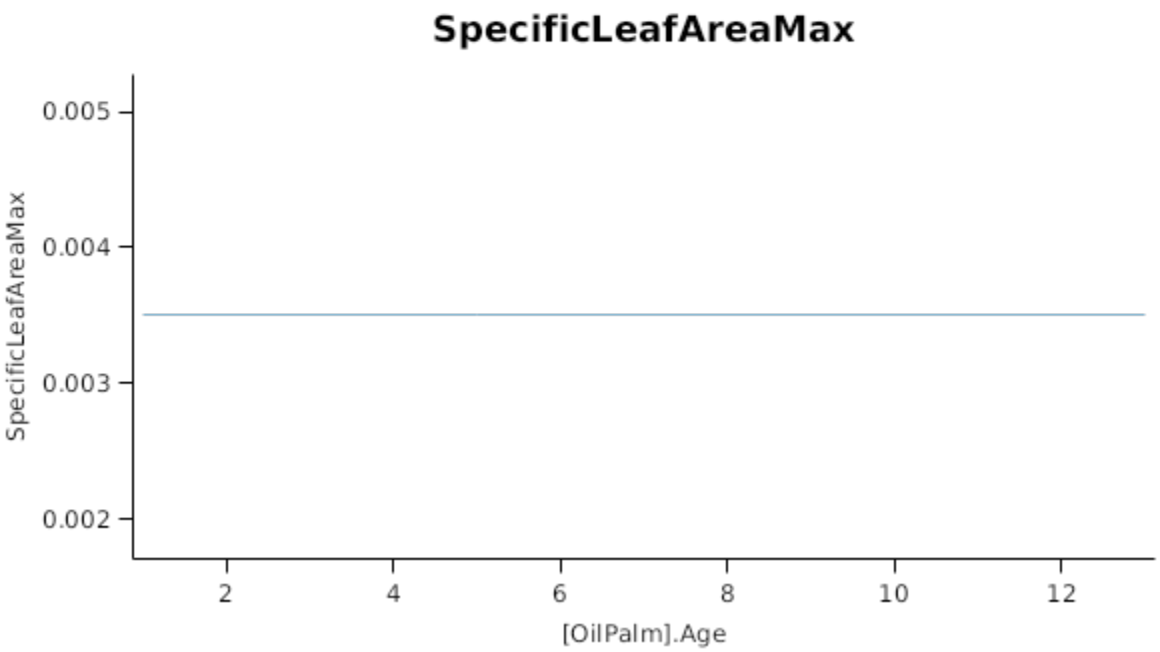
[OilPalm].Age	SpecificLeafArea
1.0	0.003
5.0	0.003
13.0	0.003



1.13 SpecificLeafAreaMax

SpecificLeafAreaMax is calculated using linear interpolation

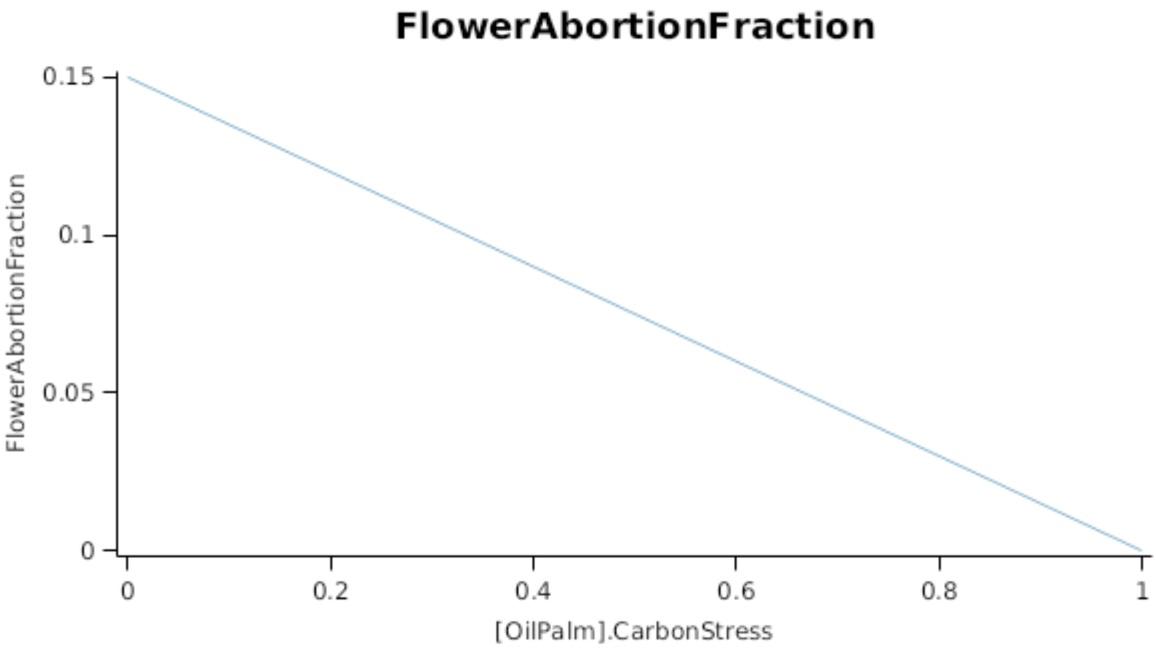
[OilPalm].Age	SpecificLeafAreaMax
1.0	0.0035
5.0	0.0035
13.0	0.0035



1.14 FlowerAbortionFraction

FlowerAbortionFraction is calculated using linear interpolation

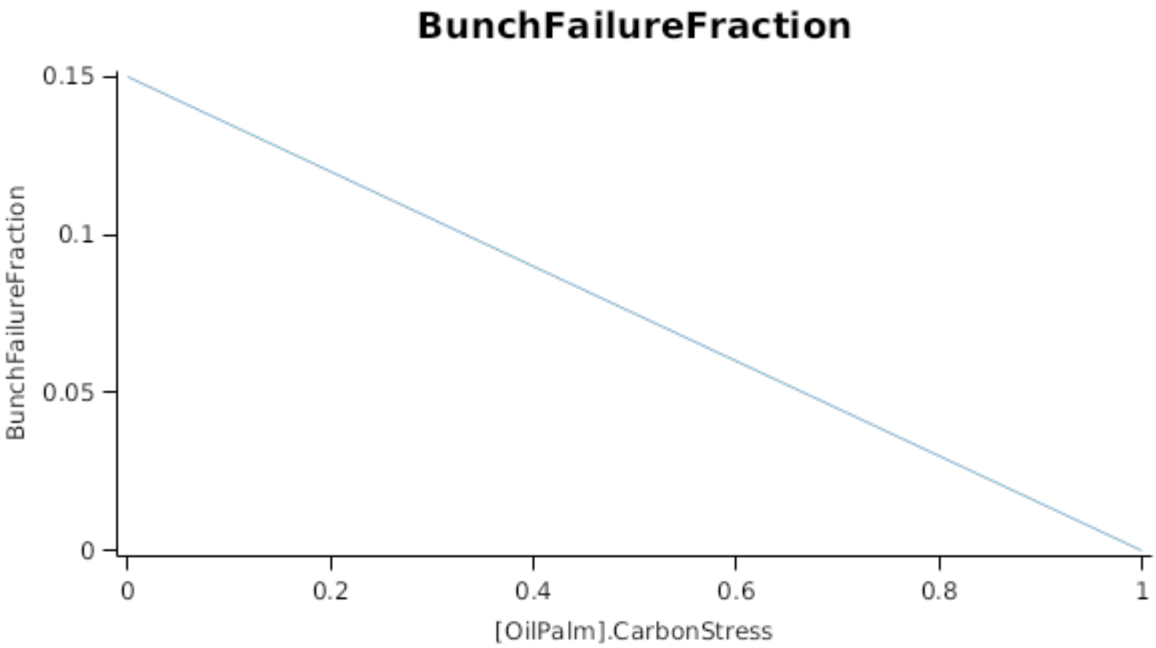
[OilPalm].CarbonStress	FlowerAbortionFraction
0.0	0.15
1.0	0.0



1.15 BunchFailureFraction

BunchFailureFraction is calculated using linear interpolation

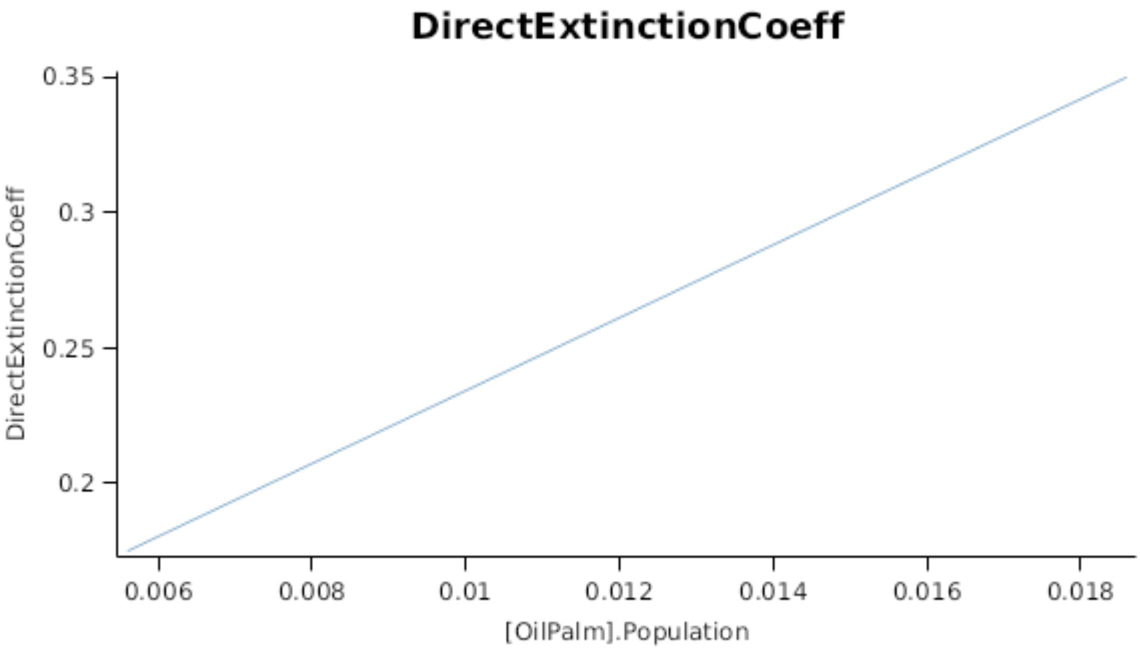
[OilPalm].CarbonStress	BunchFailureFraction
0.0	0.15
1.0	0.0



1.16 DirectExtinctionCoeff

DirectExtinctionCoeff is calculated using linear interpolation

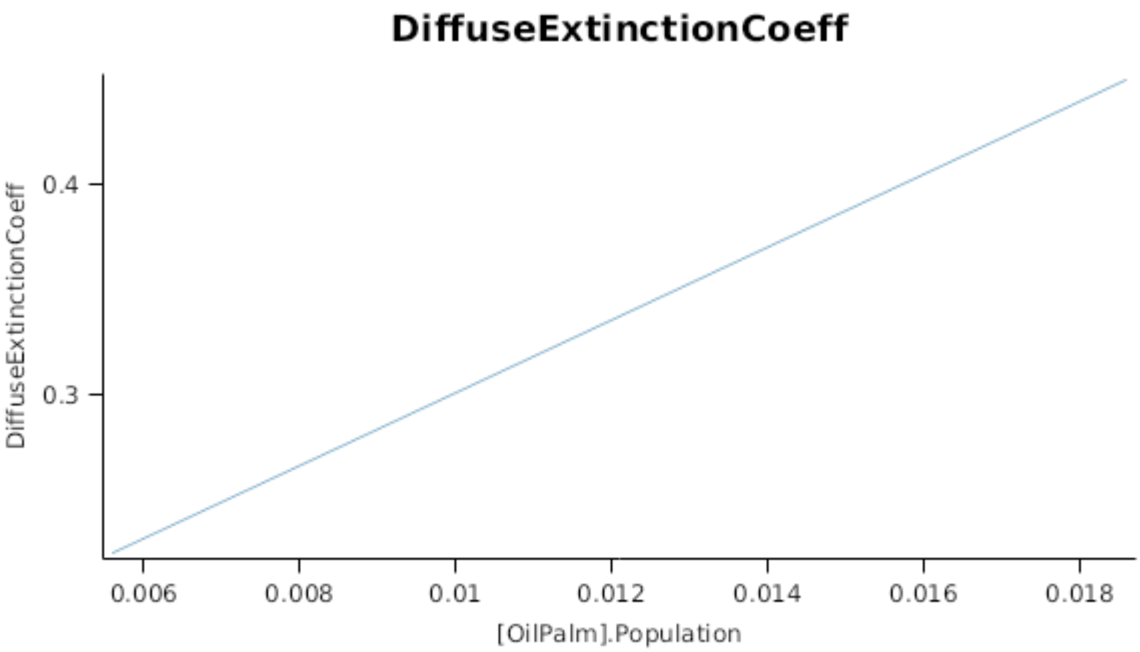
[OilPalm].Population	DirectExtinctionCoeff
0.0056	0.175
0.0186	0.35



1.17 DiffuseExtinctionCoeff

DiffuseExtinctionCoeff is calculated using linear interpolation

[OilPalm].Population	DiffuseExtinctionCoeff
0.0056	0.225
0.0186	0.45



Photosynthesis is calculated using a radiation use efficiency (RUE) of 1.22 g MJ-1 of intercepted direct beam total short wave radiation. RUE for diffuse light increases from this direct beam value by up to 33%, in proportion to the fraction of daily intercepted radiation, corresponding with the observed impact of diffuse light penetration on forest growth (Alton et al., 2007). Daily average RUE is calculated as the average of the direct and diffuse beam RUE values, weighted toward the diffuse light RUE using the square of the daily diffuse light fraction (van Kraalingen et al., 1989). This approach yields a value of 1.35 for a clear day with approximately 30% diffuse light which matches estimates provided by Henson and Dolmat (2003) assuming a density of 140 palms ha-1.

RUE = 1.22

Fixed root front velocity taken from Carr(2011).

RootFrontVelocity = 30

References

Alton, P.B., North, P.R., Los, S.O., 2007. The impact of diffuse sunlight on canopy light-use efficiency, gross photosynthetic product and net ecosystem exchange in three forest biomes. Global Change Biology 13(4) 776-787.

Araujo, L.C., Santos, P.M., Rodriguez, D., Pezzopane, J.R.M., Oliveira, P.P.A., Cruz, P.G., 2013. Simulating Guinea Grass Production: Empirical and Mechanistic Approaches. Agronomy Journal 105(1) 61-69.

Banabas, M., 2007. Study of Nitrogen loss pathways in oil palm (Elaeis guineensis Jacq.) growing agro-ecosystems in volcanic ash soils in Papua New Guinea, Soil Science. Massey University: Palmerston North, New Zealand.

Banabas, M., Scotter, D.R., Turner, M.A., 2008a. Losses of nitrogen fertiliser under oil palm in Papua New Guinea: 2. Nitrogen transformations and leaching, and a residence time model. Australian Journal of Soil Research 46(4) 340-347.

Banabas, M., Turner, M.A., Scotter, D.R., Nelson, P.N., 2008b. Losses of nitrogen fertiliser under oil palm in Papua New Guinea: 1. Water balance, and nitrogen in soil solution and runoff. Australian Journal of Soil Research 46(4) 332-339.

Breure, C.J., 1988a. The effect of different planting densities on yield trends in oil palm. Experimental Agriculture 24(1) 37-52.

Breure, C.J., 1988b. The effect of palm age and planting density on the partitioning of assimilates in oil palm (Elaeis-guineensis). Experimental Agriculture 24(1) 53-66.

Brown, H.E., Huth, N.I., Holzworth, D.P., Teixeira, E.I., Zyskowski, R.F., Hargreaves, J.N.G., Moot, D.J., these proceedings. Plant Modelling Framework: Software for building and running crop models on the APSIM platform. Environmental Modelling and Software.

Carr, M.K.V., 2011. The water relations and irrigation requirements of oil palm (Elaeis guineensis): A review. Experimental Agriculture 47(4) 629-652.

Combres, J.-C., Pallas, B., Rouan, L., Mialet-Serra, I., Caliman, J.-P., Braconnier, S., Soulie, J.-C., Dingkuhn, M., 2013. Simulation of inflorescence dynamics in oil palm and estimation of environment-sensitive phenological phases: a model based analysis. Functional Plant Biology 40(3) 263-279.

Corley, R.H.V., Hardon, J.J., Tan, G.Y., 1971. Analysis of growth of oil palm (Elaeis-guineensis Jacq) .1. Estimation of growth parameters and application in breeding. Euphytica 20(2) 307-315.

Goh, K.J., 2005. Fertilizer recommendation systems for oil palm: estimating the fertilizer rates.

Henson, I.E., Dolmat, M.T., 2003. Physiological analysis of an oil palm density trial on a peat soil. Journal of Oil Palm Research 15(2) 1-27.

Henson, I.E., Yahya, Z., Noor, M.R.M., Harun, M.H., Mohammed, A.T., 2007. Predicting soil water status, evapotranspiration, growth and yield of young oil palm in a seasonally dry region of Malaysia. Journal of Oil Palm Research 19 398-415.

Jones, L.H., 1997. The effects of leaf pruning and other stresses on sex determination in the oil palm and their representation by a computer model. Journal of Theoretical Biology 187 241-260.

Keshvadi, A., Bin Endan, J., Harun, H., Ahmad, D., Saleena, F., 2012. The reflection of moisture content on palm oil development during the ripening process of fresh fruits. Journal of Food Agriculture and Environment 10(1) 203-209.

Nelson, P.N., Banabas, M., Scotter, D.R., Webb, M.J., 2006. Using soil water depletion to measure spatial distribution of root activity in oil palm (Elaeis guineensis Jacq.) plantations. Plant and Soil 286(1-2) 109-121.

Nelson, P.N., Webb, M.J., Banabas, M., Nake, S., Goodrick, I., Gordon, J., O'Grady, D., Dubos, B., 2014. Methods to account for tree-scale variability in soil- and plant-related parameters in oil palm plantations. Plant and Soil 374(1-2) 459-471.

Nelson, P.N., Webb, M.J., Orrell, I., van Rees, H., Banabas, M., Berthelsen, S., Sheaves, M., Bakani, F., Pukam, O., Hoare, M., Griffiths, W., King, G., Carberry, P., Pipai, R., McNeill, A., Meekers, P., Lord, S., Butler, J., Pattison, T., Armour, J., Dewhurst, C., 2010. Environmental sustainability of oil palm cultivation in Papua New Guinea. Australian Centre for International Agricultural Research, Canberra, Australia.

Nelson, R.A., Cramb, R.A., Mamicpic, M.A., 1998. Erosion/productivity modelling of maize farming in the Philippine uplands part III: Economic analysis of alternative farming methods. Agricultural Systems 58(2) 165-183.

Pipai, R., 2013. Biological Nitrogen Fixation By Cover Legumes Under Oil Palm Plantations In Papua New Guinea, School of Agriculture, Food and Wine. Faculty of Sciences. The University of Adelaide: Australia.

Priestley, C.H.B., Taylor, R.J., 1972. On the assessment of surface heat flux and evaporation using large scale parameters. Monthly Weather Review 100 81-92.

Robertson, M.J., Carberry, P.S., Huth, N.I., Turpin, J.E., Probert, M.E., Poulton, P.L., Bell, M., Wright, G.C., Yeates, S.J., Brinsmead, R.B., 2002. Simulation of growth and development of diverse legume species in APSIM. Australian Journal of Agricultural Research 53 429-446.

Romero, C.C., Hoogenboom, G., Baigorria, G.A., Koo, J., Gijsman, A.J., Wood, S., 2012. Reanalysis of a global soil database for crop and environmental modeling. Environmental Modelling and Software 35 163-170.

Schultz, H.R., 1992. An empirical model for the simulation of leaf appearance and leaf area development of promary shoots of several grapevine (Vitis-vinifera L) canopy systems. Scientia Horticulturae 52(3) 179-200.

Sheil, D., Casson, A., Meijaard, E., van Noordwijk, M., Gaskell, J., Sunderland-Groves, J., Wertz, K., Kanninen, M., 2009. The Impacts and Opportunities of Oil Palm in Southeast Asia: What Do We Know and What Do We Need to Know? , Occasional Paper. Center for International Forestry Research: Bogor, Indonesia.

van Kraalingen, D.W.G., Breure, C.J., Spitters, C.J.T., 1989. Simulation of oil palm growth and yield. Agricultural and Forest Meteorology 46(3) 227-244.

Van Noordwijk, M., Lusiana, B., Khasanah, N., Mulia, R., 2011. WaNuLCAS version 4.0: Background on a model of water, nutrient and light capture in agroforestry systems. World Agroforestry Centre (ICRAF): Bogor, Indonesia, p. 224.

von Uexküll, H., Henson, I.E., Fairhurst, T., 2003. Canopy management to optimize yield, In: Fairhurst, T., Härdter, R. (Eds.), The Oil Palm – Management for Large and Sustainable Yields. Potash and Phosphate Institute of Canada, Potash and Phosphate Institute, International Potash Institute: Singapore, pp. 163-180.

2 Validation

Data from three sites across PNG with different climate and soils were used for model testing. Soils ranged from sandy clay (volcanic ash) to alluvial clay. Mean annual rainfall ranged from 2400 mm at Sagarai (1990-2008) and Sangara (1986-2009) to 4350 mm at Hargy(1989-2008) with annual rainfall variability larger at Sagarai than the other two sites. Whilst there is only a small difference in temperature across the sites, rainfall patterns do impact on both annual (Hargy 15.9 MJ; Sangara 17.0 MJ; Sagarai 18.1 MJ) and monthly variation in mean daily solar radiation.

Fertiliser trial data were obtained for each location from the PNG Oil Palm Research Association trial database (Table Below). All trials had the same commercial dura x pisifera palms planted in an equilateral triangular pattern. Trials included multiple rates of nitrogen including a control in which no nitrogen was applied. Fertilisers were applied in two to three applications per year. Trial 324 evaluated the effect of nitrogen rate and source (five sources). There was no effect of nitrogen source and so these data have been combined in this study as there was no effect of nitrogen source. Trial 504 investigated nutrient interactions (N x K). Data from treatments for which potassium was not limiting were combined. Trial 212 investigated nitrogen rate only. All other macro- and micronutrients were maintained at sufficient levels in all trials. Plots in each trial consisted of 16 to 30 palms surrounded by guard rows between neighbouring plots. Levels of replication ranged from two to four. In trials 324 and 504, trenches were dug around plots to minimise poaching of nutrients by palms from neighbouring plots.

Description of fertiliser trials and selected treatments used in model development and testing.

Location: **Hargy**
Trial number: 212
Previous land use: Oil Palm
Year planted: 1996
Treatment commenced: 2002
Population: 140 (palms/ha)
NRates: 0, 1.0, 2.0 (kg/palm/ha/y)

Location: **Sangara**
Trial number: 324
Previous land use: Oil Palm
Year planted: 1996
Treatment commenced: 2001
Population: 135 (palms/ha)
NRates: 0, 0.42, 1.68 (kg/palm/ha/y)

Location: **Sagarai**
Trial number: 504
Previous land use: Forest / Rubber plantation
Year planted: 1991
Treatment commenced: 1995

Population: 127 (palms/ha)
NRates: 0, 0.42, 1.26 (kg/palm/ha/y)

Harvested ripe bunches were counted and weighed (together with loose fruits) fortnightly for every palm. Leaf samples were collected from frond 17 from selected palms in all plots at least once a year and were oven dried and analysed for nitrogen content. Petiole cross-sectional area, leaflet lengths and frond length of frond 17 was measured to allow calculation of leaf area and mass (Corley et al., 1971). The total number of fronds on each palm was counted, and the first frond was marked twice a year to determine frond production rate. Stem heights of selected palms were measured periodically in two of the trials, and these were combined with a single measurement of stem diameter to calculate stem mass, assuming a linear increase in stem density with plantation age (Corley et al., 1971).

Parameterisation of soil process models used information from a variety of sources. Soil hydraulic properties were derived from pressure plate water retention data. Runoff curve number (Hawkins, 1996) was estimated to 72 for clay soils and 50 for ash soils using runoff data from PNG oil palm plantations (Banabas et al., 2008b). Soil organic carbon data were available for Trials 324 and 504. Simulations of Trial 212 utilised carbon measurements available for a nearby planting. The fractionation of soil organic carbon into the various model pools is very important for model accuracy. It has been shown that it is possible to deduce, a priori, the apparent soil organic matter composition from observed patterns (Huth et al., 2010). The inert fraction of the total soil organic matter is an important parameter and methods for its determination for the volcanic soils in PNG have not been developed. In this study, we have assumed that the inert carbon content does not vary significantly with depth and that it can be approximated using the carbon content at a depth of approximately 0.5 m. Most carbon cycling occurs above this depth and carbon contents vary less below this depth. Therefore we assumed that carbon above this value is available for decomposition. Finally, as trials 212 and 324 were planted after felling of existing plantations, we initialised the surface organic matter pools to consist of 24 t/ ha of fronds with a C:N of 39 and 63 t/ ha of stems with a C:N of 145. In the absence of other information, the same initial surface organic matter was used for trial 504.

Daily meteorological data (rainfall, sunshine hours, temperature) for Trial 324 were taken from the nearby research station of the PNG Oil Palm Research Association. Sunshine hour data was used to calculate incoming global shortwave radiation as described by Banabas (2007). Complete daily meteorological datasets were not available for the other two sites apart from a limited number of monthly totals for sunshine hours and rainfall. Daily estimates of the required climate weather data for these sites were derived from estimates obtained from the NASA Langley Research Center POWER Project funded through the NASA Earth Science Directorate Applied Science Program (http://power.larc.nasa.gov/). Adequacy of this dataset was tested via comparison of satellite-derived estimates of monthly mean solar radiation with that calculated from measured monthly sunshine hours for Hargy (data not shown). No data on sunshine hours were available for Sagarai and neither site had measured temperature data for comparison. Satellite-derived estimates of monthly rainfall proved inadequate when compared to available monthly data. Therefore, observed monthly rainfall totals were disaggregated into daily data using the satellite-derived daily rainfall estimates. Satellite-derived estimates of daily temperatures were used for these two sites but could not be tested for accuracy.

References

Banabas, M., 2007. Study of Nitrogen loss pathways in oil palm (Elaeis guineensis Jacq.) growing agro-ecosystems in volcanic ash soils in Papua New Guinea. Soil Sci. Massey University, Palmerston North, New Zealand.

Banabas, M., Turner, M.A., Scotter, D.R., Nelson, P.N., 2008. Losses of nitrogen fertiliser under oil palm in Papua New Guinea: 1. Water balance, and nitrogen in soil solution and runoff. Aust J Soil Res 46, 332-339.

Banabas, M., Scotter, D.R., Turner, M.A., 2008. Losses of nitrogen fertiliser under oil palm in Papua New Guinea: 2. Nitrogen transformations and leaching, and a residence time model. Aust J Soil Res 46, 340-347.

Corley, R.H.V., Hardon, J.J., Tan, G.Y., 1971. Analysis of growth of oil palm (Elaeis-guineensis Jacq) .1. Estimation of growth parameters and application in breeding. Euphytica 20, 307-315.

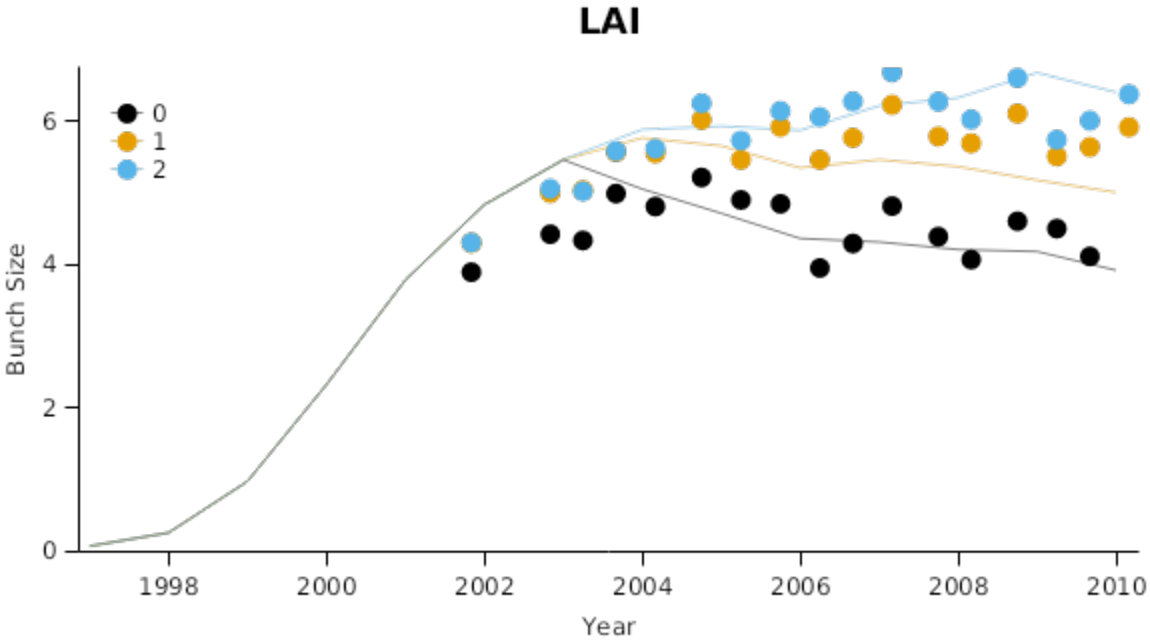
Hawkins, R.H., 1996. Runoff Curve Number: Has It Reached Maturity? Journal of Hydrologic Engineering 1, 11-19.

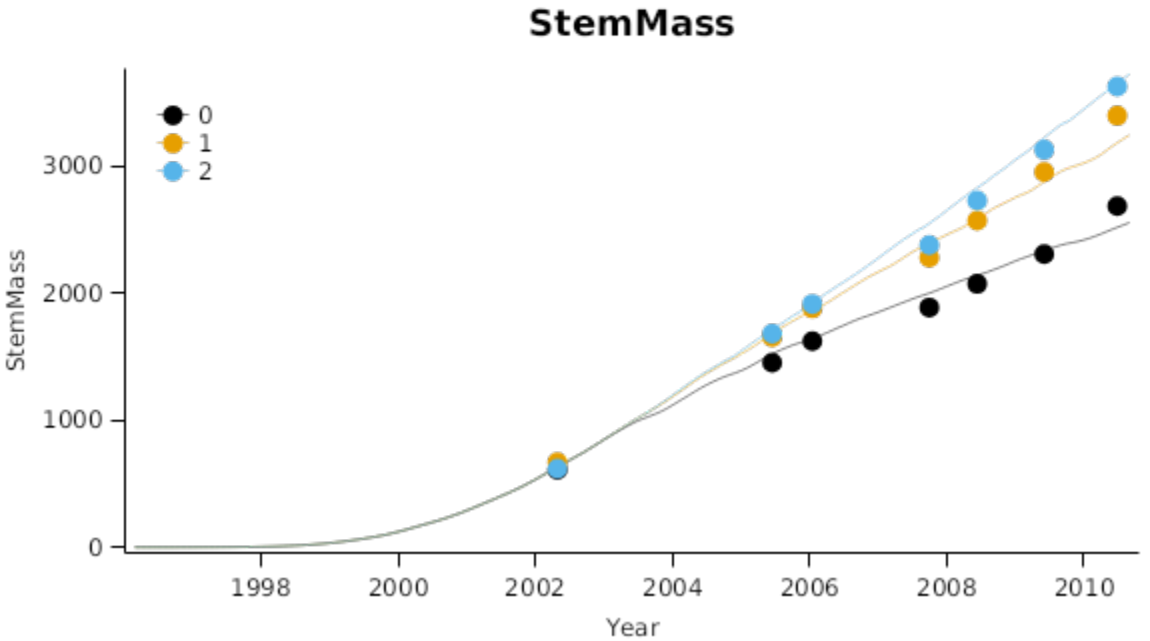
Huth, N.I., Thorburn, P.J., Radford, B.J., Thornton, C.M., 2010. Impacts of fertilisers and legumes on N2O and CO2 emissions from soils in subtropical agricultural systems: A simulation study. Agriculture Ecosystems And Environment 136, 351-357.

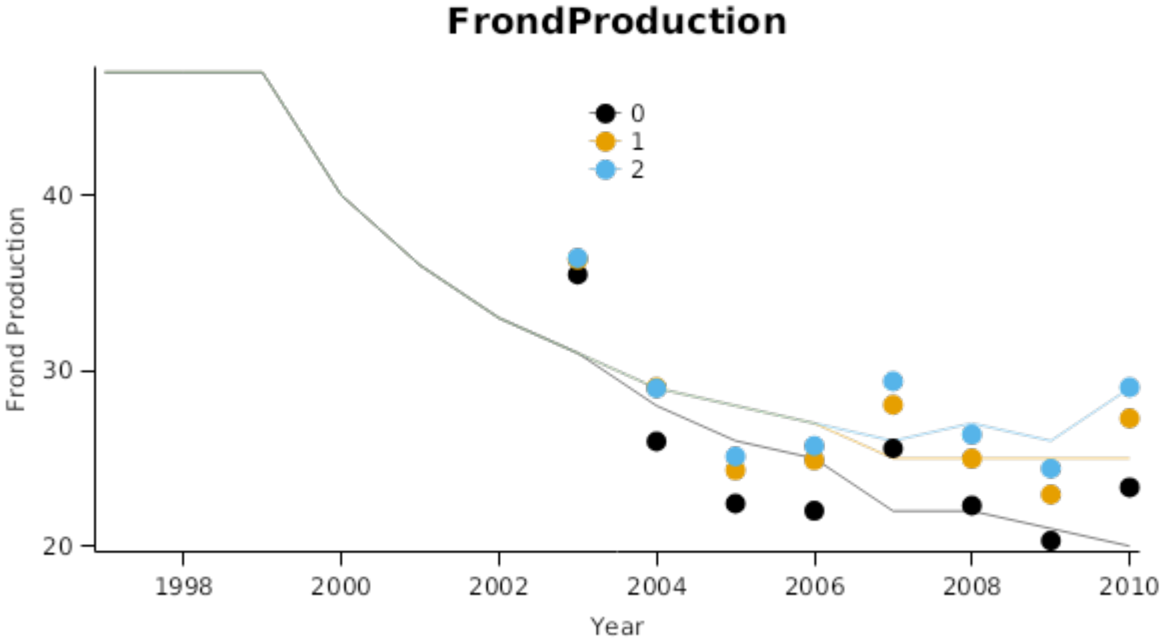
List of experiments.

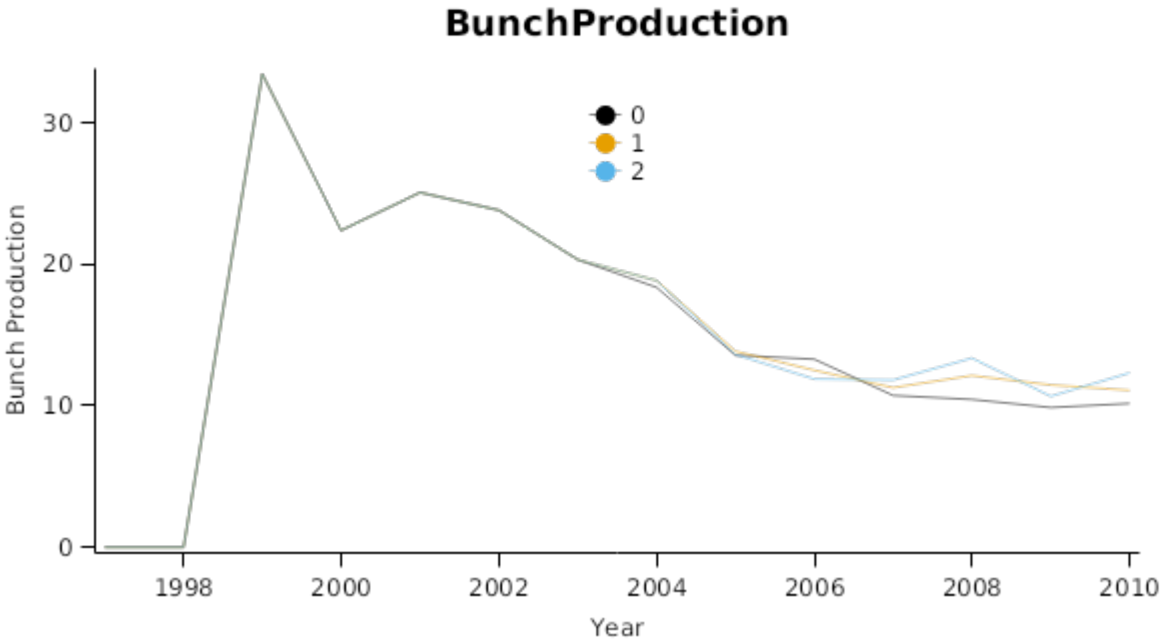
Experiment Name	Design (Number of Treatments)
Sangara	N (3)
Hargy	N (3)
Sagarai	N (3)

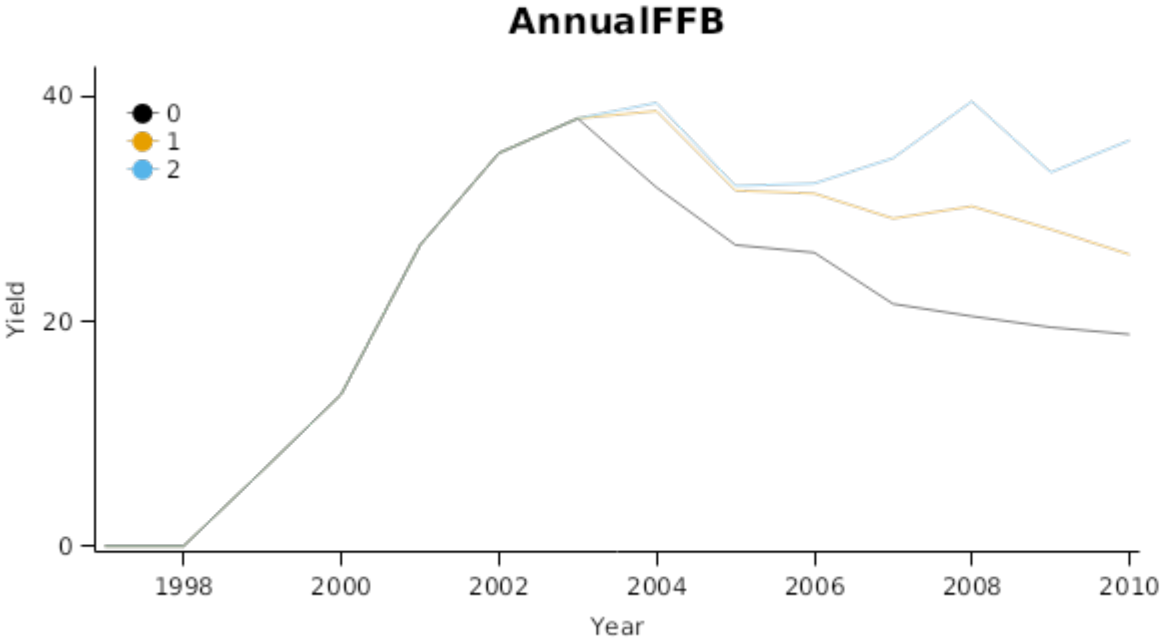
2.1 Sangara

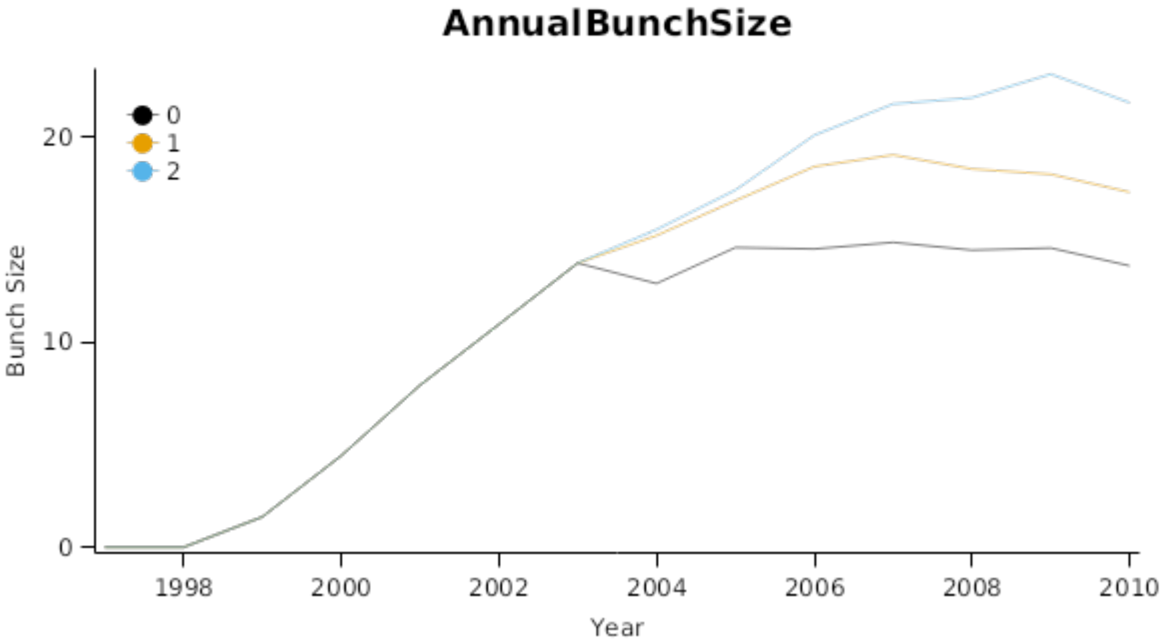

LAI
0
1
2
Bunch Size
0
2
4
6
1998
2000
2002
2004
2006
2008
2010
Year


StemMass
0
1
2
StemMass
0
1000
2000
3000
1998
2000
2002
2004
2006
2008
2010
Year

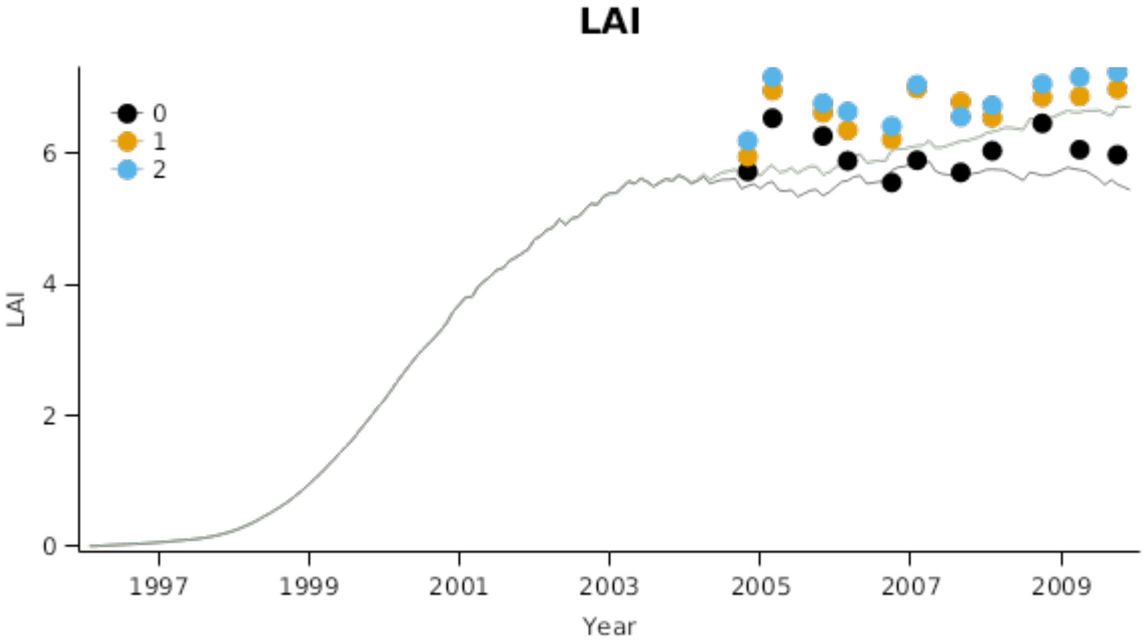

FrondProduction
0
1
2
Frond Production
40
30
20
1998
2000
2002
2004
2006
2008
2010
Year


BunchProduction
0
1
2
Bunch Production
30
20
10
0
1998
2000
2002
2004
2006
2008
2010
Year

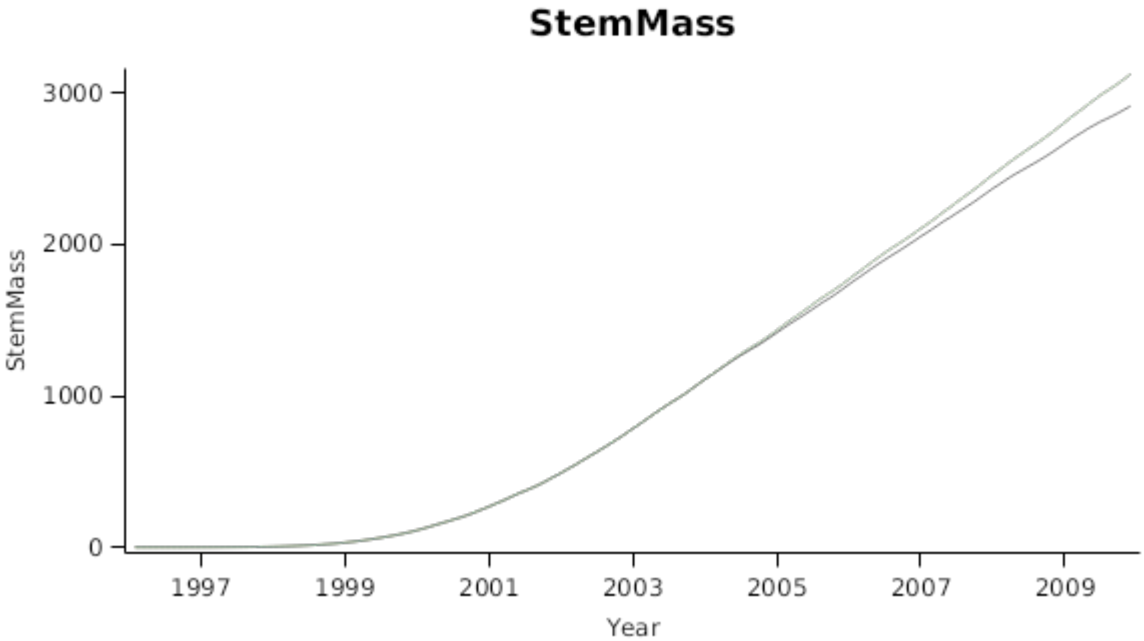

AnnualFFB
0
1
2
40
20
0
Yield
1998
2000
2002
2004
2006
2008
2010
Year


AnnualBunchSize
0
1
2
20
10
0
Bunch Size
1998
2000
2002
2004
2006
2008
2010
Year

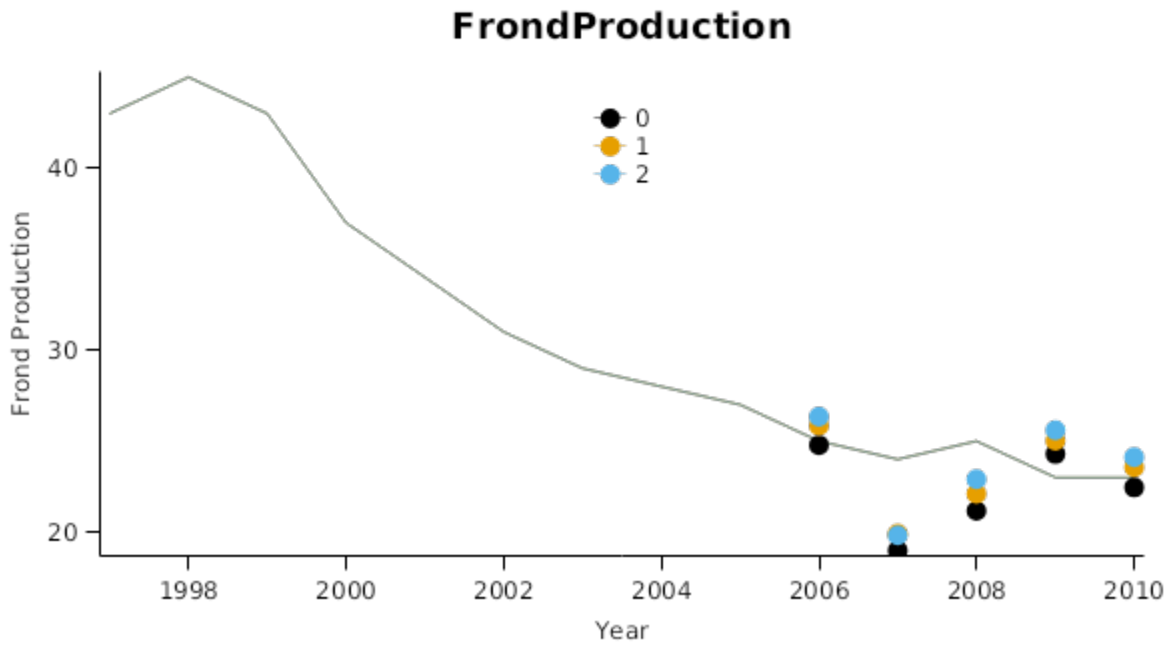
2.2 Hargy

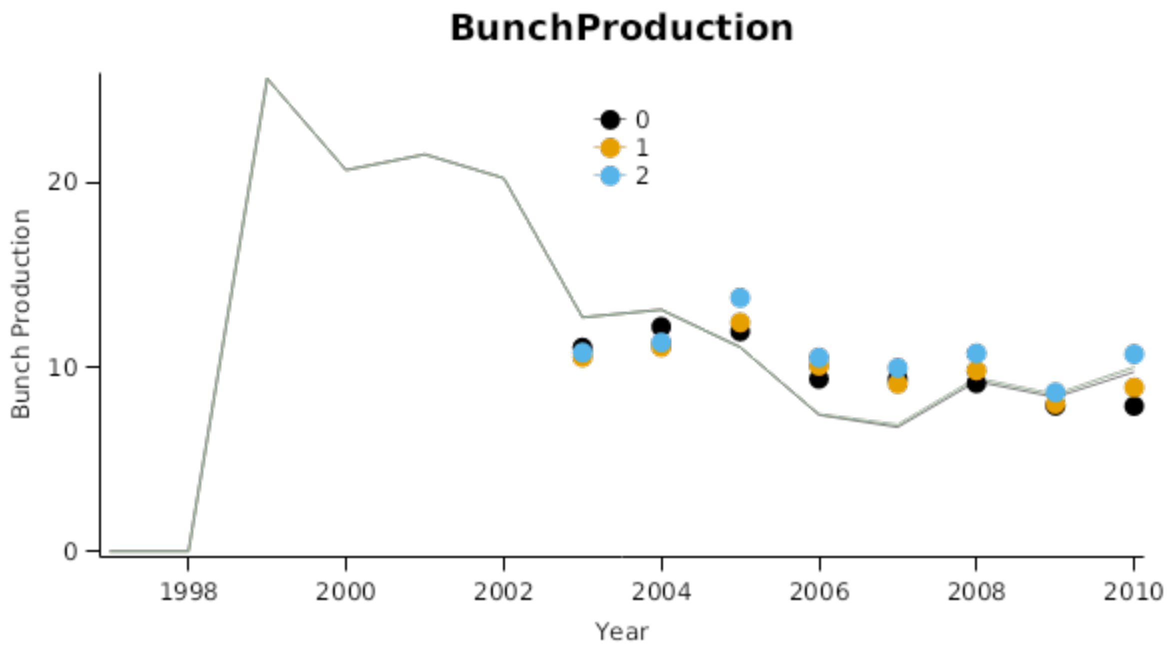


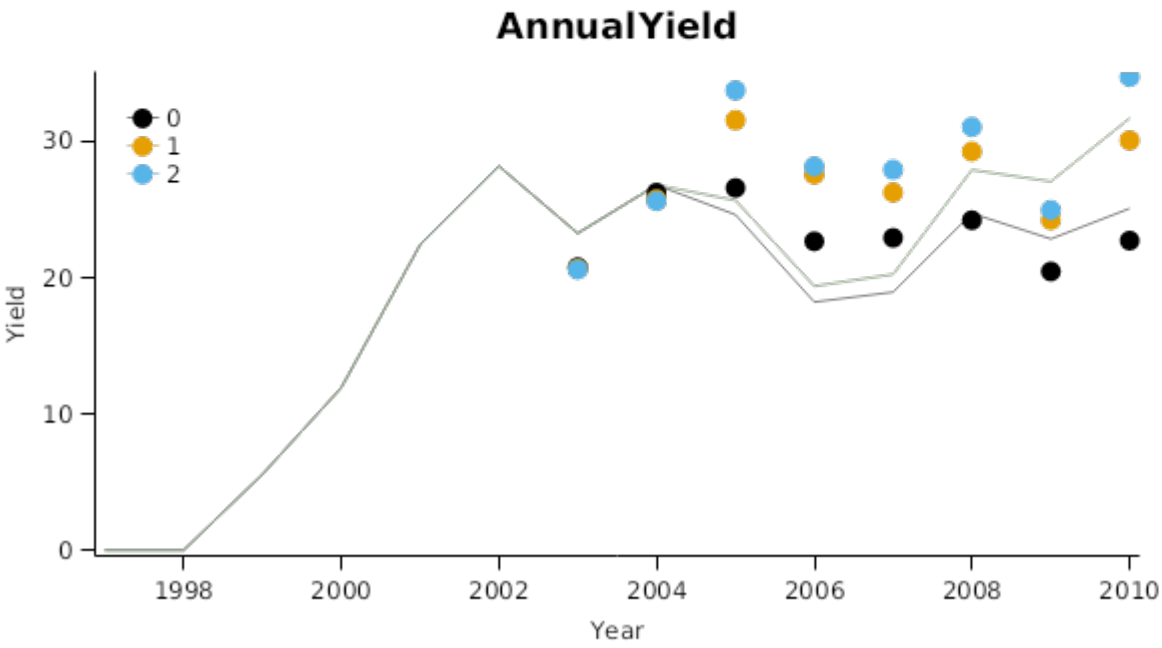
LAI
0
1
2
LAI
0
2
4
6
1997
1999
2001
2003
2005
2007
2009
Year

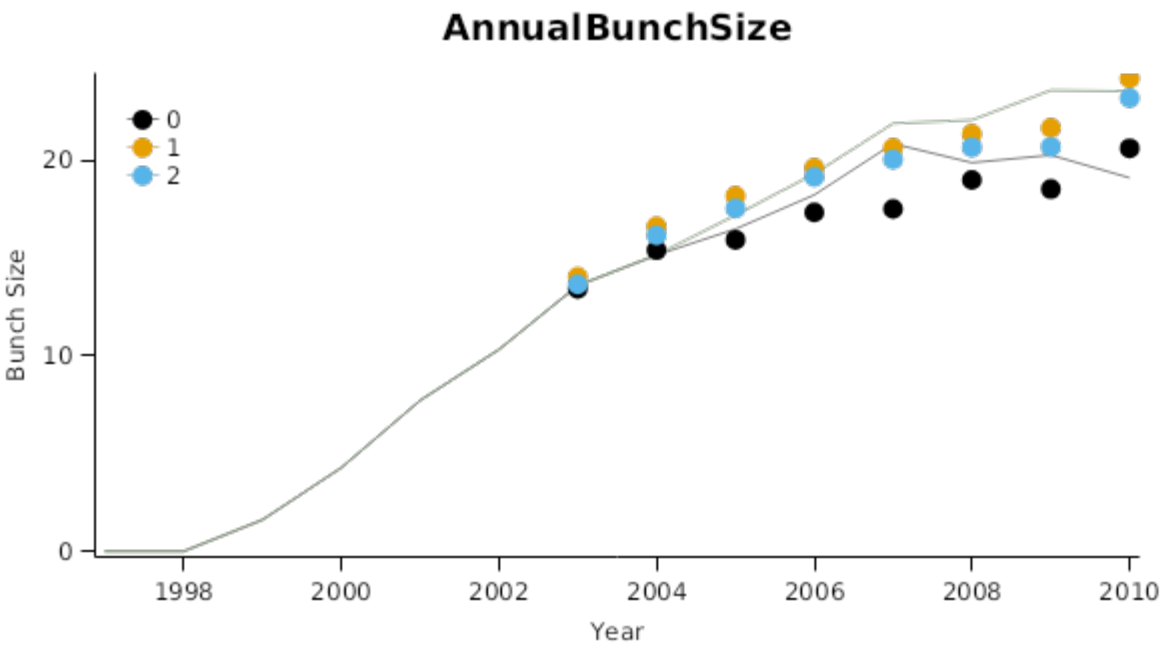


StemMass
StemMass
0
1000
2000
3000
1997
1999
2001
2003
2005
2007
2009
Year

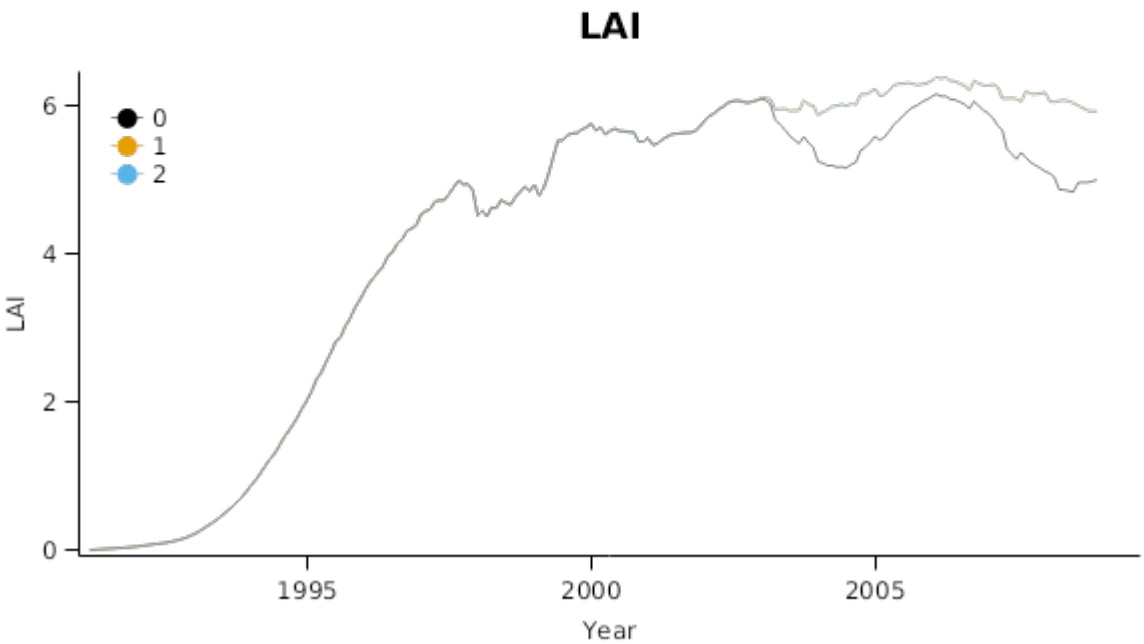

FrondProduction
0
1
2
40
30
20
Frond Production
1998
2000
2002
2004
2006
2008
2010
Year

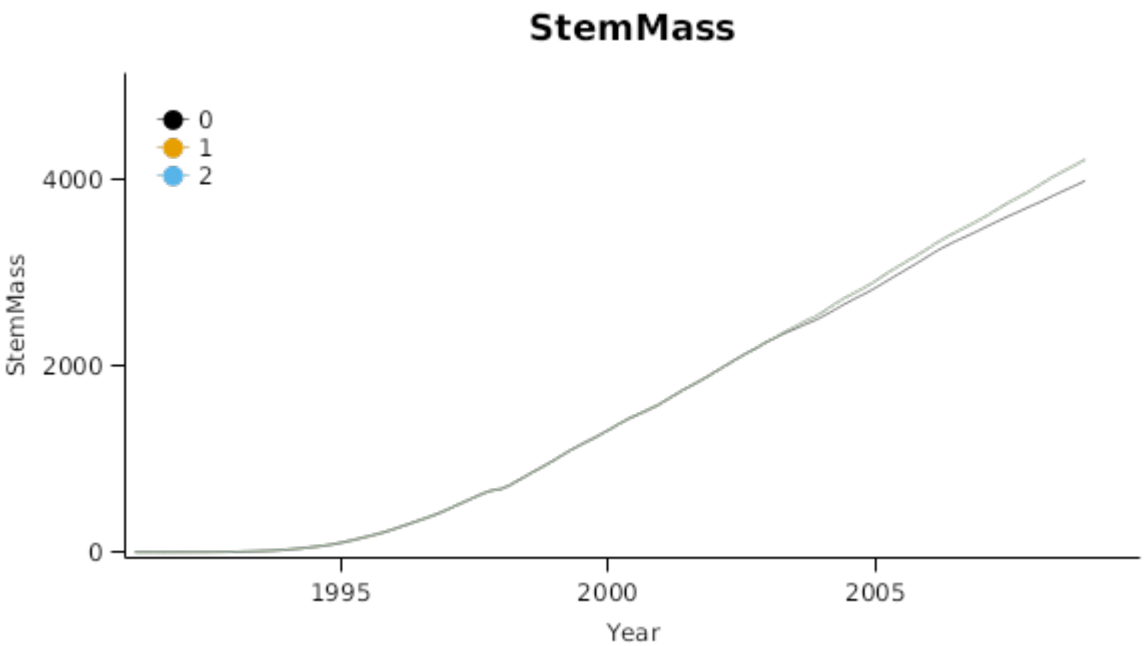

BunchProduction
0
1
2
20
10
0
Bunch Production
1998
2000
2002
2004
2006
2008
2010
Year

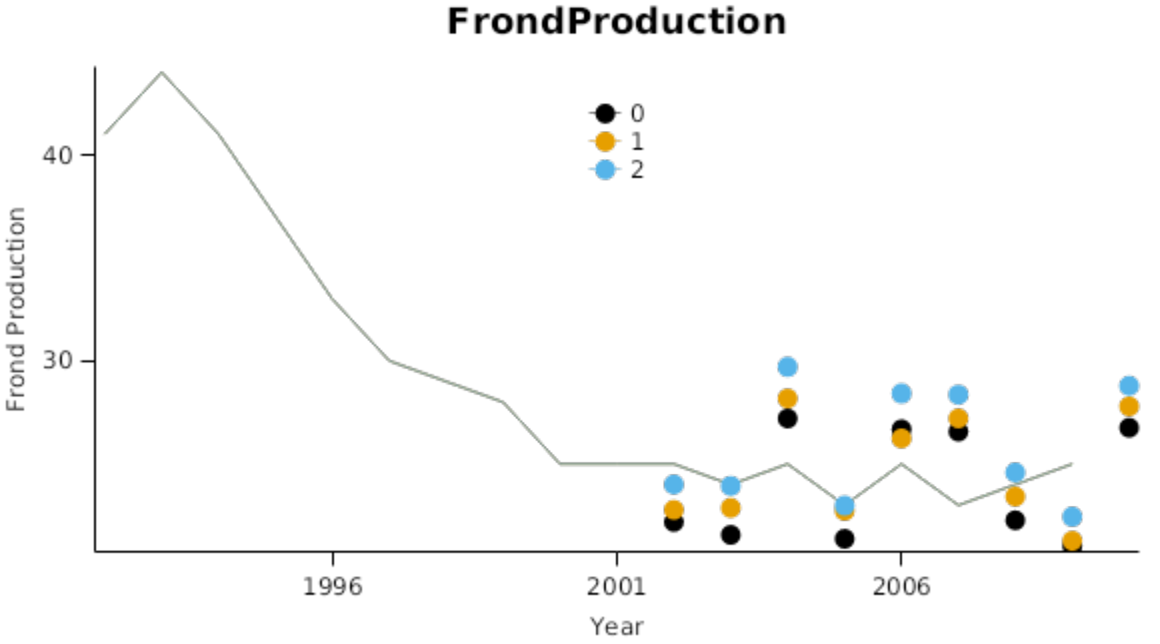

AnnualYield
0
1
2
Yield
30
20
10
0
1998
2000
2002
2004
2006
2008
2010
Year


AnnualBunchSize
0
1
2
Bunch Size
20
10
0
1998
2000
2002
2004
2006
2008
2010
Year

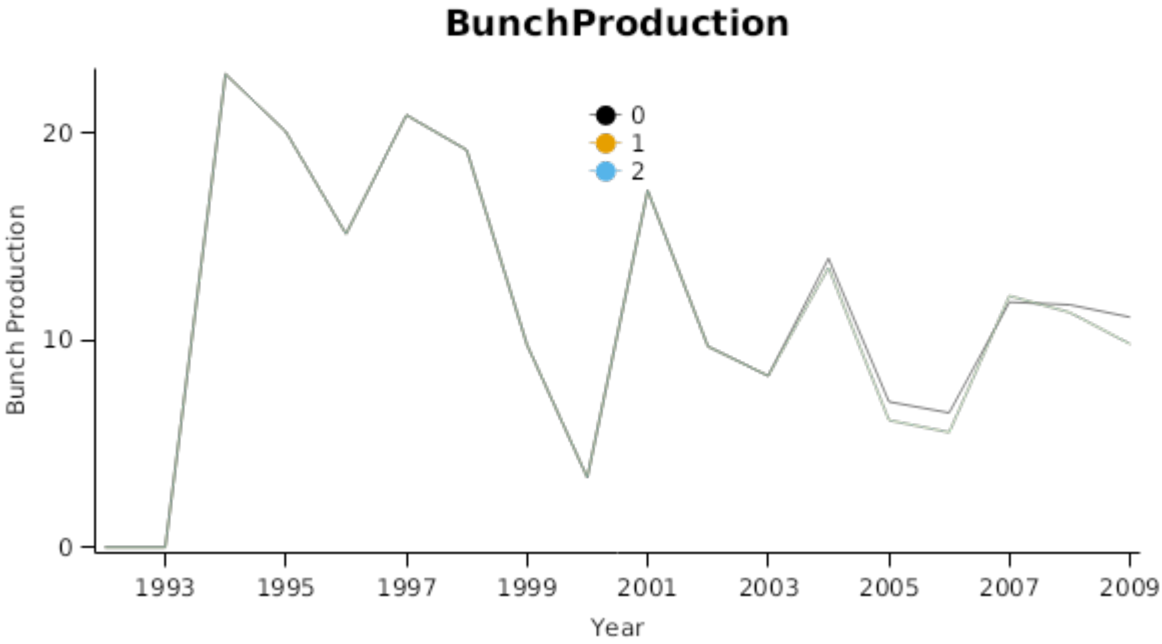
2.3 Sagarai


LAI
0
1
2
6
4
2
0
LAI
1995
2000
2005
Year

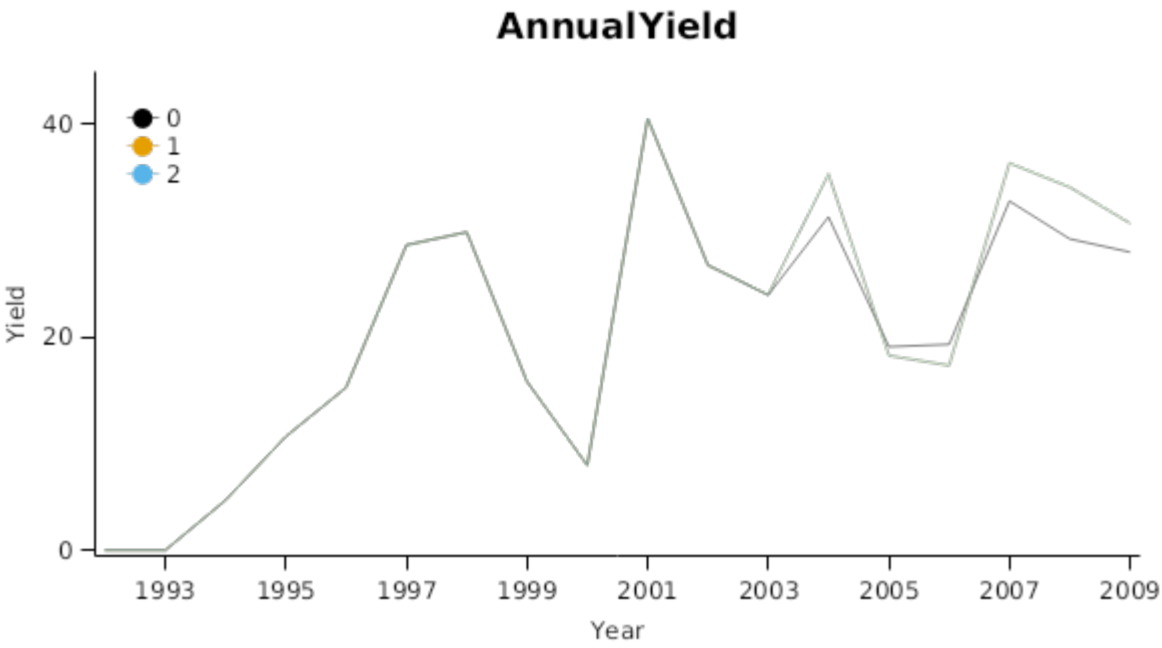

StemMass
0
1
2
4000
2000
0
StemMass
1995
2000
2005
Year

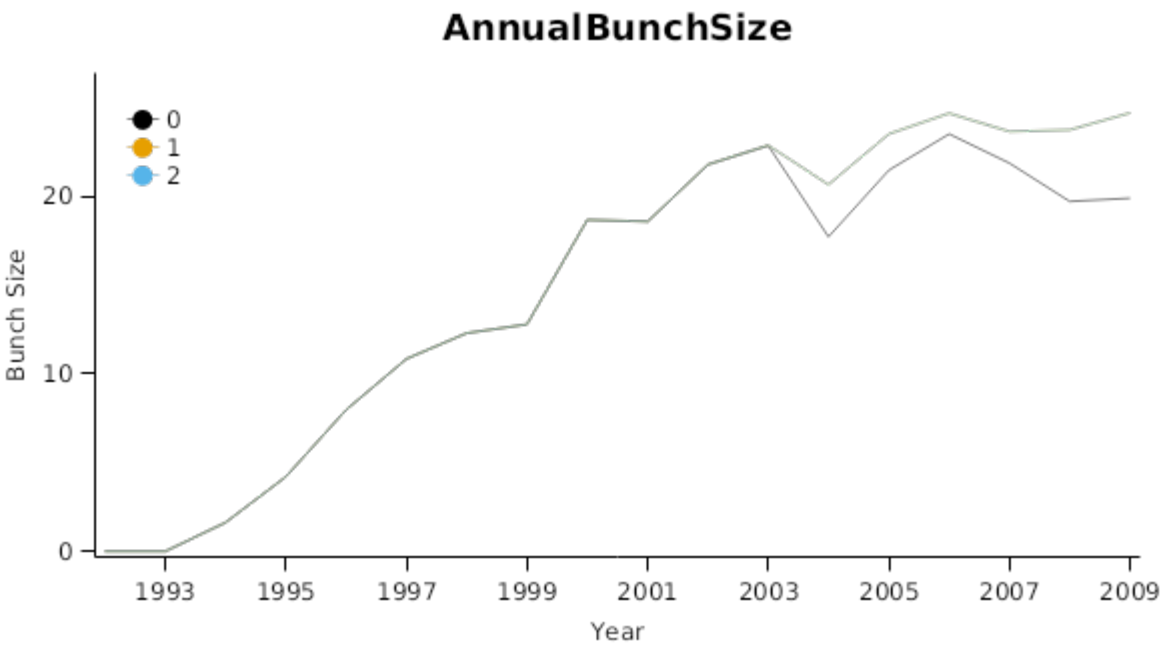


FrondProduction
0
1
2
Frond Production
40
30
1996
2001
2006
Year



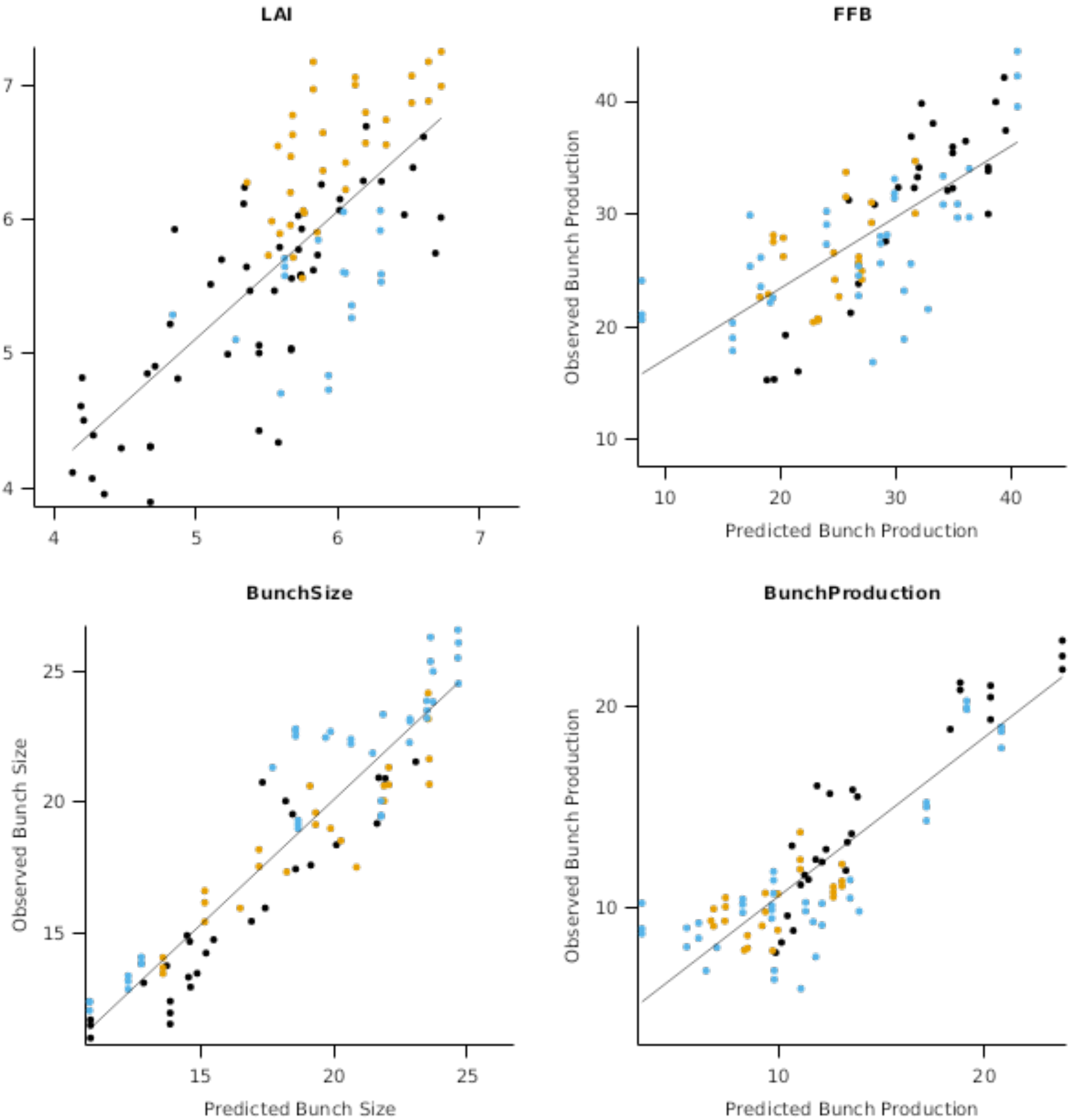
BunchProduction
0
1
2
Bunch Production
20
10
0
1993
1995
1997
1999
2001
2003
2005
2007
2009
Year





2.4 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 (Nitrogen)



3 References

Jones, C.A., Kiniry, J.R., Dyke, P.T., 1986. CERES-Maize: a simulation model of maize growth and development..