Growing fruits and vegetables in Iowa: an experiment to validate SWAT plant growth parameters

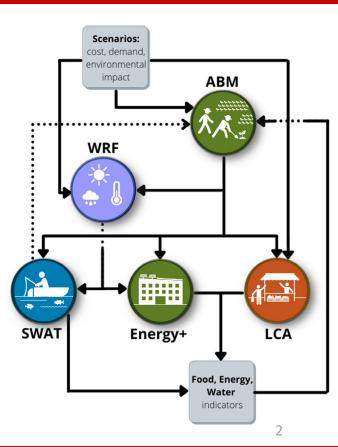
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Iowa Urban FEWS – OVERVIEW

The project is focused on developing sustainable food production systems in the Des Moines–West Des Moines, IA Metropolitan Statistical Area (DMMSA). Multiple models are being integrated (co-simulation approach) to evaluate the impact of converting cropland, peri-urban and/or urban landscapes to table food production, in DMMSA transboundary and urban subareas.

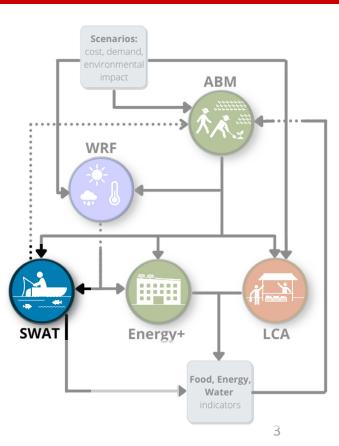






SWAT model within the Iowa UrbanFEWS:

- Quantify crop growth.
- Hydrological cycling.
- Nutrient and sediment cycling and transport for cropping systems and associated management practices.
- Simulate future climate and land use change scenarios and characterize streamflow, nutrient, sediment load conditions, and yields production.





- Why? The needed to address food insecurity and environmental impacts is still a challenge in the 21st century.
- How? Ecohydrological models are a key tool for accurate system representation and impact measurement.

Modeling tools can assist with identifying the best planting times and cultivation methods for each particular region and can evaluate the impact of food production on water and soil resources. Therefore, there has been an increasing interest in pursuing research focused on developing sustainable food production systems.



- > Conclusion
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The objective of this study was to validate crop growth parameters for 24* fruit/vegetable crop types in the SWAT model.

(*) apple, blueberries, broccoli, cabbage, carrots, cherries, collard greens, cucumber, dry beans, grapes, lettuce, kale, melon, onion, pears, potato, pumpkin, raspberries, spinach, squash, strawberries, sweet corn, sweet potato, and tomato.





Introduction

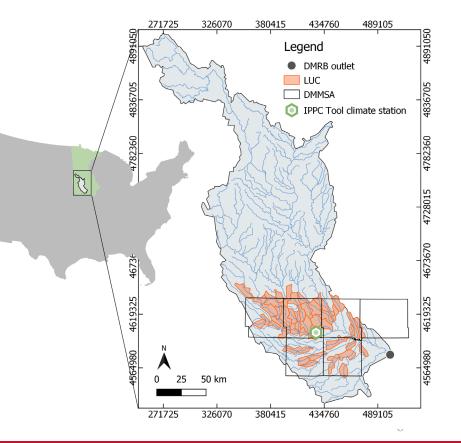
Methods > Results

Conclusion

STUDY AREA

Des Moines River Basin (DMRB) 31,892 km²

- Land use: soybean and corn fields representing together 70%.
- **Soil type**: Loamy Wisconsin Glacial Till (tile drainage represent 54%).
- Precipitation and evapotranspiration: 873 mm and 670 mm (annual average 1985-2018).





Introduction

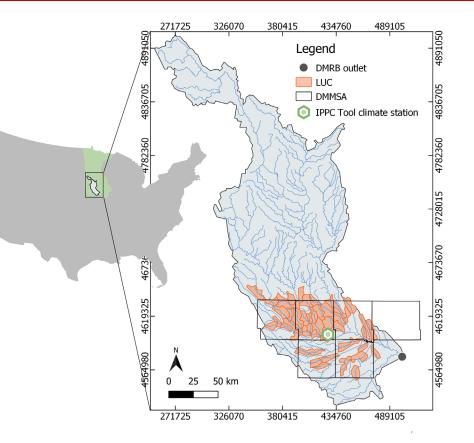
Methods > Results

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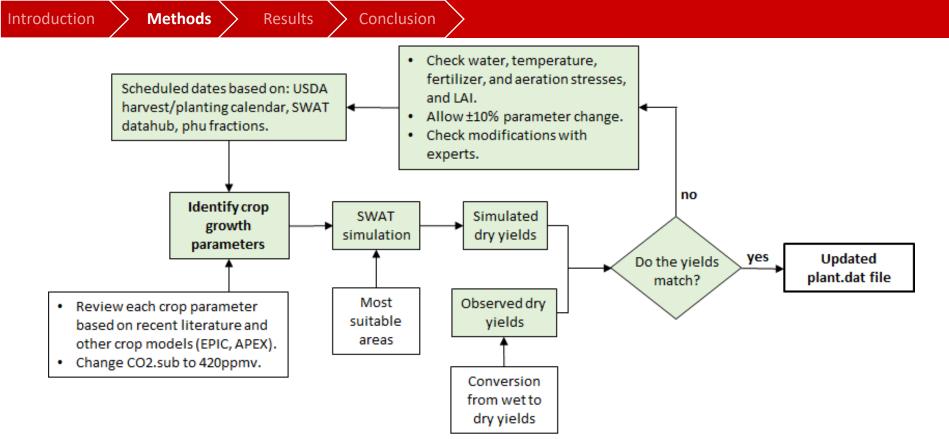
STUDY AREA

The Des Moines Metropolitan Statistical Area (DMMSA), which is the largest urban area in Iowa, served as approximate boundaries for choosing the areas to be replaced by fruits and vegetables due to:

- The focus of the Iowa UrbanFEWS project.
- Available data indicating areas suitable for growing fruits and vegetables.







Loop until the statistical coefficient of efficiency is reached



Methods

Results

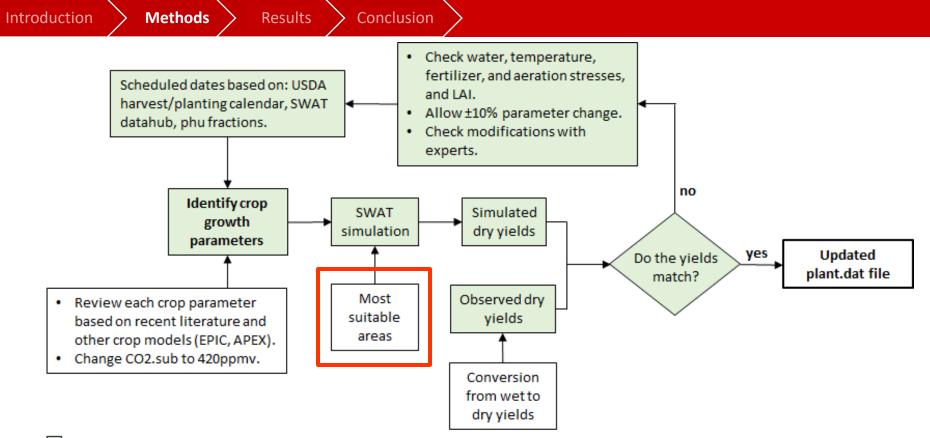
Observed yields

Average yield values for fruit and vegetable production in the state of Iowa are not collected by the United States Agricultural Census.

- National-scale FoodPrint Model that compiled average yields (2000 to 2010) from the United States Agricultural Census.
- Available Midwest yield values in combination with expert opinion.
- Fruit yields: national average yields were adjusted for Iowa production based on state Farm Service Agency (FSA) estimates in combination with input from two fruit crop specialists.

Crop type	lowa average yields (ton/ha)	Crop type	lowa average yields (ton/ha)
Apple	30.5	Lettuce	40.15
Blueberries	6.1	Melon	29.9
Broccoli	17.4	Onions	59.7
Cabbage	62.7	Pears	35.2
Carrots	62.7	Potatoes	45.2
Cherries	8.8	Pumpkin	35.9
Collard Greens	14.8	Raspberries	7.2
Sweet Corn	19.0	Spinach	18.8
Cucumber	20.1	Squash	21.9
Dry beans	2.0	Strawberries	58.7
Grapes	17.7	Sweet Potatoes	24.8
Kale	30.9	Tomatoes	90.3



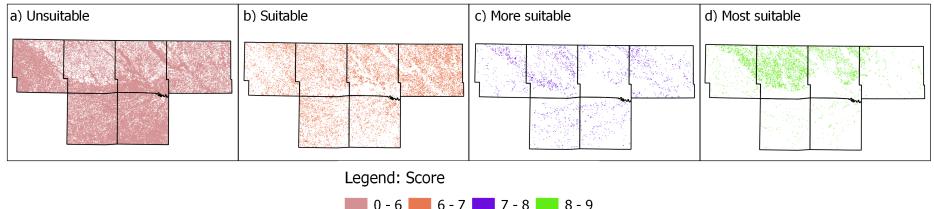


Loop until the statistical coefficient of efficiency is reached



Suitable Areas

Suitable soil classes for fruits and vegetable production based on a scoring system (0 to 9) of the biophysical features:

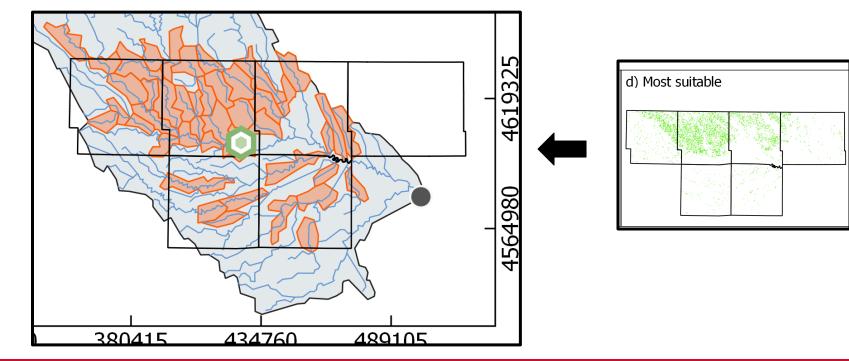


Five criteria with equal weighting:

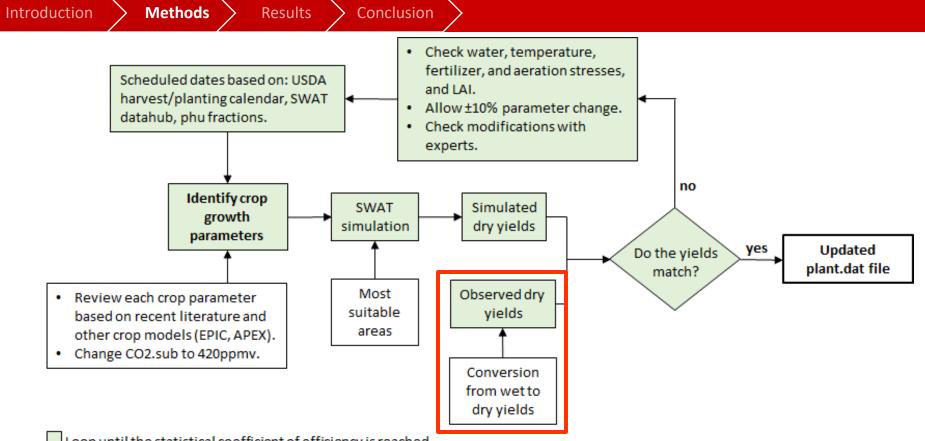
1) zoned agricultural, 2) no flooding, 3) well-drained soil drainage class, 4) slope of 0 – 5% and 5) soil texture of sandy loam, loam or silt loam.



Suitable soil classes for fruits and vegetable production based on a scoring system of the biophysical features and the distribution between subbasins.







Loop until the statistical coefficient of efficiency is reached



Methods > Results

Observed fresh to dry yields

Amount of water content of the crop types selected and the conversion from fresh to dry yields, to allow SWAT output comparison.

Crop variety	Water content (%)	Crop variety	Water content (%)
Apple	83	Lettuce	94
Blueberries	80	Melon	90
Broccoli	91	Onions	91
Cabbage	93	Pears	83
Carrots	88	Potatoes	79
Cherries	20	Pumpkin	92
Collard Greens	94	Raspberries	85
Sweet Corn	76	Spinach	92
Cucumber	96	Squash	91
Dry beans	0	Strawberries	92
Grapes	78	Sweet Potatoes	76
Kale	85	Tomatoes	94



The SWAT plant growth

Plant growth formulation is based on daily accumulation of heat units.

Plant development is dependent on temperature, water, nitrogen or phosphorus stress; operation management timing; the leaf area development; light interception; and conversion of intercepted light into biomass assuming a plant species-specific radiation-use efficiency.

The plant growth database contains 36 parameters:

Parameter	Parameter description					Parameter	Parameter description
SWAT code	Parameter description			Parameter		SWAT code	Parameter description
IDC	Land cover/plant classification	Parameter		SWAT code	Parameter description	CO2HI	Elevated CO2 concentration
BIO_E	Radiation use efficiency	SWAT code	Parameter description			BIOEHI	CO2HI biomass energy ratio
HVSTI	Harvest index	CHTMX	Maximum canopy height	PLTPFR(1)	Phosphorus uptake emergence	RSDCO_PL	Daily Residue Decomposition
BLAI	Max Potential Leaf Area Index	RDMX	Maximum root depth			ALAI_MIN	Minimum Leaf Area Index
FRGRW1	PHU fraction point 1	T_OPT	Optimal growth temperature	PLTPFR(2)	Phosphorus uptake midseason	BIO_LEAF	Biomass Fraction Leaf
LAIMX1	BLAI fraction point 1	T_BASE	Minimum growth temperature	PLTPFR(3)	Phosphorus uptake maturity	MAT_YRS	Tree Years Maturity
FRGRW2	PHU fraction point 2	_ CNYLD	Nitrogen in yield	WSYF	Minimum harvest index	BMX_TREES	Forest Maximum Biomass
LAIMX2	BLAI fraction point 2	CPYLD	Phosphorus in yield	USLE_C	Minimum C factor	EXT_COEF	Light Extinction Coefficient
DLAI	Growing season decline fraction	PLTNFR(1)	Nitrogen uptake emergence	GSI	Maximum stomatal conductance	BMDIEOFF	Biomass Dieoff Fraction
		PLTNFR(2)	Nitrogen uptake midseason				
		PLTNFR(3)	Nitrogen uptake maturity	VPDFR	Vapor pressure deficit		
	-			FRGMAX	Max Stomatal Conductance 2		
				WAVP	BIO_E decline		

Center for Agricultural and Rural Development

Introduction

Methods > Results

Conclusion

Heat Unit calculation

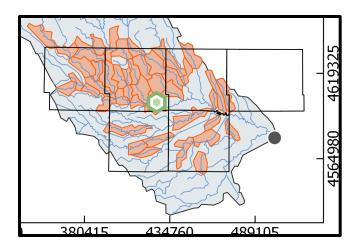
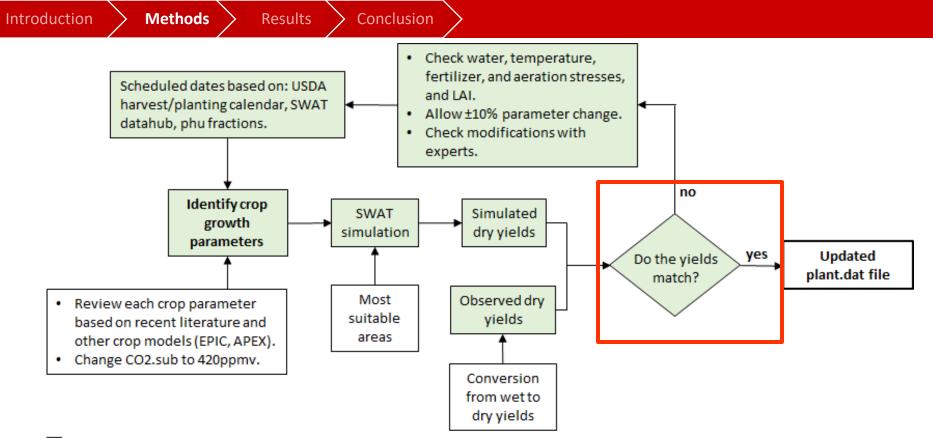


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Loop until the statistical coefficient of efficiency is reached



Statistical evaluation

To calculate the error:

$$Pbias = \left[\frac{\sum_{t=1}^{n} (X_i^{obs} - X_i^{sim})}{\sum_{t=1}^{n} (X_i^{obs})}\right] * 100$$

To calculate the acceptable range:

$$Ep = \left[\frac{1}{n}\sum_{s=1}^{n} (d_s^2)\right]^{\frac{1}{2}}$$

- The formulation is for grouping and propagating error.
- The potential error sources : observed yields (±25%), water content (±5%), epistemic errors (10%) and non-calibrated model errors (±20%).
- Total probable error is determined as a function of these four errors, and is **Ep = 34%**.



Observed fresh to dry yields

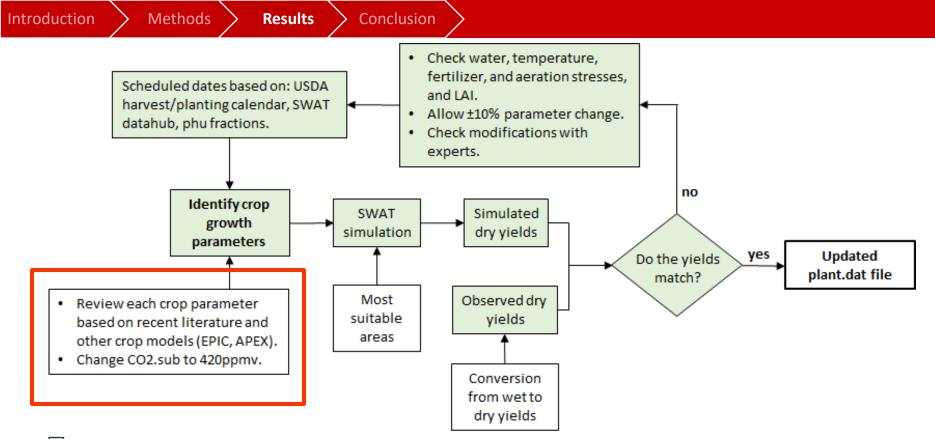
Crop variety	Dry yield (ton/ha)	Crop variety	Dry yield (ton/ha)
Apple	5.2	Lettuce	2.2
Blueberries	1.2	Melon	3.0
Broccoli	1.6	Onions	5.4
Cabbage	4.4	Pears	6.0
Carrots	7.5	Potatoes	9.5
Cherries	7.1	Pumpkin	2.9
Collard Greens	0.9	Raspberries	1.1
Sweet Corn	4.6	Spinach	1.5
Cucumber	0.8	Squash	2.1
Dry beans	1.7	Strawberries	4.7
Grapes	3.9	Sweet Potatoes	6.0
Kale	4.6	Tomatoes	5.4



Heat Unit calculation

Crop variety	Heat unit (HU) 10-year average	Crop variety	Heat unit (HU) 10-year average
Apple	1129	Lettuce	1603
Dry Beans	1756	Melon	2186
Blueberries	948	Onions	3827
Broccoli	551	Pears	1256
Cabbage	790	Potatoes	925
Carrots	2288	Pumpkin	898
Cherries	1533	Raspberries	1893
Collard greens	1453	Spinach	539
Sweet corn	2341	Squash	719
Cucumber	1505	Strawberries	1268
Grapes	1205	Sweet potatoes	989
Kale	1290	Tomatoes	1689





Loop until the statistical coefficient of efficiency is reached



Review each crop parameter based on recent literature, and **other models** (EPIC, APEX)

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Nitrogen uptake maturity 0.021 0.021 0.021 0.021	
Phosphorus uptake emergence 0.0084 0.0084 0.0084 0.0084 0.0084	
Phosphorus uptake midseason 0.0032 0.0032 0.0032 0.0032 0.0032	
Phosphorus uptake maturity 0.0019 0.0019 0.0019 0.0019 0.0019	
Minimum harvest index 0.01 0.01 0.8 0.8 0.8	
Minimum C factor 0.01	
Maximum stomatal conductance 0.003 0.0025 0.0122 0.0122 0.0122	
Vapor pressure deficit 4	
Max Stomatal Conductance 2 0.75	
BIO_E decline 8 0.5 0.5 0.5 0.5	
Elevated CO2 concentration 660 660.25 660.31 660.26 660.31	
CO2HI biomass energy ratio 25	
Daily Residue Decomposition 0.05	
Minimum Leaf Area Index 0 0.1 0.1 0.1 0.1	
Biomass Fraction Leaf 0	
Tree Years Maturity 0	
Forest Maximum Biomass 0	
Light Extinction Coefficient 0.65	
Biomass Dieoff Fraction 0.1	
Root Shoot Ratio Initial	
Root Shoot Ratio Final	

Review each crop parameter based on **recent literature**, **other models**, **similar phenology**.

Parameters		Squash	
	Apex (pumpkin)	suggested by Kim2020 (Straight Neck)	book
Radiation use efficiency	30	25	
Harvest index	0.5	0.64	
Max Potential Leaf Area Index	1.5		
PHU fraction point 1	0.15	0.73	
BLAI fraction point 1	0.01	0.2	
PHU fraction point 2	0.5	0.95	
BLAI fraction point 2	0.95	0.82	
Growing season decline fraction	0.6	0.75	
Maximum canopy height	0.8	0.55	
Maximum root depth	1.1		
Optimal growth temperature	35	25	
Minimum growth temperature	18	15	7.5
Nitrogen in yield	0.0117		
Phosphorus in yield	0.0011		
Nitrogen uptake emergence	0.025		
Nitrogen uptake midseason	0.015		
Nitrogen uptake maturity	0.01		
Phosphorus uptake emergence	0.0053		
Phosphorus uptake midseason	0.0025		
Phosphorus uptake maturity	0.0012		
Minimum harvest index	0.25		
Minimum C factor			
Maximum stomatal conductance	0.007		
Vapor pressure deficit			
Max Stomatal Conductance 2			
BIO_E decline	1		
Elevated CO2 concentration	660.41		
CO2HI biomass energy ratio			
Daily Residue Decomposition			
Minimum Leaf Area Index	1		
Biomass Fraction Leaf			
Tree Years Maturity			
Forest Maximum Biomass			
Light Extinction Coefficient			
Biomass Dieoff Fraction			
Root Shoot Ratio Initial			
Root Shoot Ratio Final			



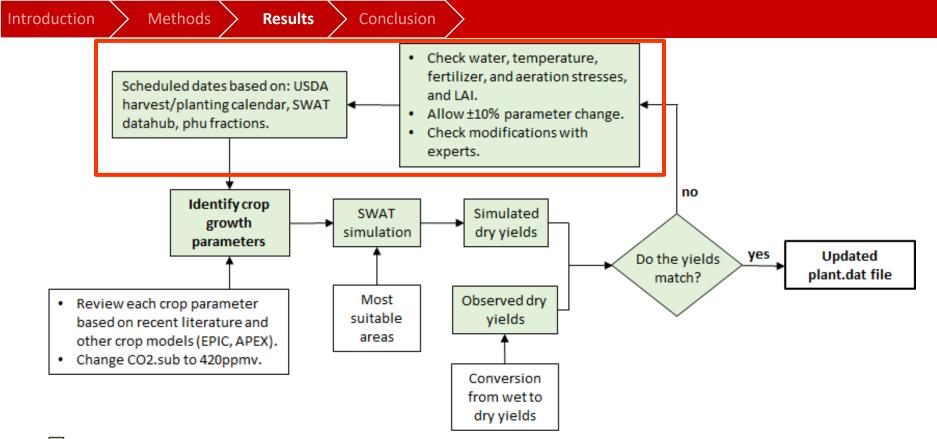


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Review each crop parameter based on **recent literature**, and other models (EPIC, APEX)

Parameters			Broccoli	
	swat	apex	epic	suggested by Kim2021
Radiation use efficiency	26	26	26	31
Harvest index	0.8	0.8	0.95	0.23
Max Potential Leaf Area Index	4.2	4.2	4.2	4.83
PHU fraction point 1	0.25	0.25	0.25	0.17
BLAI fraction point 1	0.23	0.23	0.23	0.18
PHU fraction point 2	0.4	0.4	0.4	0.67
BLAI fraction point 2	0.86	0.86	0.86	0.62
Growing season decline fraction	1	1	1	0.75
Maximum canopy height	0.5	1.2	1.2	
Maximum root depth	0.6	0.7	0.7	
Optimal growth temperature	18	24	24	16
Minimum growth temperature	4	4	4	0
Nitrogen in yield	0.0512	0.0512	0.0512	
Phosphorus in yield	0.0071	0.0071	0.0071	
Nitrogen uptake emergence	0.062	0.07	0.07	
Nitrogen uptake midseason	0.009	0.05	0.05	
Nitrogen uptake maturity	0.007	0.04	0.04	
Phosphorus uptake emergence	0.005	0.006	0.006	
Phosphorus uptake midseason	0.004	0.004	0.004	
Phosphorus uptake maturity	0.003	0.003	0.003	
Minimum harvest index	0.95	0.8	0.8	
Minimum C factor	0.2			
Maximum stomatal conductance	0.006	0.01	0.01	
Vapor pressure deficit	4			
Max Stomatal Conductance 2	0.75			
BIO_E decline	5	0.1	0.1	
Elevated CO2 concentration	660	660.41	660.41	
CO2HI biomass energy ratio	30			
Daily Residue Decomposition	0.05			
Minimum Leaf Area Index	0	0.1	0.1	
Biomass Fraction Leaf	0			
Tree Years Maturity	0			
Forest Maximum Biomass	0			
Light Extinction Coefficient	0.65			
Biomass Dieoff Fraction	0.1			
Root Shoot Ratio Initial				
Root Shoot Ratio Final				

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Loop until the statistical coefficient of efficiency is reached



Scheduled dates based on: **USDA harvest/planting calendar,** SWAT datahub, phu fractions

Season	Usual Plant	ting Dates	Usual Harvesting Dates			
and State	Begins	Ends	Begins	Most Active	Ends	
Summer						
CA	Apr 1	Jul 31	Aug 1	Sep 1 - Oct 31	Nov 30	
Faii IL	Jun 1	Jun 25	Sep 1	Oct 10 - Oct 25	Oct 31	
МІ	Jun 1	Jun 15	Sep 15	Oct 1 - Oct 31	Nov 15	
NY	May 25	Jun 30	Sep 10	Sep 20 - Oct 20	Oct 31	
ОН	May 20	Jun 10	Sep 1	Sep 7 - Oct 31	Oct 31	
РА	May 20	Jun 15	Sep 20	Oct 10 - Oct 31	Nov 10	

Pumpkins for Fresh Market and Processing (continued)

Scheduled dates based on: USDA harvest/planting calendar, SWAT datahub, **phu fractions**

crop/fe 🕶	Operati 🏋	phubase 👻	phuacc 🔽
COLG	HARV/KILL	·	0.62
COLG	HARV/KILL	0.42	0.6
COLG	HARV/KILL	0.45	0.67
COLG	HARV/KILL	0.44	0.6
COLG	HARV/KILL	0.44	0.6
COLG	HARV/KILL	0.45	0.64
COLG	HARV/KILL	0.46	0.65
COLG	HARV/KILL	0.48	0.69
COLG	HARV/KILL	0.39	0.59
COLG	HARV/KILL	0.43	0.61
COLG	HARV/KILL	0.47	0.66
COLG	HARV/KILL	0.42	0.63
COLG	HARV/KILL	0.55	0.71

Yield was too high, before adjustment the phuace was ~5 (used the 85 days of growing range)

Check water stress, **temp. stress**, fertilizer stress, aeration stress, **LAI**

Expert "changed the lai-phu curve points to the same as corn. the previous points for squash never allowed the lai to get close to the maximum lai (1.5). at 0.73 fraction of heat units to maturity the lai was 0.2* lai max. at 0.95 (* 1,700) the lai was 0.82 * lai max."

Parameters		Squash		
	Apex (pumpkin)	suggested by Kim2020 (Stra	ight Neck)	book
Radiation use efficiency	30		25	
Harvest index	0.5		0.64	
Max Potential Leaf Area Index	1.5			
PHU fraction point 1	0.15		0.73	
BLAI fraction point 1	0.01		0.2	
PHU fraction point 2	0.5		0.95	
BLAI fraction point 2	0.95		0.82	
Growing season decline fraction	0.6		0.75	
Maximum canopy height	0.8		0.55	
Maximum root depth	1.1			
Optimal growth temperature	35		25	
Minimum growth temperature	18		15	7.5
Nitrogen in yield	0.0117			
Phosphorus in yield	0.0011			
Nitrogen uptake emergence	0.025			
Nitrogen uptake midseason	0.015			
Nitrogen uptake maturity	0.01			
Phosphorus uptake emergence	0.0053			
Phosphorus uptake midseason	0.0025			
Phosphorus uptake maturity	0.0012			
Minimum harvest index	0.25			
Minimum C factor				
Maximum stomatal conductance	0.007			
Vapor pressure deficit				
Max Stomatal Conductance 2				
BIO_E decline	1			
Elevated CO2 concentration	660.41			
CO2HI biomass energy ratio				
Daily Residue Decomposition				
Minimum Leaf Area Index	1			
Biomass Fraction Leaf				
Tree Years Maturity				
Forest Maximum Biomass				
Light Extinction Coefficient				
Biomass Dieoff Fraction				
Root Shoot Ratio Initial				
Root Shoot Ratio Final				

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Allow 10% parameter change

Parameters Apple 10% + book swat apex epic 13.5 Radiation use efficiency 15 15 15 0.09 Harvest index 0.1 0.1 0.1 Max Potential Leaf Area Index Λ PHU fraction point 1 0.1 0.1 0.1 BLAI fraction point 1 0.15 0.15 0.15 0.5 0.5 0.5 PHU fraction point 2 **BLAI fraction point 2** 0.75 0.75 0.75 Growing season decline fraction 0.99 0.99 0.99 3.5 3.5 Maximum canopy height 3.5 Maximum root depth 1 20 22 22 Optimal growth temperature Minimum growth temperature 7 6 Nitrogen in vield 0.0019 0.0019 0.0019 Phosphorus in yield 0.0004 0.0004 0.0004 0.006 0.006 0.006 Nitrogen uptake emergence 0.002 0.002 0.002 Nitrogen uptake midseason 0.0015 0.0015 0.0015 Nitrogen uptake maturity 0.0007 0.0007 Phosphorus uptake emergence 0.0007 Phosphorus uptake midseason 0.0004 0.0004 0.0004 0.0003 Phosphorus uptake maturity 0.0003 0.0003 0.05 Minimum harvest index 0.05 0.05 Minimum C factor 0.001 Maximum stomatal conductance 0.007 0.007 0.007 Vapor pressure deficit 0.75 Max Stomatal Conductance 2 BIO E decline 660 660 Elevated CO2 concentration 660 20 CO2HI biomass energy ratio 0.05 Daily Residue Decomposition Minimum Leaf Area Index 0.75 0.3 **Biomass Fraction Leaf** 10 Tree Years Maturity Forest Maximum Biomass 500 Light Extinction Coefficient 0.65 **Biomass Dieoff Fraction** 0.1

Root Shoot Ratio Initial

Root Shoot Ratio Final

→10%

Edible Horticultural Crops book

Different values for Pear Edible Horticultural Crops book

Final parameters example

Сгор	IDC ¹	Primary model data set source	Modified plant parameters based on model testing and other data sources ²
Apple	7	SWAT	BIO_E ([85] and ±10% change), HVSTI (±10% change), T_OPT (APEX & EPIC), T_BASE [85,87]
Blueberry	6	APEX	WSYF, WAVP, HVSTI (modeling team expertise), T_OPT & T_BASE [85]
Broccoli	5	SWAT	BIO_E, HVSTI, BLAI, FRGRW1, FRGRW2, LAIMX1, LAIMX2, DLAI, T_OPT, T_BASE and WSYF ([93] and modeling team expertise)
Cabbage	5	SWAT	BIO_E, FRGRW1, FRGRW2, LAIMX1, LAIMX2, DLAI, CHTMX, T_OPT, T_BASE and WSYF ([94] and modeling team expertise)
Carrot	4	SWAT	BIO_E, BLAI, WSYF (±10% change); HVSTI [95] & T_BASE [85]
Cherry	7	SWAT ³	T_OPT & T_BASE [85]
Collard greens	5	APEX	No further modifications

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Simulated yields



Crops	Yield (ton/ha)			Crops	Yield (ton/ha)		
	Observed	Simulated	Pbias (%)	Crops	Observed	Simulated	Pbias (%)
Apple	5.2	6.7	29.3	Lettuce	2.2	1.6	-25.6
Blueberries	1.2	1.0	-16.6	Melon	3.0	2.2	-25.9
Broccoli	1.6	2.0	24.6	Onions	5.4	7.1	32.9
Cabbage	4.4	4.0	-8.9	Pears	6.0	5.9	-0.1
Carrots	7.5	9.7	29.6	Potatoes	9.5	7.3	-23.6
Cherries	7.1	8.6	21.2	Pumpkin	2.9	2.2	-24.8
Collard greens	0.9	1.2	33.1	Raspberries	1.1	1.8	8.1
Sweet corn	4.6	5.8	26.1	Spinach	1.5	1.8	21.3
Cucumber	0.8	0.7	-12.3	Squash	2.1	2.6	23.5
Dry beans	1.7	1.4	-21.1	Strawberries	4.7	4.5	-3.7
Grapes	3.9	3.3	-14.1	Sweet potatoes	6.0	5.1	-13.8
Kale	4.6	5.7	21.2	Tomatoes	5.4	6.8	26.3





Conclusion & Highlights

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- The plant parameters established in this study will be used to support Iowa UrbanFEWS SWAT simulation.
- These parameters could also be used for other possible future applications in Iowa and similar production areas in the western Corn Belt region.
- Additional testing of the plant parameters is recommended for Iowa conditions as additional observed data becomes available.

Caution should be used in extrapolating these parameter values to other regions. It is recommended that:

- Users consult the literature to determine what SWAT fruit and vegetable parameters have been used for specific regions of interest, and
- Testing should be performed to ensure that the most reliable choice of parameter values are used for SWAT fruit and vegetable applications in other regions.

Iowa UrbanFFWS

for Agricultural and Rural Development



Thank you!

