

Development and Application of Agricultural Irrigation and Nutrient Decision Support Model

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Development of preliminary citrus model for DSSAT called Treegro

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Development of Treegro: A Fruit Tree Model for DSSAT

INTRODUCTION

The simulation of agricultural crop plant growth is highly complex due to the interactions of biological functions, soil physical characteristics, and environmental factors (Jones and Luyten, 1998). These biological functions and soil physical characteristics make up the crop system and include photosynthesis, respiration, transpiration, biomass accumulation, soil water and nitrogen uptake, and nitrogen leaching. Environmental factors such as temperature, radiation, wind, humidity, rainfall, and irrigation influence these processes and are typically required as model inputs. Modeling these processes requires the estimation of many state variables over time through the use of non-linear functions and associated parameters and constants.

Due to the complexity of grower decision-making processes, researchers have developed computer based decision support systems (DSS). A DSS can provide information on management options based on local environmental conditions. These systems also provide a means to facilitate our understanding of complex plant, soil, and environmental interactions that are critical to decision makers. Frequently, information from simulation models has formed the foundation for these DSS.

Cropgro is a family of crop-specific models for the prediction of legume and vegetable crops (Hogenboom et al., 1992; Jones et al., 1991; Wagner-Riddle et al., 1997). These are process-oriented models that simulate vegetative growth and reproductive development. The models predict dry matter growth (Shen et al., 1998), crop development (Batchelor et al., 1994; Batchelor et al., 1997; Piper et al., 1996) and final yield (Batchelor et al., 1996; Heinemann et al., 2000) for a range of agronomic crops.

Inputs are daily weather data, soil profile characteristics, and crop management conditions (Gijsman et al., 2002). Crop and soil water status (Hoogenboom et al., 1994; Gabrielle et al., 1995; Xie et al., 2001), and nitrogen and carbon balances (Gabrielle and Kengni, 1996; Quemada and Cabrera, 1995; Sexton et al., 1998) are modeled. These models, as well as others such as CERES, have been combined into the DSSAT Decision Support System for Agrotechnology Transfer software (DSSAT) (Hoogenboom et al., 1994; and Jones et al., 1998).

Growth rates estimated by many model parameters can change over time due to growth stage of the plant and/or environmental conditions. Changes in some processes can be in response to a change in a state variable. An example of this would be the effect of leaf-nitrogen concentration on photosynthesis. These state variables are themselves influenced by the effects of soil physical characteristics, rainfall, and irrigation on soil water content and nitrogen leaching.

Many models exist for determinate cereal, legume, and vegetable crops with relatively short life cycles. These models are currently being used for a number of purposes such as current year management of irrigation, nutrition, and pests. Yield forecasting and long-term effects of crop sequencing can be simulated under given management inputs and weather conditions. Modeling of perennial fruit crops with no dormancy period and crops spanning more than one calendar year is particularly difficult. An example of such a fruit crop is citrus. Subtropical in nature, citrus goes through an annual winter quiescent period of reduced vegetative growth, but there is no true dormancy due to environmental conditions (Turrell et al., 1969). Citrus can grow vegetatively year round during warm, wet winters under Florida conditions. This is

particularly true during early growth years, and if fertilized too late in the growing season.

All Citrus cultivars bloom for a period of three to six weeks, from mid February to late March under Florida conditions. The time required for fruit maturity is species and cultivar specific. Grapefruit (*Citrus paradisi* Macf.) cultivars mature as early as September, but can be harvested well into the next calendar year. Mandarins (*C. reticulata* L.) and mandarin hybrids mature from October to January. Sweet orange (*C. sinensis* L. Osbeck) cultivars mature from November to the following April and can be harvested as late as June (16 months after bloom). Citrus trees typically undergo one to two spring and one or more summer vegetative flushes, and one late spring fruit drop regardless the timing of fruit maturity (Mooney and Richardson, 1992).

In three studies (Cameron and Appleman, 1936; Cameron and compton, 1945; and Feignbaum, 1987), 8-9, and 20 year old 'Valencia' orange trees were harvested and used for growth analysis. These studies showed that leaves were approximately 17% of the tree total dry matter and contained 45% of total tree N. Twigs, and branches and trunk totaled approximately 65% and 35% dry matter and total N, respectively. Roots made up the remaining 18% of dry matter and 20% of total tree N.

Increased tree size and yield have been related to root system depth and fibrous root quantity. The depth of root of 'Orlando' tangelo trees on 10 rootstocks growing in deep, sandy soils was significantly correlated with changes in tree height (Castle and Krezdorn, 1975). Ford (1954, 1964, 1968, 1969, and 1972) conducted many studies of citrus trees in poorly drained spodosols of Florida and concluded that fibrous root quantity was closely related to tree size. Citrus root densities decrease with distance from

the tree trunk and depth. Elezaby (1989) and Menocal-Barberena (2000) reported that 40-42% of fibrous roots were located between 0 and 30 cm from the soil surface, and 9-14% in each 30 cm increment to 1.8 m in deep well drained soils. Fibrous root length densities range from 0.5 cm cm⁻³ for 'Swingle' citrumelo roots [*C. paradisi* Macf. x *P. trifoliata* (L.) Raf] to 2.0 cm cm⁻³ for trifoliate orange (*P. trifoliata* (L.) Raf) (Eissenstat, 1991).

Wallace et al. (1945) estimated that citrus leaves function on the tree for a period of up to 18 to 24 months before senescence. They found an average of 18.1 kg tree⁻¹ dry matter loss per year from mature 'Valencia' orange trees grown in California. Dry matter losses were 9.1, 4.0, and 4.9 kg tree⁻¹ for leaves, twigs and branches. In the same study, dry matter additions from leaves and twigs were estimated at 10.4 kg tree⁻¹, resulting in nearly zero net seasonal dry matter change for mature trees. Seasonal leaf and stem N concentrations have been reported to fluctuate in very narrow ranges (Feignbaum, 1987; Wutscher et al., 1987). Lowest values are during the months of April to June and highest values from December to February. Legaz et al. (1982) suggested that the N concentration in the spring leaves decreased after flowering due to new leaf tissue becoming an N source for the developing fruit. Kato et al (1982) found that total N contents decreased in both bark and wood during the vegetative growth flushes of 21 year-old Satsuma mandarins. Greatest decreases in N were found in parts with higher levels of N (ie. leaves, shoots, and fine roots). They also concluded that the trunk and large roots are main nitrogen reservoirs for new shoot development. The N was reserved mainly as protein, free proline, arginine, and asparagines. Protein decreased in all plant

parts in proportion to total N in the plant part. Poline decreased mainly in the leaves and bark, arginine in wood of shoots and asparagines in bark of fine roots.

The objective of this project was to simulate citrus production by altering model parameters using data from literature sources. Parameters for the Cropgro tomato model were used as a starting point. Characteristics of the 'Hamlin' cultivar of sweet orange were used for simulation citrus and development of Treegro. This cultivar was chosen because it is one of the two most highly grown sweet orange cultivars in Florida, and its fruit matures within one calendar year of flowering. Treegro is designed to be a series of perennial tree fruit crop simulation model for various fruit crops.

Crop Simulation

The Cropgro parameters for tomato in DSSAT version 4.0 were modified during this project. This crop was chosen due to its indeterminate nature. Model parameters affecting crop phenology, dry matter partitioning, tissue nitrogen concentration, and biomass accumulation were estimated using information obtained from the literature.

Simulations were run using three fertilizer treatments. Each treatment used the same sandy Grossarenic Paleudult soil (Millhopper fine sand), and was automatically irrigated at 66 percent available water to a depth of 90 cm. The soil has drained upper limits (DUL) of 0.086 to $0.076 \text{ m}^3 \text{ cm}^{-3}$ and lower limits (LL) of 0.023 to $0.020 \text{ m}^3 \text{ cm}^{-3}$ to a depth of 1.2 m. These values are similar to those of the "Ridge" citrus production area of central Florida. Daily weather data collected at Gainesville, Florida for the 10-year period of 1978 through 1987 were used for simulations under varying seasonal weather conditions. Daily photosynthesis estimations were made using the hedgerow and

leaf options of Cropgro. Fertilizer applications were 40, 60 and 80 kg N ha⁻¹. Each fertilizer level was applied in 3 applications on 15 March, 15 May, and 15 September.

Cropgro utilizes parameters in three files (Species, Cultivar, and Ecotype) during simulations. The Cultivar file stores the number of photothermal days between phonological events, leaf size and photosynthesis, and fruit development parameters for specific crop cultivars. The Ecotype file contains parameters that modify physiological quantities and phenological timing. Parameters in these two files were changed until average seasonal phenology over the 10 years of simulation reflected values in the literature. The Species file contains parameters specific to the crop for photosynthesis, respiration, seed composition, C and N mining, vegetative partitioning, leaf growth, leaf senescence, root uptake and senescence, and fruit growth. Parameters within this file were changed to simulate citrus biomass and N partitioning, and seasonal biomass and N accumulation. Photosynthesis (PARMAX and PTHMAX), C and N mining (CMOBBMX, CADSTF, NMOBBMX, NVSMOB, ALPHL, ALPHR, and ALPHSH), Vegetative partitioning (FRSTMF, and FRLFF), Leaf senescence (SEN RTE, TCMP, and SENPOR), and root N uptake factors (RTNO₃, and RTNH₄) were optimized during repeated simulations. Optimization criteria were maximum leaf N concentration, and fruit dry weight at harvest. The citrus trees simulated were mature trees that vary little in leaf and stem dry weight at harvest from season to season (Feigenbaum, 1987; Wutscher et al., 1987) thus, the above criteria were used while maintaining leaf and stem biomass at harvest within +/- 20% of initial conditions.

Phenology

Cropgro was developed to simulate the growth of single relatively short-term crops or the rotation of several crops annually. Such crops can be initialized as either sown seeds or transplants but not as established mature plants. To simulate mature citrus trees, initial conditions were set in the experiment file to start the simulation as a transplant. A "planting date" of 1 January was used as a simulation start date. A value of 10 photothermal days was used to simulate the quiescent period between the beginning of the calendar year and first flower (EM-FL). Three and eight photothermal days were used for the period between first flower and first fruit (FL-SH), and first flower and first seed (FL-SD), respectively. To extend the growing season to the end of the calendar year, 250 photothermal days were used for the period of first seed to physiological maturity (SD-PM). While citrus trees typically have two or more vegetative growth flushes per year; they are capable of adding leaves past harvest if weather conditions are conducive. Therefore, a value of 300 photothermal days for the period of first flower to last leaf (FL-LF) was used. Citrus fruits increase linearly in dry weight over the course of the fruit season. For this reason, a period of 60 photothermal days was used for fruit-fill (PODUR) and 200 for seed-fill (SFDUR) durations. 'Hamlin' oranges are typically harvested in mid to late December of each year; therefore, a harvest date of 15 December was used to end the simulation.

Biomass and N Partitioning

An average total dry matter of $98.4 \text{ kg tree}^{-1}$ was used in these simulations. Tree spacing for this grove was 3.05 m in-row and 6.1 m between rows resulting in 538 trees ha^{-1} . Total biomass would be approximately $53,000 \text{ kg ha}^{-1}$, however, the Cropgro model

was limited to total initial dry matter weight of less than 10,000 kg ha⁻¹. Formats in various files were changed to accommodate the large biomass of mature citrus trees.

The initial distribution of total biomass was based on mature citrus trees from Cameron and Appleman (1936), Cameron and Compton (1945), and Feigenbaum (1987). In these studies average distribution of leaf, stem and root dry weight were 17, 65, and 18 percent, respectively. Partitioning of initial leaf, stem, and root dry matter weights were preformed using the YLEAF and YSETM parameters of the species file. These parameters were set at 0.2 for leaves, 0.6 for stems, resulting in 20% of biomass to each of leaves and roots and 60% to stems. Leaf area per leaf mass parameter (SIZREF) was reduced from 300 cm² g⁻¹ for tomato to 200 cm² g⁻¹ reflecting leaf morphology under Florida growing conditions (Morgan, unpublished data).

The model assumes root densities to be uniform from the soil surface to the initial root depth. This, however, is not a valid assumption for mature citrus. Code within the root growth routine was added to distribute root density proportionally to the ratio of root growth factor (SRGF) for a given layer to total root growth factor over the initial rooting depth (RTDEPI). The root growth factor is an estimate of favorable conditions for each soil layer and is present in the soil characteristics file. Rooting depth for this study was set at 90cm.

These changes resulted in the accumulation of leaf and stem tissue dry matter in late April, and June through September and essentially mimicked the biomass accumulation observed under field conditions. Specific leaf area value under leaf growth parameters was changed to 275 (cm² g⁻¹) to reflect reported values. This change was small and appeared to have little effect on leaf biomass increase.

Seasonal Biomass and N Accumulation

Initial tissue nitrogen concentrations were estimated using research reports by Cameron and Appleman (1936), and Cameron and Compton (1945). The initial values were changed to 0.16, 0.05, and 0.05 for PROLFI, PROSTI, and PRORTI, respectively. This change resulted in initial tissue nitrogen concentrations of 2.64, 0.74, and 1.0% for leaves, stems, and roots respectively. Root length per unit mass parameter (RFACI) was set at 500 (Morgan, unpublished data) compared to the maximum value 9999 used for tomato. Leaf and root senescence rate after fruit set (SENRT2 and RTSEN, respectively) were changed to 0.0 due to the perennial nature of citrus.

Parameter Optimization

Parameters changed during this project in the Species, and Cultivar and Ecology files are provided in Tables 1 and 2, respectively. The photosynthesis parameters (PARMAX and PTHMAX) were similar to parameters used in tomatoes and reported by Huang et al. (1992). Optimized C and N mobilization parameters (MOBMX, NMOBMX, and NVSMOB) for citrus were much lower than used for tomato, while carbohydrate allocation parameters were mixed, with higher values for stem tissue prior to fruit set (CADPR1) and lower values for existing stem tissue after initiation of fruit development (CADSTF), and newly formed leaves and roots (ALPHL and ALPHR). Dry matter increase values for leaves and stems (FRSTM and FRLFF) were opposite those used for tomato with more dry matter accumulation in leaves than stems. Leaf senescence factors for grams of leaf tissue senesced per gram of protein mobilized (SEN RTE) and light compensation point (TCMP) were much reduced from values used for tomato. Likewise, daily leaf abscission late in the season (SENPOR) was reduced for the citrus simulation.

Maximum rate of root NO₃ and NH₄ uptake per unit root length (RTNO₃ and RTNH₄) parameters were one-third those used for tomato.

Phenology

Mean date of first flower was 20 February over the 10 years of simulation. Average date for the appearance of first fruit, and first seed were 1 March and 18 March, respectively. These dates are approximately correct for typical citrus production under Florida conditions. Large increases in leaf and stem biomass starting in the spring of the year and continuing through the summer months are typical, depending on environmental conditions. Leaf, stem, root and fruit biomass accumulation over the season using weather data from 1987 are illustrated in figures 1, 2, 3, and 4 respectively. Vegetative growth flushes occurred on 14 Feb, 23 March, 19 April, 3 June, 30 July, 25 August, and 5 October. These were followed by biomass losses, leaf losses were particularly high after the 19 April and 5 October flushes. These dates and relative values were typical for the 10-year simulation period.

Seasonal Biomass and N Accumulation

Mean simulated leaf tissue biomass dry weights at harvest (n=10) were similar or slightly lower than initial conditions for all treatments (Table 3). The ranges of leaf biomass at harvest were 9910 to 12785, 9652 to 11299, and 9536 to 10926 kg ha⁻¹ for the 120, 180 and 240 kg N ha⁻¹ treatments respectively. Leaf N concentration decreased through the spring and was lowest between 5 May and 27 September for all treatments. Increase in N content of developing fruit and leaves increases greatly during this time period. Reduction in leaf tissue nitrogen concentration due to mobilization of nitrogen from leaves to support fruit production did not lower leaf nitrogen values below

acceptable values under typical N application rates. Simulated mean minimum and at-harvest leaf N concentrations were 2.13 and 2.19, 2.19 and 2.26, and 2.23 and 2.31 for the 120, 180 and 240 kg N ha⁻¹ treatments respectively. These values are similar to seasonal leaf N values reported by Wutscher et al. (1987).

Mean stem and root biomass gain at the end-of-the season was proportional to total N application treatment (Table 3). Stem N concentrations increased throughout the season for all treatments. Mean stem N concentrations at harvest were 0.89, 0.96, and 1.00% for the 120, 180, and 240 kg N ha⁻¹ treatments respectively or a seasonal increase of 0.15, 0.22, and 0.26% respectively. These values are greater than those reported by Wutscher (1987). Mean root biomass gain over the season for the 120, 180 and 240 kg ha⁻¹ treatments were 11.5, 12.9, and 12.7 % respectively. Root length densities changed little over the season with the exception of an increase early in the season followed by a decline at the 0-5 cm depth. Mean fruit biomass at harvest was greatest for the 180 and 240 kg N ha⁻¹ treatment with a large season to season variation within fertilizer treatments (Table 3). Sweet orange fruit production ranges from 5 to 10 Mg DW ha⁻¹. Mean fruit dry weights for the 10 years of simulation were 8.97, 9.99, and 9.98 Mg ha⁻¹ for the 120, 180, and 240 kg ha⁻¹ (Table 3). The simulated range of fruit yield well within average production values for citrus trees under adequate nutrition.

Leaf loss of approximately 50 to 66 percent can be expected in a given season. Leaf and stem biomass loss through the growing season exhibited similar trends with greater dry weight loss with lower total N applied. Seasonal leaf and stem biomass losses for the 180 kg ha⁻¹ treatment ranged from 1393 to 2853 kg ha⁻¹ (mean = 1879 kg ha⁻¹) and a range of 348 to 713 kg ha⁻¹ (mean = 470 kg ha⁻¹) respectively. The mean leaf biomass

loss was equal to 17.1% of initial biomass and 38.4% of the value reported by Wallace et al. (1945).

Nitrogen Balance

Net gain in biomass at harvest was greatest for the 180 kg N ha⁻¹ treatment (Table 4). Net seasonal gain in total N was greatest for the 240 kg N ha⁻¹ treatment due to the higher N concentration levels of all tissues at harvest for this treatment. Nitrogen use efficiency (NUE) was greatest for the 120 kg N ha⁻¹ treatment at 99%. The 160 and 240 kg N ha⁻¹ treatments had similar NUE of 95 and 96% respectively. These values are high compared to the 57 to 85% reported by Dasberg (1987) and Syvertsen et al. (1993,1996). However, Syvertsen et al. (1996) reported leaching losses from lysimeters of only 2 to 9%, and did not attempt to account for N accumulated in the tree biomass.

CONCLUSION

Cropgro has been proven to be sufficiently adaptive to simulate a number of important aspects of citrus growth and production from flowering to harvest with a few minor code changes. Two limitations of Cropgro was total biomass of less than 10,000 kg ha⁻¹ and uniform root distribution. Code changes allowing a total biomass of 100,000 kg ha⁻¹ and the ability to vary initial root mass by depth results in more realistic biomass estimates. Soil water and N uptake patterns were comparable to those found in the literature. Timing of flowering, fruit development, and growth flushes were similar to those under Florida production conditions. Leaf, stem, root and fruit biomass value at harvest over a 10-year simulation were within the range of values found in the literature.

However, simulated leaf biomass losses were lower and end-of-season stem N values were greater than those found in field experiments. This illustrates that a number

of modifications are needed to adequately simulate citrus tree growth and yield over a number of seasons. These modifications to Cropgro were used to develop the first of a series of models for simulation of perennial tree crops called Treegro. The addition of functions to divide stem biomass into size categories based on stem diameter and redistribution of N from leaves, stems, and roots at different rates should allow for simulation of increased leaf production. This should allow for increased senesced leaf biomass and fruit yield improving agreement with values reported in the literature. The addition of the ability to simulate the increase in biomass of two fruit crops simultaneously will allow for the simulation of citrus cultivars with fruit seasons greater than 12 months. Simulation of irrigation and fertilizer applications under the tree canopy only will provide the ability to simulate drip irrigation and fertigation management of citrus production.

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Table 1.
Changes made to the Species file in DSSAT.

Variable	Discription	Tomato	Citrus
PARMAX	Daily canopy photosynthetic assimilation	25.91	27.00
PHTMAX	Asymptote of assimilation response	75.54	75.50
PROLFI	Maximum leaf protein concentration	0.370	0.165
PROLFG	Normal leaf protein concentration	0.220	0.165
PROLFF	Final leaf protein concentration	0.110	0.165
PROSTI	Maximum stem protein concentration	0.256	0.046
PROSTG	Normal stem protein concentration	0.156	0.046
PROSTF	Final stem protein concentration	0.094	0.046
PRORTI	Maximum root protein concentration	0.144	0.064
PRORTG	Normal root protein concentration	0.119	0.064
PRORTF	Final root protein concentration	0.060	0.064
CMOBMX	Maximum carbohydrate mobilization	0.015	0.003
CADSTF	Fraction of carbohydrate reserve to stem	0.70	0.15
CADPR1	Stem carbohydrate allocation before fruit load	0.25	0.50
NMOBMX	Maximum protein mobilization	0.080	0.001
NVSMOB	Max. carbohydrate mobilization from Vegetative	0.40	0.06
ALPHL	Fraction on new leaf available carbohydrate	0.04	0.02
ALPHR	Fraction of new root available carbohydrate	0.04	0.02
ALPHSH	Fraction of new fruit available carbohydrate	0.08	0.02
YLEAF values	Dry matter partitioning to leaf by growth stage	0.37-0.52	0.20
YSTEM values	Dry matter partitioning to stem by growth stage	0.27-0.54	0.60
PORPT	Stem mass abscised with senesced leaf mass	0.21	0.25
FRSTMF	Fraction of dry matter growth to stem at final stage	0.45	0.30
FRLFF	Fraction of dry matter growth to leaf at final stage	0.30	0.70
SLAREF	Specific leaf area under optimum conditions	245	275
SIZREF	Leaf area per leaf	300	200
SEN RTE	Leaf mass loss per gram protein mobilized	1.0	0.5
SENRT2	Rate of leaf abscission after physiological maturity	0.02	0.00
FREEZ1	Temperature below which leaves are killed	-2.22	-5.0
FREEZ2	Temperature below which simulation stops	-5.0	-8.0
TCMP	Light compensation point for leaf senescence	50.0	15.0
SENPOR	Daily fraction of leaf abscission by growth stage	0-0.16	0-0.01
RTDEPI	Initial rooting depth	10	90
RFACI	Root length per unit mass	9999	500
RTSEN	Root senescence rate after maturity	0.015	0.00
YRTFAC	Max. rate of root depth progression per day	0.012	0.004
RTNO3	Maximum rate of root NO ₃ uptake/unit root length	0.012	0.004
RTNH4	Maximum rate of root NH ₄ uptake/unit root length	0.012	0.004

Table 2.
Changes to Cultivar and Ecotype files in DSSAT.

Variable	Discription	Tomato	Citrus
Cultivar file			
EM-FL	Time for emergence to flower	23.0	10.0
FL-SH	Time between first flower and first fruit	8.0	3.0
FL-SD	Time between first flower and first seed	17.0	8.0
SD-PM	Time between first seed and maturity	50.0	350
FL-LF	Time between first flower and last leaf	50.0	350
XFRT	Max. fraction of growth to allocated fruit	0.75	0.90
WTPSD	Max weight per seed	0.04	0.14
PODUR	Fruit fill duration	25	60
SFDUR	Seed fill duration	245	300
SDPDV	Average number of seed per fruit	300	50
Ecotype file			
JU-RO	Number of days for flower induction	12.0	0
PMO9	proportion of time from seed to maturity	0.45	0.05
LNGSH	Time required for growth of individual fruit	5.0	180
TRIFL	Max. ratio of seed weight to fruit weight	0.52	0.12

Table 3.

Initial conditions and mean simulated (n=10years) final dry weight and nitrogen distribution of citrus by tissue type and N application rate. Numbers in parentheses are standard deviations.

Simulated N Application	Leaves	Stems	Roots	Fruit
Biomass	-----kg DW ha ⁻¹ -----			
Initial Conditions	10600	31800	10600	0
120 kg N ha ⁻¹	10391 (577)	31808 (521)	11817 (302)	8965 (1799)
180 kg N ha ⁻¹	10155 (540)	31825 (518)	11964 (267)	9987 (1999)
240 kg N ha ⁻¹	10012 (478)	31871 (527)	11951 (269)	9977 (1943)
N Concentration	-----%-----			
Initial Conditions	2.65	0.74	1.00	0.00
120 kg N ha ⁻¹	2.26	0.89	1.10	0.49
180 kg N ha ⁻¹	2.32	0.96	1.16	0.46
240 kg N ha ⁻¹	2.36	1.00	1.22	0.47

Table 4.
Seasonal biomass and nitrogen balance by fertilizer treatment using simulation means
(n=10 years).

Simulated N Application	Initial Conditions	Harvest	Senesced Tissue	Seasonal Total	Net Change
Biomass (kg N ha ⁻¹)					
120 kg N ha ⁻¹	53000	63081	2495	65576	12576
180 kg N ha ⁻¹	53000	63931	2455	66386	13386
240 kg N ha ⁻¹	53000	63811	2404	66215	13215
N Content (kg N ha ⁻¹)					
120 kg N ha ⁻¹	621.2	692.8	47.6	740.4	119.2
180 kg N ha ⁻¹	621.2	725.6	46.8	772.4	151.2
240 kg N ha ⁻¹	621.2	748.5	46.3	794.8	173.6

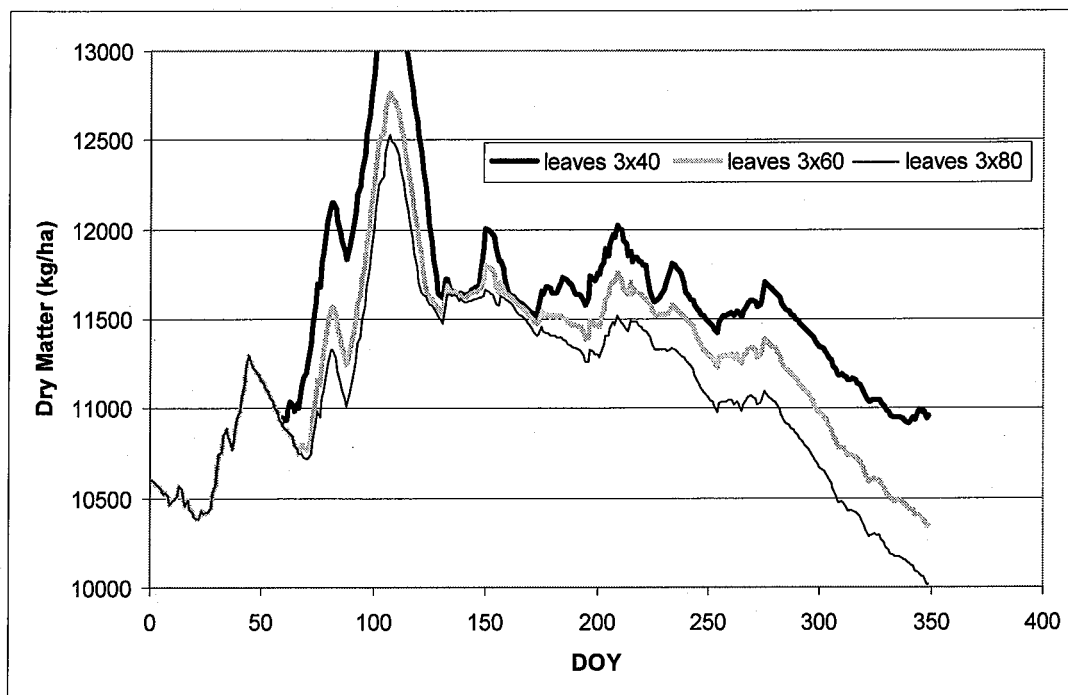


Figure 1. Simulated seasonal leaf biomass accumulation by nitrogen application rate.

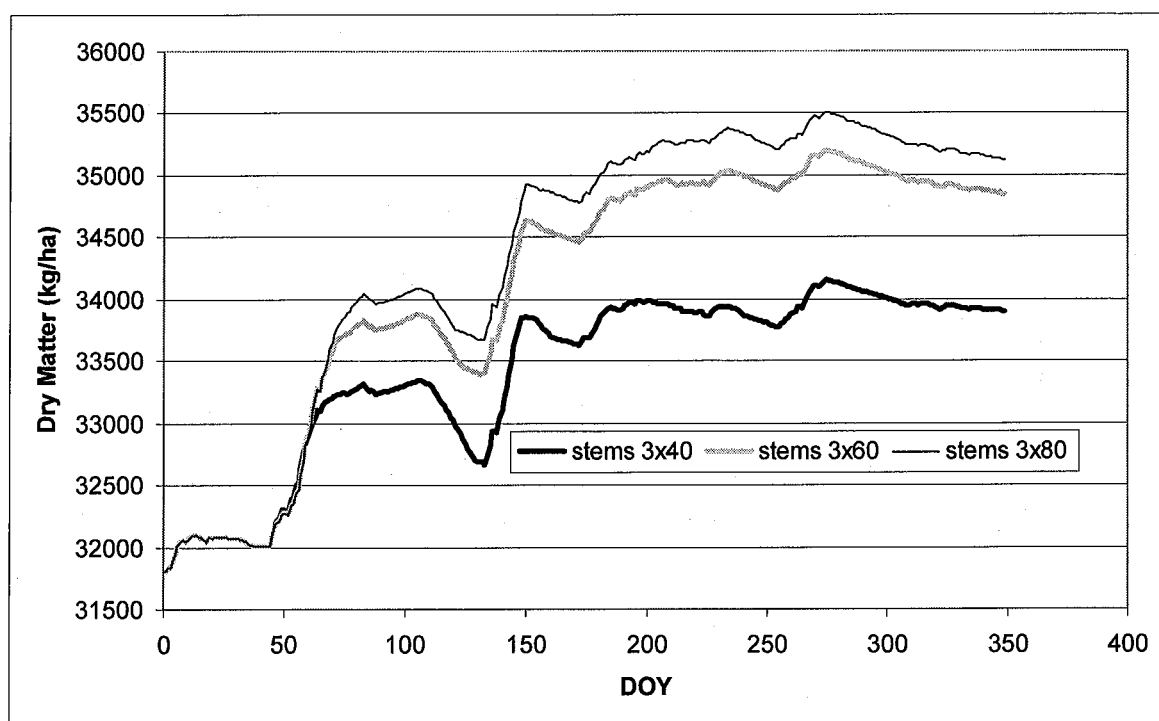


Figure 2. Simulated seasonal stem biomass accumulation by nitrogen application rate.

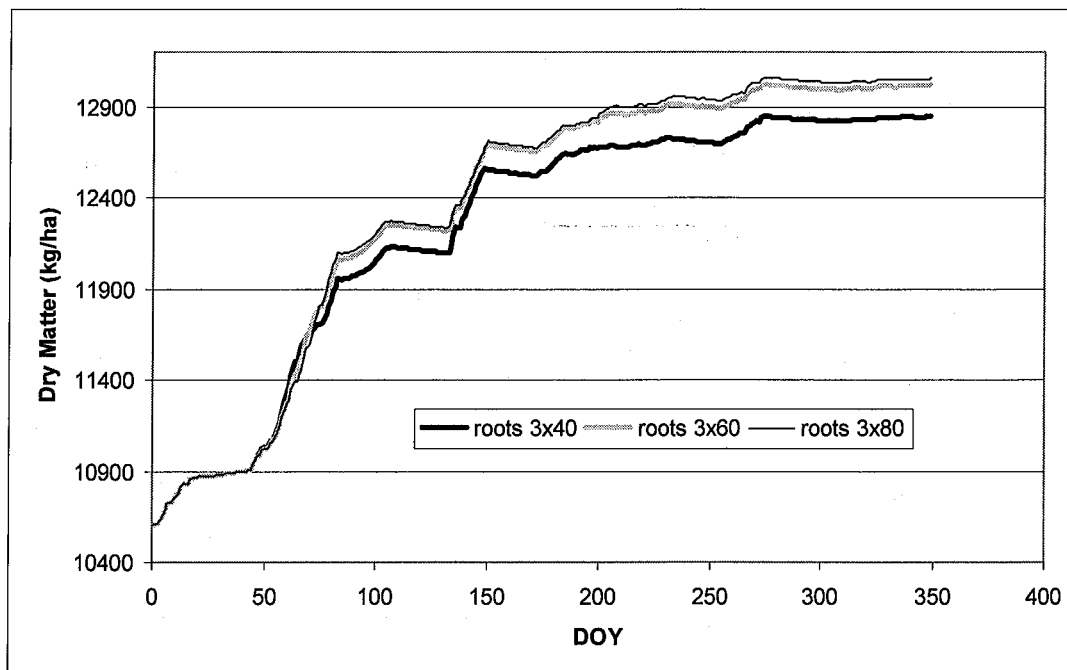


Figure 3. Simulated seasonal root biomass accumulation by nitrogen application rate.

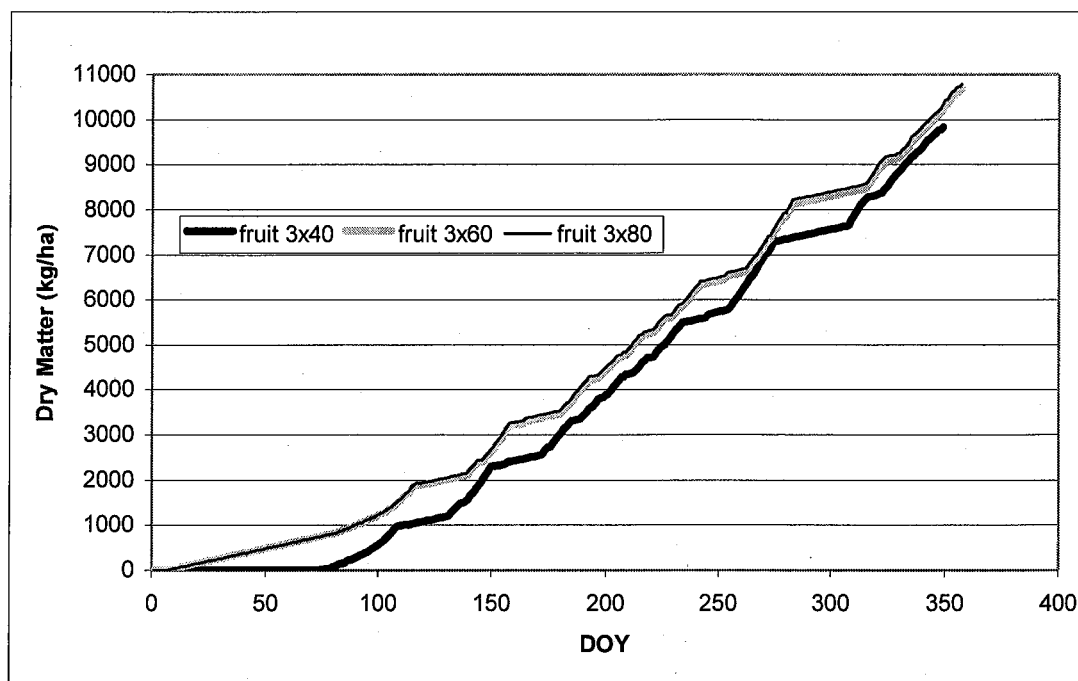


Figure 4. Simulated seasonal fruit biomass accumulation by nitrogen application rate.