Food and Agriculture Organization
of the United Nations

Annexes

AquaCrop
Version 7.1

Reference manual

August 2023

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Food and Agriculture Organization of the United Nations
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Annexes

Table of contents

Annex I: Crop parameters

Note

The recommended values provided for the crop parameters in the tables below represent estimates obtained in calibration/validation exercises of AquaCrop with experimental data. How good these estimates are, depends on how extensive and thorough were the calibration and validation, and varies with the crop species listed. The experimental data used for a crop might have been taken in one to many locations, with or without water and temperature as limiting factors, and representing a few to many years of experiments. The notes and symbols before each table provide indications of the thoroughness of the calibration/validation process with respect to optimal and water stress conditions, as well as with respect to the coverage of major production areas of that crop around the world. Note that if a crop is important in many geographical areas, even if testing with data from four or five diverse locations would not be considered thorough, whereas testing with data from three locations for a crop limited to one geographical area may be considered as adequate.

The experiments used for calibration and validation were generally conducted under high levels of management, with the control treatments aimed at production levels close to the maximum potential achievable in that location. All the data used were obtained under conditions of good soil mineral nutrient status. The soil fertility feature of AquaCrop is just beginning to be tested now with data.

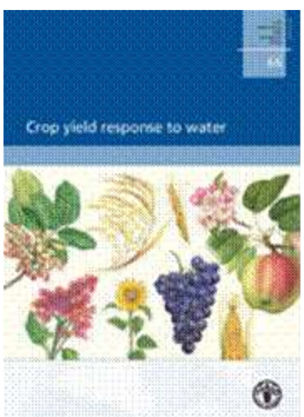
In using the tables the differences in thoroughness of calibration and validation of the parameters for the different crops should be considered. For the better tested crops, the values provided should yield reasonable results, although small adjustments in the parameter values may prove to be desirable. For the less tested crops, the user may want to consider the values provided as preliminary and starting values subject to revision, either by user calibration or by revision in future versions of AquaCrop, as more experimental data are brought to bear. We encourage users to contact AquaCrop Help-desk aquacrop@fao.org, in order to contribute to the calibration and validation of AquaCrop either for crops not yet in the list of tables or for those in the tables, for future revisions of the current version.

In the simulation output crop yield is always reported as dry matter, although the calibration for grain crops was performed against yield measurements that had water contents not too far from the water content of commercial grain (10-15 %). For potato and sugar beet, the simulated dry matter yield can be converted to fresh weight (usual way commercial yields are reported) best by using the measured water or dry matter content of the product. If that information is not available, a general conversion factor, in terms of kg of dry matter per kg fresh weight, of 0.20 to 0.25 may be used.

AquaCrop is a relatively simple model by design, yet suitable for the simulation of most herbaceous species. The decision was made to keep the model simple and more general. The model can be modified to account for some unusual characteristic specific for a particular crop, but to do that for a number of crops each with its own special characteristics would make the model too complex. The user should be aware of this limitation of the model. Examples of such special characteristics are: (1) The cut-out phenomenon exhibited by cotton under some conditions, when additional flowers (squares) and young fruits (bolls) no longer form when the fruit load is already large; but once the existing fruits mature and conditions are favourable, new flowers and fruits are produced again. Cut-out can be induced by mild to moderate water stress but is simulated only indirectly in a limited way by the model. (2) Low land (flooded) rice can experience substantial variations in the water level of the field. This would determine how much of the canopy is submerged and not transpiring or photosynthesizing, and hence not producing biomass. The model does not consider submergence and assumes only a very small part of the canopy is submerged and this has no effect on transpiration or biomass production.

FAO Irrigation and Drainage Paper Nr. 66
Crop yield response to water

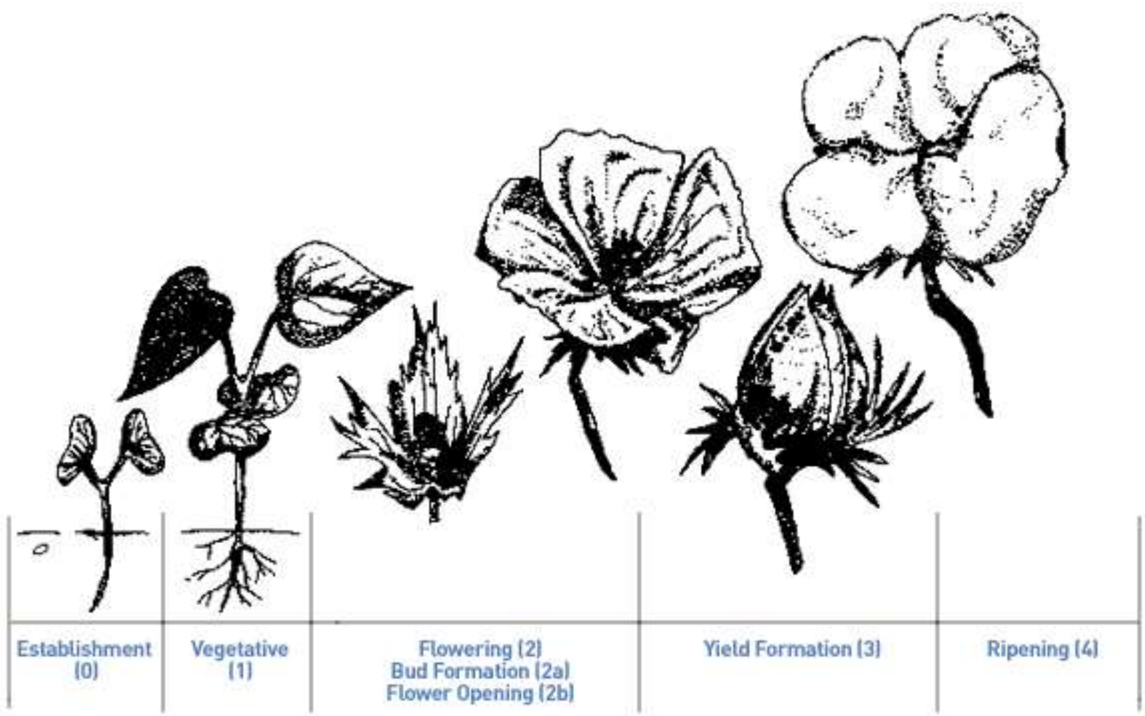
In this handbook, a general description, growth and development, water use and productivity, responses to stresses, irrigation practices and crop yield for the listed crops are provided.



Steduto, P., Hsiao, T.C., Fereres, E., Raes, D. 2012. Crop yield response to water. Irrigation and Drainage Paper Nr. 66, FAO, Rome, Italy. 500 pages.

Download from website:
http://www.fao.org/docrep/016/i2800e/i2800e00.htm

I.1 Cotton



Goodness of the calibration

- Non-limiting conditions ☺ ☺
- Water stress conditions ☺ ☺
- Geographical coverage (with respect to the world cropped areas) ☺ ☺
- Overall ☺ ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

Note - The cut-out phenomenon exhibited by cotton under some conditions, when additional flowers (squares) and young fruits (bolls) no longer form when the fruit load is already large; but once the existing fruits mature and conditions are favourable, new flowers and fruits are produced again. Cut-out can be induced by mild to moderate water stress but is simulated only indirectly in a limited way by the model.

I.1 Cotton

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	12.0
T_{upper}	Upper temperature (°C)	Conservative (1)	35.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	5.00 - 7.00
	Number of plants per hectare	Management (3)	60,000 – 150,000
	Time from sowing to emergence (growing degree day)	Management (3)	10 - 80
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative (1)	0.006 - 0.008
CC_x	Maximum canopy cover (%)	Management (3)	Almost entirely covered - Entirely covered
	Time from sowing to start senescence (growing degree day)	Cultivar (4)	Time to emergence + 1000 - 1800
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.002 - 0.003
	Time from sowing to maturity, i.e. length of crop cycle (growing degree day)	Cultivar (4)	Time to emergence + 1200 - 2000
1.3 Flowering			
	Time from sowing to flowering (growing degree day)	Cultivar (4)	Time to emergence + 450 - 700
	Length of the flowering stage (growing degree day)	Cultivar (4)	450 - 750
	Crop determinancy linked with flowering	Conservative (1)	No
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 2.50
	Shape factor describing root zone expansion	Conservative (1)	1.5

I.1 Cotton continued

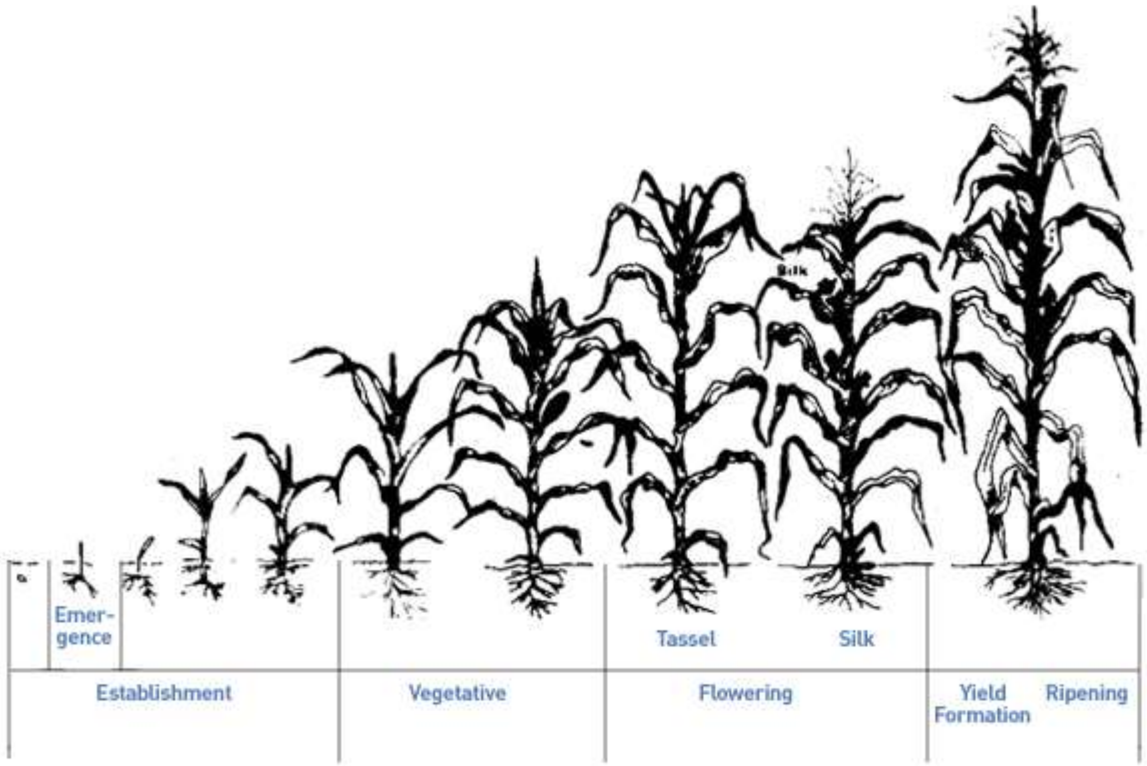
2. Crop transpiration			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative [(1)]	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative [(1)]	0.30
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative [(1)]	60
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative [(1)]	15.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative [(1)]	70
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar [(4)]	25 - 40
	Possible increase (%) of HI due to water stress before flowering	Conservative [(1)]	Small
	Excess of potential fruits (%)	Conservative [(2)]	Large
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative [(1)]	Moderate
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative [(1)]	Small
	Allowable maximum increase (%) of specified HI	Conservative [(1)]	30

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

I.1 Cotton continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.20
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.70
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	3.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.75
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	2.5
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.75
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	2.5
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.85 (Estimate)
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	Moderately tolerant to water logging
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	15.0 (Estimate)
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	40.0 to 45.0 (Estimate)
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	Not considered
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	7.7
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	26.9

I.2 Maize



Goodness of the calibration

- Non-limiting conditions ☺ ☺ ☺
- Water stress conditions ☺ ☺
- Geographical coverage (with respect to the world cropped areas) ☺ ☺ ☺
- Overall ☺ ☺ ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

Note - Maize parameters have been mostly generated from the calibration reported by Hsiao et al., 2009. AquaCrop — the FAO crop model to simulate yield response to water: III. Parameterization and testing for maize. Agron. J. 101 (3): 448-459.

I.2 Maize

1. Crop Phenology			
Symbol	Description	Type [(1), (2), (3), (4)]	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative [(1)]	8.0
T_{upper}	Upper temperature (°C)	Conservative [(1)]	30.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative [(2)]	6.50
	Number of plants per hectare	Management [(3)]	50,000 – 100,000
	Time from sowing to emergence (growing degree day)	Management [(3)]	60 - 100
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative [(1)]	0.012 - 0.013
CC_x	Maximum canopy cover (%)	Management [(3)]	65 – 99 %
	Time from sowing to start senescence (growing degree day)	Cultivar [(4)]	Time to emergence + 1150 - 1500
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative [(1)]	0.010
	Time from sowing to maturity, i.e. length of crop cycle (growing degree day)	Cultivar [(4)]	Time to emergence + 1450 - 1850
1.3 Flowering			
	Time from sowing to flowering (growing degree day)	Cultivar [(4)]	Time to emergence + 600 - 900
	Length of the flowering stage (growing degree day)	Cultivar [(4)]	150 - 200
	Crop determinacy linked with flowering	Conservative [(1)]	Yes
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management [(3)]	0.30
Z_x	Maximum effective rooting depth (m)	Management [(3)]	Up to 2.80
	Shape factor describing root zone expansion	Conservative [(1)]	1.3

I.2 Maize continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.05
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.30
	Effect of canopy cover on reducing soil evaporation in late season stage	Management (3)	50
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	33.7
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	48 - 52
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	None
	Excess of potential fruits (%)	Conservative (2)	Small
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	Small
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Strong
	Allowable maximum increase (%) of specified HI	Conservative (1)	15

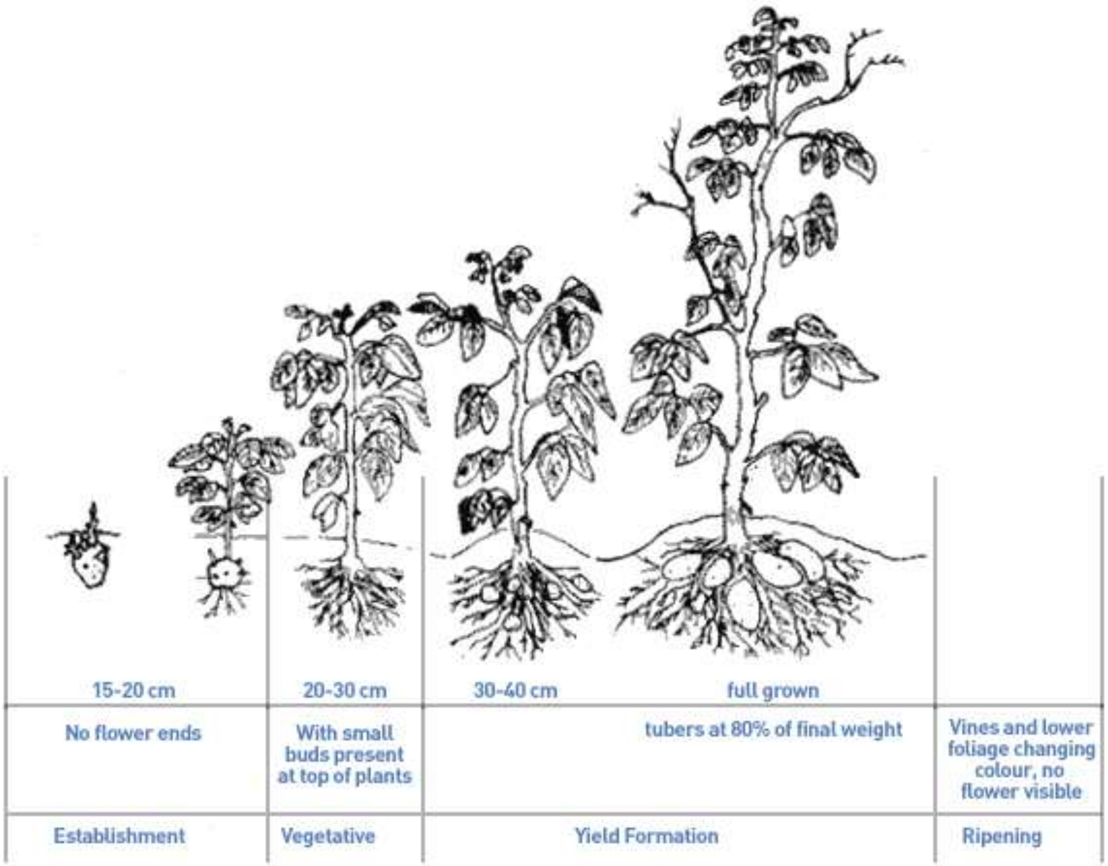
(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

Note - Maize yield is considered having water content not far from that of commercial grain (10-15 %).

I.2 Maize continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.14
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.72
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	2.9
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.69
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	6.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.69
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	2.7
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.80 (Estimate)
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	Moderately tolerant to water logging
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	10.0 (Estimate)
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	40.0 (Estimate)
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	12.0 (Estimated)
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	1.7
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	10.0

I.3 Potato



Goodness of the calibration

- Non-limiting conditions ☺
- Water stress conditions ☺
- Geographical coverage (with respect to the world cropped areas) ☺
- Overall ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

I.3 Potato

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	2.0
T_{upper}	Upper temperature (°C)	Conservative (1)	26.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2) Management (3)	10 - 20
	Number of plants per hectare	Management (3)	30,000 – 60,000
	Time from sowing to emergence (growing degree day)	Management (3)	150 - 250
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative (1)	0.017 - 0.020
CC_x	Maximum canopy cover (%)	Management (3)	Almost entirely covered
	Time from sowing to start senescence (growing degree day)	Cultivar (4)	Time to emergence + 850 - 1000
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.002
	Time from sowing to maturity, i.e. length of crop cycle (growing degree day)	Cultivar (4)	Time to emergence + 800 - 1800
1.3 Yield formation			
	Time from sowing to start yield formation (growing degree day)	Cultivar (4)	Time to emergence + 350 - 650
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 1.80
	Shape factor describing root zone expansion	Conservative (1)	1.5

I.3 Potato continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.15
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	60
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	18.0 - 20.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	70 - 85
	Possible increase (%) of HI due to water stress before starting yield formation	Conservative (1)	Small
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	None
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Small
	Allowable maximum increase (%) of specified HI	Conservative (1)	5

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

Note - Potato yield is expressed as dry matter. Simulated dry matter yield can be converted to fresh weight best by using the measured water or dry matter content of the product. A general conversion factor of 20% to 25%, in terms of kg of dry matter per kg fresh weight, may be used.

I.3 Potato continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.20
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.60
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	3.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.60
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	3.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.70
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	3.0
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	Moderately tolerant to water logging
4.2 Air temperature stress			
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	5.0 - 9.0 (Estimated)
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	1.7
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	10.0

I.4 Quinoa

Goodness of the calibration

- Non-limiting conditions ☺ ☺
- Water stress conditions ☺ ☺
- Geographical coverage (with respect to the world cropped areas) ☺ ☺ ☺
- Overall ☺ ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

Note - Quinoa parameters have been generated from the calibration reported by Geerts et al., 2009. Simulating Yield Response to Water of Quinoa (Chenopodium quinoa Willd.) with FAO-AquaCrop. Agron. J. 101 (3): 499-508.

Note - Calendar days instead of growing degree day mode is herein suggested in order to keep the calibration more generic for different varieties with unknown growing degree days sums for different phenological stages.

I.4 Quinoa

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	0.0 – 3.0 (Estimate)
T_{upper}	Upper temperature (°C)	Conservative (1)	Not calibrated
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	6.50 (Estimate)
	Number of plants per hectare	Management (3)	5,000 – 300,000
	Time from sowing to emergence (days)	Management (3)	5 – 10 [1]
CGC	Canopy growth coefficient (fraction per day)	Conservative (1)	0.100
CC_x	Maximum canopy cover (%)	Management (3)	50 - 100
	Time from sowing to start senescence (days)	Cultivar (4)	Time to emergence + 135 - 170
CDC	Canopy decline coefficient (fraction per day)	Conservative (1)	0.100
	Time from sowing to maturity, i.e. length of crop cycle (days)	Cultivar (4)	Time to emergence + 165 - 195
1.3 Flowering			
	Time from sowing to flowering (growing degree day)	Cultivar (4)	Time to emergence + 65 - 110
	Length of the flowering stage (growing degree day)	Cultivar (4)	15 - 20
	Crop determinacy linked with flowering	Conservative (1)	No [2]
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 1.00
	Shape factor describing root zone expansion	Conservative (1)	1.5 [3]

[1] In Crop Program settings, Germination reduce the Minimum soil water content required for germination from the default 20% to 10% of TAW.
[2] Artificial measure to account for the flexible phenology of quinoa in response to drought stress.
[3] In Crop Program settings, Root zone put the effect of water stress on root development as Not considered.

I.4 Quinoa continued

2. Crop transpiration			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative [(1)]	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative [(1)]	0.15
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative [(1)]	60
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative [(1)]	10.5
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative [(1)]	90
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar [(4)]	50
	Possible increase (%) of HI due to water stress before flowering	Conservative [(1)]	None
	Excess of potential fruits (%)	Conservative [(2)]	Small
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative [(1)]	None
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative [(1)]	Small
	Allowable maximum increase (%) of specified HI	Conservative [(1)]	10 (Estimate)

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

I.4 Quinoa continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.50
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.80
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	4.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.60
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	4.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.98
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	4.0
	Sum(ETo) during stress period to be exceeded before senescence is triggered	Conservative [(1)]	200
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.90 (Estimate)
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	Sensitive to water logging
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	Not considered
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	Not considered
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	Not considered
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	5.0 (Estimated)
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	18.0 (Estimated)

I.5 Rice

Goodness of the calibration

- Non-limiting conditions ☺ ☺
- Water stress conditions ◘
- Geographical coverage (with respect to the world cropped areas) ☺
- Overall ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

Note – The present AquaCrop calibration applies to Paddy (flooded) rice only. Simulate puddled soil (e.g. default soil file PADDY.SOL) and soil bunds (e.g. default Field management file BUNDS.MAN)

I.5 Rice

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	8.0
T_{upper}	Upper temperature (°C)	Conservative (1)	30.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% recover (cm2/plant)	Conservative (2) Management (3)	3.00 - 8.00
	Number of plants per hectare	Management (3)	300,000 – 1,500,000
	Time from transplanting to recover (growing degree day)	Management (3)	35 - 100
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative (1)	0.006 - 0.008
CC_x	Maximum canopy cover (%)	Management (3)	Almost entirely covered
	Time from transplanting to start senescence (growing degree day)	Cultivar (4)	Time to recover + 1000 - 1500
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.005
	Time from transplanting to maturity, i.e. length of crop cycle (GD day)	Cultivar (4)	Time to recover + 1500 - 2000
1.3 Flowering			
	Time from sowing to flowering (growing degree day)	Cultivar (4)	Time to recover + 1000 - 1300
	Length of the flowering stage (growing degree day)	Cultivar (4)	300 - 400
	Crop determinacy linked with flowering	Conservative (1)	Yes
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 0.60
	Shape factor describing root zone expansion	Conservative (1)	2.0 - 3.0

I.5 Rice   continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.15
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	50
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	19.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	35 - 50
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	None
	Excess of potential fruits (%)	Conservative (2)	Large
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	Small
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Moderate
	Allowable maximum increase (%) of specified HI	Conservative (1)	15

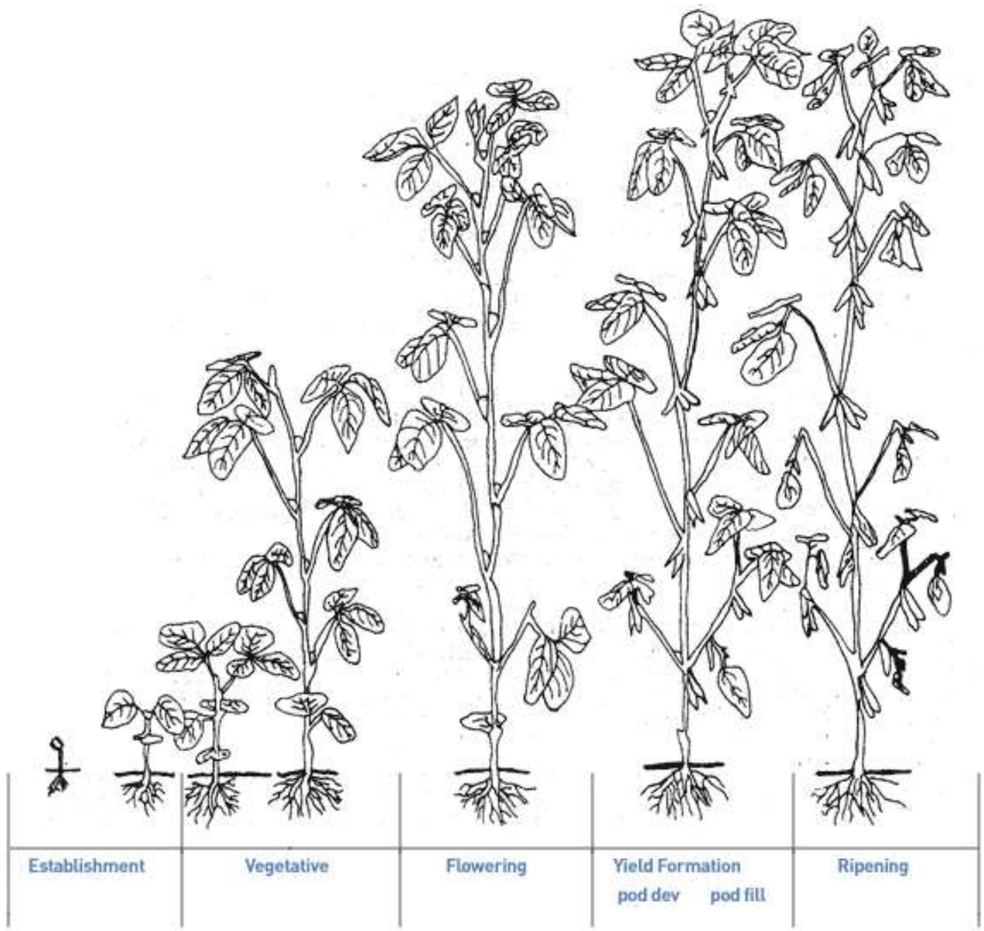
(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

Note - Rice yield is considered having water content not far from that of commercial grain (10-15 %).

I.5 Rice continued

4. Stresses			
Symbol		Type [1], [2], [3], [4]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [1]	0.00
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [1]	0.40
	Shape factor for Water stress coefficient for canopy expansion	Conservative [1]	3.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [1]	0.50
	Shape factor for Water stress coefficient for stomatal control	Conservative [1]	3.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [1]	0.55
	Shape factor for Water stress coefficient for canopy senescence	Conservative [1]	3.0
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [1]	0.75 (Estimate)
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [4] Environment [3]	Not stressed when water logged
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [1]	8.0
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [1]	35.0
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [1]	10.0 (Estimated)
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [1]	3.0
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [1]	11.3

I.6 Soybean



Goodness of the calibration

- Non-limiting conditions ☺ ☺
- Water stress conditions ☺
- Geographical coverage (with respect to the world cropped areas) ☺ ☺ ☺
- Overall ☺ ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

I.6 Soybean

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	5.0
T_{upper}	Upper temperature (°C)	Conservative (1)	30.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	5.00
	Number of plants per hectare	Management (3)	250,000 – 450,000
	Time from sowing to emergence (growing degree day)	Management (3)	150 - 300
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative (1)	0.004 - 0.005
CC_x	Maximum canopy cover (%)	Management (3)	Almost entirely covered - Entirely covered
	Time from sowing to start senescence (growing degree day)	Cultivar (4)	Time to emergence + 1600 - 2400
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.015
	Time from sowing to maturity, i.e. length of crop cycle (growing degree day)	Cultivar (4)	Time to emergence + 2000 - 3000
1.3 Flowering			
	Time from sowing to flowering (growing degree day)	Cultivar (4)	Time to emergence + 1000 - 1500
	Length of the flowering stage (growing degree day)	Cultivar (4)	400 - 800
	Crop determinacy linked with flowering	Conservative (1)	Yes
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 2.40
	Shape factor describing root zone expansion	Conservative (1)	1.5

I.6 Soybean continued

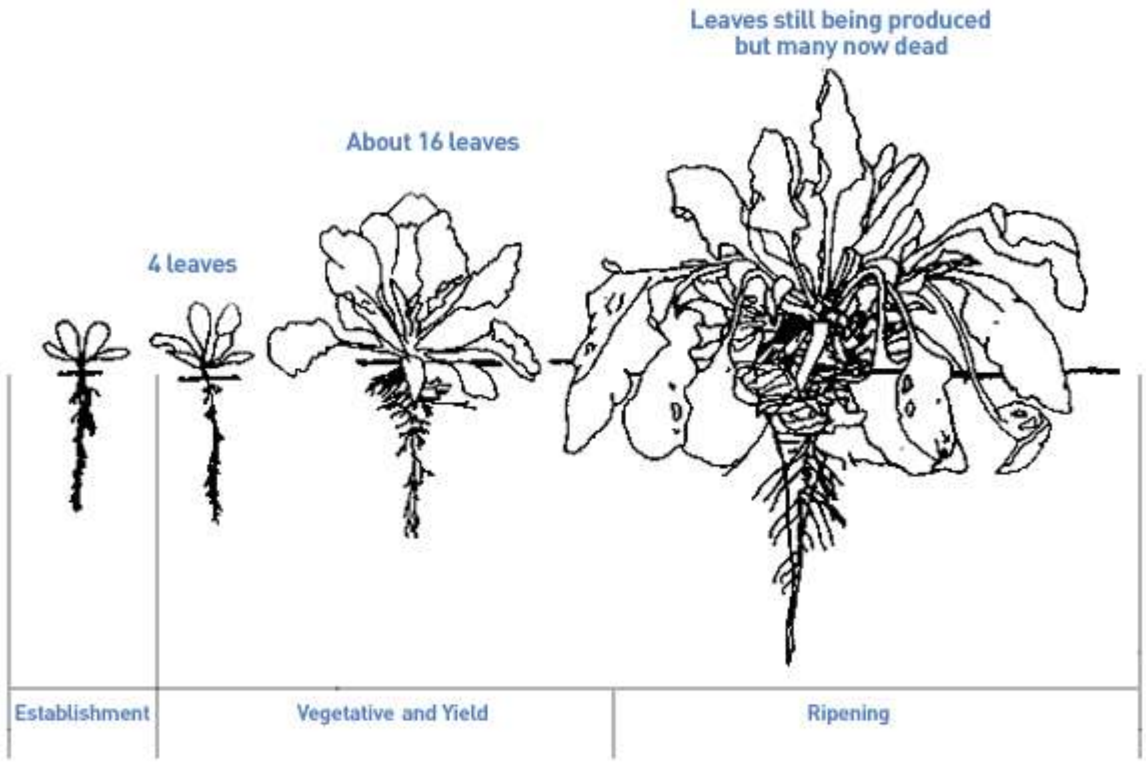
2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.30
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	25
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	15.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	60
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	40
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	Small
	Excess of potential fruits (%)	Conservative (2)	Medium
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	None
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Strong
	Allowable maximum increase (%) of specified HI	Conservative (1)	10

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

I.6 Soybean continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.15
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.65
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	3.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.60
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	3.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.70
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	3.0
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.85 (Estimate)
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	Moderately tolerant to water logging
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	8.0 (Estimate)
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	40.0 (Estimate)
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	10.0 (Estimate)
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	5.0
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	10.0

I.7 Sugar Beet



Goodness of the calibration

- Non-limiting conditions ☺ ☺
- Water stress conditions ◘
- Geographical coverage (with respect to the world cropped areas) ☺
- Overall ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

I.7 Sugar Beet

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	5.0
T_{upper}	Upper temperature (°C)	Conservative (1)	30.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	1.00
	Number of plants per hectare	Management (3)	80,000 – 120,000
	Time from sowing to emergence (growing degree day)	Management (3)	20 - 50
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative (1)	0.010 - 0.012
CC_x	Maximum canopy cover (%)	Management (3)	Up to Almost entirely covered
	Time from sowing to start senescence (growing degree day)	Cultivar (4)	Time to emergence + 1700 - 2300
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.003 - 0.004
	Time from sowing to maturity, i.e. length of crop cycle (growing degree day)	Cultivar (4)	Time to emergence + 2000 - 2800
1.3 Yield formation			
	Time from sowing to start yield formation (growing degree day)	Cultivar (4)	Time to emergence + 800 - 1000
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 2.40
	Shape factor describing root zone expansion	Conservative (1)	1.5

I.7 Sugar Beet   continued

2. Crop transpiration			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative [(1)]	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative [(1)]	0.15
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative [(1)]	60
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative [(1)]	17.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative [(1)]	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar [(4)]	65 - 75
	Possible increase (%) of HI due to water stress before starting yield formation	Conservative [(1)]	None
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative [(1)]	Small
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative [(1)]	None
	Allowable maximum increase (%) of specified HI	Conservative [(1)]	20

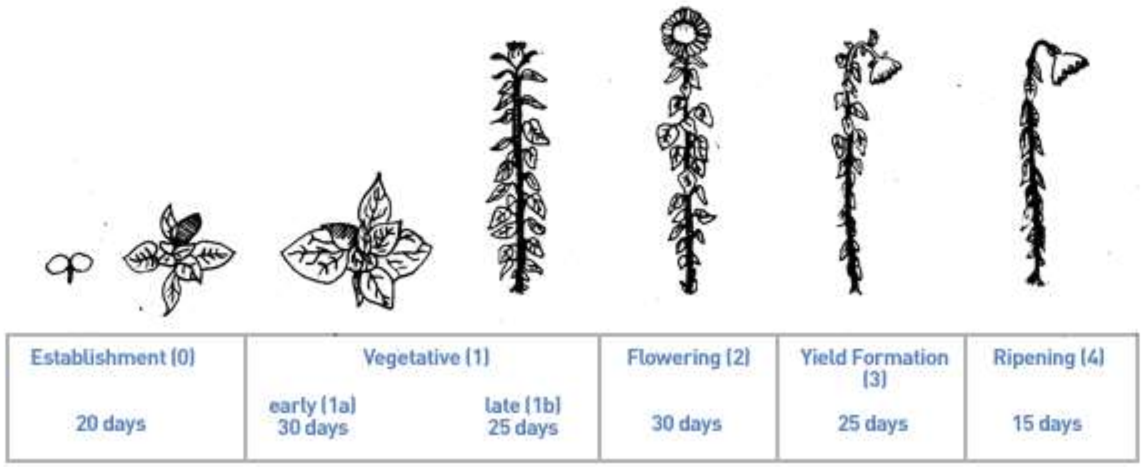
(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

Note - Sugarbeet yield is expressed as dry matter. Simulated dry matter yield can be converted to fresh weight best by using the measured water or dry matter content of the product. A general conversion factor of 25 to 20%, in terms of kg of dry matter per kg fresh weight, may be used.

I.7 Sugar Beet   continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.20
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.60
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	3.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.65
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	3.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.75
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	3.0
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	Moderately tolerant to water logging
4.2 Air temperature stress			
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	9.0 (Estimated)
4.3 Salinity stress			
EC_{e_n}	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	7.0
EC_{e_x}	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	24.0

I.8 Sunflower



Goodness of the calibration

- Non-limiting conditions ☺ ☺
- Water stress conditions ☺ ☺
- Geographical coverage (with respect to the world cropped areas) ☺
- Overall ☺ ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

Note -There is more variation in season length in sunflower than in many other crops. Commercial varieties range from very early to very late maturing, differing by more than 50 % in season length. The parameters in the Table are recommended for medium to late maturing cultivars .

I.8 Sunflower

1. Crop Phenology			
Symbol	Description	Type [(1), (2), (3), (4)]	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative [(1)]	4.0
T_{upper}	Upper temperature (°C)	Conservative [(1)]	30.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative [(2)]	5.00
	Number of plants per hectare	Management [(3)]	50,000 – 70,000
	Time from sowing to emergence (growing degree day)	Management [(3)]	150 - 200
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative [(1)]	0.015
CC_x	Maximum canopy cover (%)	Management [(3)]	Entirely covered
	Time from sowing to start senescence (growing degree day)	Cultivar [(4)]	Time to emergence + 1400 - 1800
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative [(1)]	0.006
	Time from sowing to maturity, i.e. length of crop cycle (growing degree day)	Cultivar [(4)]	Time to emergence + 2200 - 2800
1.3 Flowering			
	Time from sowing to flowering (growing degree day)	Cultivar [(4)]	Time to emergence + 1000 - 1300
	Length of the flowering stage (growing degree day)	Cultivar [(4)]	300 - 400
	Crop determinancy linked with flowering	Conservative [(1)]	Yes
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management [(3)]	0.30
Z_x	Maximum effective rooting depth (m)	Management [(3)]	Up to 3.00
	Shape factor describing root zone expansion	Conservative [(1)]	1.3

I.8 Sunflower continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.30
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	60
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	18.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	60
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	35
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	Small
	Excess of potential fruits (%)	Conservative (2)	Large
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	None
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Strong
	Allowable maximum increase (%) of specified HI	Conservative (1)	10

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

I.8 Sunflower continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.15
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.65
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	2.5
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.60
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	2.5
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.70
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	2.5
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.85 (Estimate)
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	Moderately tolerant to water logging
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	10
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	40
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	12
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	2.0 (Estimate)
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	12.0 (Estimate)

I.9 Tomato

Goodness of the calibration

- Non-limiting conditions ☺
- Water stress conditions ◘
- Geographical coverage (with respect to the world cropped areas) ☺ ☺
- Overall ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

Note – The present AquaCrop calibration applies to Processing tomato only.

I.9 Tomato

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	7.0
T_{upper}	Upper temperature (°C)	Conservative (1)	28.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	1.0 (direct seeding) 5.0 to 20.0 (transplant)
	Number of plants per hectare	Management (3)	15,000 – 80,000
	Time from sowing to emergence / transplant to recovery (growing degree day)	Management (3)	40 - 80
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative (1)	0.0075
CC_x	Maximum canopy cover (%)	Management (3)	Fairly to almost entirely covered
	Time from sowing / transplant to start senescence (growing degree day)	Cultivar (4)	Recovery + 1300 - 1600
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.004
	Time from sowing / transplant to maturity, i.e. length of crop cycle (growing degree day)	Cultivar (4)	Recovery + 1500 - 2000
1.3 Flowering			
	Time from sowing / transplant to flowering (growing degree day)	Cultivar (4)	Recovery + 250 - 400
	Length of the flowering stage (growing degree day)	Cultivar (4)	600 - 900
	Crop determinacy linked with flowering	Conservative (1)	No
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 2.00
	Shape factor describing root zone expansion	Conservative (1)	1.5

I.9 Tomato continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.15
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	60
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	18.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	55 - 65
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	None (Estimated)
	Excess of potential fruits (%)	Conservative (2)	Large
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	None (Estimated)
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Strong (Estimated)
	Allowable maximum increase (%) of specified HI	Conservative (1)	15 (Estimated)

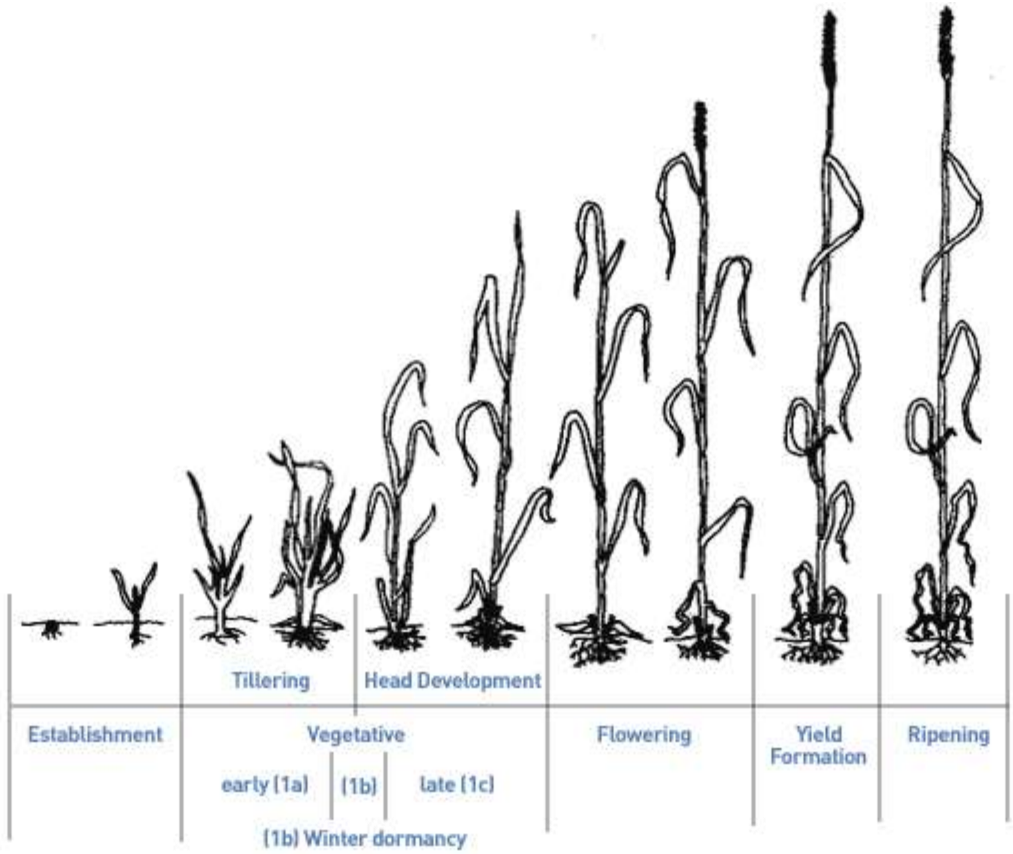
(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

Note - Harvest Index refers to the ratio between the dry yield (including red, green, and rotten production) and dry above ground biomass. To convert dry into fresh yield, 93 to 95% water content should be considered. Red production compared to the total one varies with management.

I.9 Tomato continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.15 (Estimated)
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.55 (Estimated)
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	3.0 (Estimated)
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.50 (Estimated)
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	3.0 (Estimated)
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.70 (Estimated)
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	3.0 (Estimated)
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.92
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	5.0
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	10.0 (Estimated)
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	40.0 (Estimated)
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	Not considered
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	1.7
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	12.8

I.10 Wheat



Goodness of the calibration

- Non-limiting conditions ☺ ☺
- Water stress conditions ☺
- Geographical coverage (with respect to the world cropped areas) ☺ ☺
- Overall ☺ ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

Note - The present AquaCrop calibration applies to Wheat grown as spring wheat in northern latitudes or grown as winter wheat in temperatures latitudes in the absence of a cold period below 5 GDD.

I.10 Wheat

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	0.0
T_{upper}	Upper temperature (°C)	Conservative (1)	26.0
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	1.50
	Number of plants per hectare	Management (3)	2,000,000 – 7,000,000
	Time from sowing to emergence (growing degree day)	Management (3)	100 - 250
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative (1)	0.005 - 0.007
CC_x	Maximum canopy cover (%)	Management (3)	80 – 99 %
	Time from sowing to start senescence (growing degree day)	Cultivar (4)	Time to emergence + 1000 - 2000
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.004
	Time from sowing to maturity, i.e. length of crop cycle (growing degree day)	Cultivar (4)	Time to emergence + 1500 - 2900
1.3 Flowering			
	Time from sowing to flowering (growing degree day)	Cultivar (4)	Time to emergence + 1000 - 1300
	Length of the flowering stage (growing degree day)	Cultivar (4)	150 - 280
	Crop determinacy linked with flowering	Conservative (1)	Yes
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 2.40
	Shape factor describing root zone expansion	Conservative (1)	1.5

I.10 Wheat continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.15
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	50
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	15.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	45 - 50
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	Small
	Excess of potential fruits (%)	Conservative (2)	Medium
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	Small
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Moderate
	Allowable maximum increase (%) of specified HI	Conservative (1)	15

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

Note - Wheat yield is considered having water content not far from that of commercial grain (10-15 %).

I.10 Wheat continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.20
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.65
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	5.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.65
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	2.5
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.70
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	2.5
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.85 (Estimate)
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	Moderately tolerant to water logging
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	5.0 (Estimate)
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	35.0 (Estimate)
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	13.0 - 15.0 (Estimated)
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	6.0
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	20.1

I.11 Barley

Goodness of the calibration

- Non-limiting conditions ☺ ☺
- Water stress conditions ☺
- Geographical coverage (with respect to the world cropped areas) ☺
- Overall ☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

I.11 Barley

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	0
T_{upper}	Upper temperature (°C)	Conservative (1)	15
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	1.50
	Number of plants per hectare	Management (3)	1,500,000 – 3,000,000
	Time from sowing to emergence (growing degree day)	Management (3)	90 – 200
CGC	Canopy growth coefficient (fraction per growing degree day)	Conservative (1)	0.008
CC_x	Maximum canopy cover (%)	Management (3)	50 – 99
	Time from sowing to start senescence (growing degree day)	Cultivar (4)	900 – 2,000
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.006
	Time from sowing to maturity, i.e. length of crop cycle (growing degree day)	Cultivar (4)	1296
1.3 Flowering			
	Time from sowing to flowering (growing degree day)	Cultivar (4)	700 – 1,300
	Length of the flowering stage (growing degree day)	Cultivar (4)	150 – 250
	Crop determinacy linked with flowering	Conservative (1)	Yes
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	up to 2.50 m
	Shape factor describing root zone expansion	Conservative (1)	15

I.11 Barley continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.15
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	50
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	15.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	30 – 50
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	Small
	Excess of potential fruits (%)	Conservative (2)	Medium
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	Small
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Moderate
	Allowable maximum increase (%) of specified HI	Conservative (1)	15

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

I.11 Barley continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.20
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.65
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	3.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.60
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	3.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.55
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	3.0
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.85
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	15
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	5
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	35
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	14
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	6.0
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	20.1

I.12 Sugar Cane

Goodness of the calibration

- Non-limiting conditions
- Water stress conditions
- Geographical coverage (with respect to the world cropped areas)
- Overall

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

I.12 Sugar cane

1. Crop Phenology			
Symbol	Description	Type [(1), (2), (3), (4)]	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative [(1)]	9
T_{upper}	Upper temperature (°C)	Conservative [(1)]	32
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative [(2)]	6.50
	Number of plants per hectare	Management [(3)]	140,000
	Time from transplanting to emergence (day)	Management [(3)]	7
CGC	Canopy growth coefficient (fraction per day)	Conservative [(1)]	0.12548
CC_x	Maximum canopy cover (%)	Management [(3)]	95
	Time from transplanting to start senescence (day)	Cultivar [(4)]	330
CDC	Canopy decline coefficient (fraction per day)	Conservative [(1)]	0.07615
	Time from transplanting to maturity, i.e. length of crop cycle (day)	Cultivar [(4)]	365
1.3 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management [(3)]	0.30
Z_x	Maximum effective rooting depth (m)	Management [(3)]	1.80
	Shape factor describing root zone expansion	Conservative [(1)]	1.3

I.12 Sugar Cane continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.15
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	60
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	30
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%) - sucrose	Cultivar (4)	35

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

I.12 Sugar Cane continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.25
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.55
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	3.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.50
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	3.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.60
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	3.0
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	5
4.2 Air temperature stress			
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	12.0
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	1.7
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	18.6

I.13 Sorghum

Goodness of the calibration

- Non-limiting conditions
- Water stress conditions
- Geographical coverage (with respect to the world cropped areas)
- Overall

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

I.13 Sorghum

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	8
T_{upper}	Upper temperature (°C)	Conservative (1)	30
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	3
	Number of plants per hectare	Management (3)	200,000
	Time from sowing to emergence (day)	Management (3)	7 - 13
CGC	Canopy growth coefficient (fraction per day)	Conservative (1)	0.16
CC_x	Maximum canopy cover (%)	Management (3)	60 – 98
	Time from sowing to start senescence (day)	Cultivar (4)	91
CDC	Canopy decline coefficient (fraction per growing degree day)	Conservative (1)	0.01
	Time from sowing to maturity, i.e. length of crop cycle (day)	Cultivar (4)	102
1.3 Flowering			
	Time from sowing to flowering (day)	Cultivar (4)	65
	Length of the flowering stage (day)	Cultivar (4)	20
	Crop determinacy linked with flowering	Conservative (1)	YES
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	Up to 2.8 m
	Shape factor describing root zone expansion	Conservative (1)	1.3

I.13 Sorghum continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.07
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.3
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	50
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	33.7
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	45
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	Small
	Excess of potential fruits (%)	Conservative (2)	Medium - Large
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	Very strong
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Moderate
	Allowable maximum increase (%) of specified HI	Conservative (1)	25

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

I.13 Sorghum continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.15
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.70
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	3.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.75
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	3.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.70
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	3.0
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.80
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	5
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	10
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	40
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	12.0
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	6.8
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	13.1

I.14 Tef

Goodness of the calibration

• Non-limiting conditions	☺ ☺
• Water stress conditions	☺ ☺
• Geographical coverage (with respect to the world cropped areas)	☺
• Overall	☺

◘	No calibration
☺	Minimum degree of calibration
☺ ☺	Medium degree of calibration
☺ ☺ ☺	Good degree of calibration
☺ ☺ ☺ ☺	Optimum degree of calibration

I.14 Tef

1. Crop Phenology			
Symbol	Description	Type (1), (2), (3), (4)	Values / ranges
1.1 Threshold air temperatures			
T_{base}	Base temperature (°C)	Conservative (1)	10
T_{upper}	Upper temperature (°C)	Conservative (1)	30
1.2 Development of green canopy cover			
cc_0	Soil surface covered by an individual seedling at 90% emergence (cm2/plant)	Conservative (2)	0.25
	Number of plants per hectare	Management (3)	10,000,000
	Time from sowing to emergence (day)	Management (3)	14
CGC	Canopy growth coefficient (fraction per day)	Conservative (1)	0.146
CC_x	Maximum canopy cover (%)	Management (3)	80 - 90
	Time from sowing to start senescence (day)	Cultivar (4)	75
CDC	Canopy decline coefficient (fraction per day)	Conservative (1)	0.116
	Time from sowing to maturity, i.e. length of crop cycle (day)	Cultivar (4)	99
1.3 Flowering			
	Time from sowing to flowering (day)	Cultivar (4)	55
	Length of the flowering stage (day)	Cultivar (4)	11
	Crop determinacy linked with flowering	Conservative (1)	YES
1.4 Development of root zone			
Z_n	Minimum effective rooting depth (m)	Management (3)	0.30
Z_x	Maximum effective rooting depth (m)	Management (3)	0.60
	Shape factor describing root zone expansion	Conservative (1)	1.5

I.14 Tef continued

2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.30
	Effect of canopy cover on reducing soil evaporation in late season stage	Conservative (1)	60
3. Biomass production and yield formation			
3.1 Crop water productivity			
WP*	Water productivity normalized for ETo and CO_2 (gram/m^2)	Conservative (1)	14.0
	Water productivity normalized for ETo and CO_2 during yield formation (as percent WP* before yield formation)	Conservative (1)	100
3.2 Harvest Index			
HI_o	Reference harvest index (%)	Cultivar (4)	27
	Possible increase (%) of HI due to water stress before flowering	Conservative (1)	None
	Excess of potential fruits (%)	Conservative (2)	Small
	Coefficient describing positive impact of restricted vegetative growth during yield formation on HI	Conservative (1)	Very strong
	Coefficient describing negative impact of stomatal closure during yield formation on HI	Conservative (1)	Small
	Allowable maximum increase (%) of specified HI	Conservative (1)	40

(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

I.14 Tef   continued

4. Stresses			
Symbol		Type [(1), (2), (3), (4)]	Values / ranges
4.1 Soil water stresses			
$p_{exp,lower}$	Soil water depletion threshold for canopy expansion - Upper threshold	Conservative [(1)]	0.32
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [(1)]	0.66
	Shape factor for Water stress coefficient for canopy expansion	Conservative [(1)]	3.0
p_{sto}	Soil water depletion threshold for stomatal control - Upper threshold	Conservative [(1)]	0.60
	Shape factor for Water stress coefficient for stomatal control	Conservative [(1)]	3.0
p_{sen}	Soil water depletion threshold for canopy senescence - Upper threshold	Conservative [(1)]	0.58
	Shape factor for Water stress coefficient for canopy senescence	Conservative [(1)]	3.0
p_{pol}	Soil water depletion threshold for failure of pollination - Upper threshold	Conservative [(1)]	0.92
	Vol% at anaerobiotic point (with reference to saturation)	Cultivar [(4)] Environment [(3)]	6
4.2 Air temperature stress			
	Minimum air temperature below which pollination starts to fail (cold stress) (°C)	Conservative [(1)]	8
	Maximum air temperature above which pollination starts to fail (heat stress) (°C)	Conservative [(1)]	40
	Minimum growing degrees required for full biomass production (°C - day)	Conservative [(1)]	11.1
4.3 Salinity stress			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [(1)]	2 (estimated)
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [(1)]	12 (estimated)

I.15 Dry beans

Table 15. – Calibration values for selected parameters of the Crop Data file

Description	Value	Unit
☐ **Temperature**		
Base temperature (T_{base})	9	ºC
Cut-off temperature (T_{upper})	30	ºC
☐ **Canopy development**		
Canopy cover per seedling at 90% emergence (cc_o)	10	cm^2/plant
Canopy growth coefficient (CGC)	11.8	%/day
Maximum canopy cover (CC_x)	99	%
Crop coefficient for transpiration ($Kc_{Tr,x}$)	1.05	
Canopy decline coefficient (CDC)	0.881	%/GDD
Time from DAP [1] to emergence	59	GDD
Time from DAP to maximum Canopy	752	GDD
Time from DAP to senescence	903	GDD
Time from DAP to maturity	1298	GDD
☐ **Flowering**		
Duration of flowering	233	GDD
Time from DAP to flowering	556	GDD
Length building up Harvest Index	668	GDD
☐ **Root development**		
Maximum rooting depth (Zr_x)	1.7	m
Time from DAP to maximum rooting depth	888	GDD

☐ **Water stress response**		
Canopy expansion p(upper)	0.15	%TAW
Canopy expansion p(lower)	0.65	%TAW
Canopy expansion shape factor	2.5	
Stomatal closure p(upper)	0.6	%TAW
Stomatal closure shape factor	3.0	
Early canopy senescence p(upper)	0.7	%TAW
Early canopy senescence shape factor	2.5	
Maximum positive effect on HI	10%	
Before flowering (+)	small	
During flowering (-)	moderate	
During yield formation (+)	none	
During yield formation (-)	very strong	
☐ **Production**		
Reference harvest index (HI)	40	%
Normalized water productivity (WP*)	15	g/m2
Adjustment for yield formation	90	%

[1] DAP: day after planting

I.16 Casava

Reference:
Wellens, J., Raes, D., Fereres, E., Diels, J., Coppye, C., Adiele, J.G., Ezui, K.S.G., Becerra, L.A., Gomez Selvaraj, M., Dercon, G., Heng, L.K. 2022. Calibration and validation of the FAO AquaCrop water productivity model for cassava (*Manihot esculenta* Crantz). Agricultural Water Management (263), 107491.

Crop parameter	Value	Method [1] of Determination
A. Conservative and/or crop specific parameters		
Base temperature (°C)	10.0	L
Upper temperature (°C)	30.0	L
Soil water depletion factor for canopy expansion (p-exp) - Upper threshold	0.25	C
Soil water depletion factor for canopy expansion (p-exp) - Lower threshold	0.60	C
Shape factor for water stress coefficient for canopy expansion	3.0	D
Soil water depletion fraction for stomatal control (p-sto) - Upper threshold	0.50	C
Shape factor for water stress coefficient for stomatal control	3.0	D
Soil water depletion factor for canopy senescence (p-sen) - Upper threshold	0.50	C
Shape factor for water stress coefficient for canopy senescence	3.0	D
vol% for Anaerobiotic point (* (SAT - [vol%]) at which deficient aeration occurs *)	5	D
Canopy growth coefficient (CGC): Increase in canopy cover (fraction soil cover per day)	0.10425	C
Canopy decline coefficient (CDC): Decrease in canopy cover (in fraction per day)	0.04100	C
Crop coefficient when canopy is complete but prior to senescence ($K_{c,Tr,x}$)	0.85	C
Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	0.050	C
Water Productivity normalized for ETo and	17.0	C

Crop parameter	Value	Method [1] of Determination
CO_2 (WP*) (gram/m²)		
Possible increase (%) of HI due to water stress before start of yield formation	4	C
Coefficient of positive impact on HI of restricted vegetative growth during yield formation	4.0	C
Coefficient of negative impact on HI of stomatal closure during yield formation	10.0	C
Allowable maximum increase (%) of specified HI	15	C
B. Non-tested crop specific parameters		
Minimum growing degrees required for full crop transpiration (°C - day)	11.1	C
Minimum and maximum air temperature below which pollination starts to fail	–	NA
Response to soil fertility	–	NA
Soil salinity stress	–	NA
C. Non-conservatives and/or cultivar specific parameters		
Calendar Days from transplanting to recovered transplant	10	E
Calendar Days from transplanting to maximum rooting depth	70	E
Calendar Days from transplanting to start senescence	300	E
Calendar Days from transplanting to maturity	360	E
Calendar Days from transplanting to start of yield formation	80	E
Minimum effective rooting depth (m)	0.30	D
Maximum effective rooting depth (m)	1.00	L
Shape factor describing root zone expansion	1.50	D
Maximum root water extraction (m³ water/m³ soil.day) in top quarter of root zone	0.048	D
Maximum root water extraction (m³ water/m³ soil.day) in bottom quarter of root zone	0.013	D
Effect of canopy cover in reducing soil evaporation in late season stage	60	E
Soil surface covered by an individual seedling at	10.00	M

Crop parameter	Value	Method [1] of Determination
90% emergence (cm²)		
Number of plants per hectare	10,000–15,625	M
Maximum canopy cover (CCx) in fraction soil cover	0.77–0.99	M
Building up of Harvest Index starting at root/tuber enlargement (days)	250	C
Reference Harvest Index (HIo) (%)	60	C

(1) Code: C: calibration; D: AquaCrop default; E: estimation; L: literature; M: measured; NA: not applicable.

I.17 Alfalfa

Reference: Raes, D., Fereres, E., García Vila, M., Curnel, Y., Knoden, D., Kale Çelik, S., Ucar, Y., Türk, M., Wellens, J. 2023. Simulation of alfalfa yield with AquaCrop. Agricultural Water Management (284), 108341.
https://doi.org/10.1016/j.agwat.2023.108341.

Crop parameter	Value	Source
A. Conservative and/or crop specific parameters		
▪ **Air temperature stress**		
T_{base}: Base temperature (°C)	5	Lit
T_{upper}: Upper temperature (°C)	30	Est
Minimum growing degrees required for full crop transpiration (GDD.day^{-1})	8	Est
▪ **Soil water stress**		
Soil water depletion for canopy expansion - Upper threshold (fraction of TAW)	0.15	Est
Soil water depletion for canopy expansion - Lower threshold (fraction of TAW)	0.55	Est
Shape factor for water stress coefficient for canopy expansion	3.0	Default
Soil water depletion for stomatal control - Upper threshold (fraction of TAW)	0.60	Est
Shape factor for water stress coefficient for stomatal control	3.0	Default
Soil water depletion for canopy senescence - Upper threshold (fraction of TAW)	0.70	Est
Shape factor for water stress coefficient for canopy senescence	3.0	Default
Soil water stress at which deficient aeration occurs (vol% below saturation)	5	Default
▪ **Soil salinity stress**		
Electrical Conductivity of soil saturation extract at which crop starts to be affected by soil salinity (dS/m)	2	FAO29
Electrical Conductivity of soil saturation extract at which crop can no longer grow (dS/m)	16	FAO29
▪ **Development of Crop Canopy Cover**		
Canopy growth coefficient (CGC) (increase of the fraction soil cover per growing degree)	0.012	Est
Canopy decline coefficient (CDC) (decrease of the fraction soil cover per growing degree)	0.006	Est
Soil surface covered by an individual seedling at 90 % emergence (cm²)	2.0	Est
▪ **Crop transpiration and biomass production**		
Kc_{Trx}: Crop coefficient when canopy is complete but prior to senescence	1.15	Est
f_{age}: Decline of crop coefficient as a result of ageing, nitrogen deficiency, etc. (%/day)	0.050	Est
Water Productivity normalized for ETo and CO_2 (gram/m²)	15.0	Cal
B. Non-conservatives and/or cultivar specific parameters		
Minimum effective rooting depth (m)	0.30	Default
Maximum effective rooting depth (m)	3.00	Lit
Shape factor describing root zone expansion	15	Default
Maximum root water extraction in top quarter of root zone (m³ water/m³ soil.day)	0.020	Default
Maximum root water extraction in bottom quarter of root zone (m³ water/m³ soil.day)	0.010	Default
Effect of canopy cover in reducing soil evaporation in late season stage	60	Default

Number of plants per hectare	2,500,000	
Maximum canopy cover (CCx) in fraction soil cover	0.95	Est

Lit: literature; Est: estimation based on authors' experience with AquaCrop; FAO56: FAO Irrigation and Drainage paper N° 56 (Allen et al., 1998); FAO29: FAO Irrigation and Drainage Paper N° 29 (Ayers and Westcot, 1985); Default: AquaCrop default values.

Annex II: Indicative values for lengths of crop development stages

Reference

Allen, R., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper N° 56. Rome, Italy. 300 p.

Table II.1 Indicative values for lengths of crop development stages for various planting periods and climatic regions

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	*Late* (L_{late})	Total	Plant Date	Region
a. Small Vegetables							
Broccoli	35	45	40	15	135	Sept	Calif. Desert, USA
Cabbage	40	60	50	15	165	Sept	Calif. Desert, USA
Carrots	20 30 30	30 40 50	50/30 60 90	20 20 30	100 150 200	Oct/Jan Feb/Mar Oct	Arid climate Mediterranean Calif. Desert, USA
Cauliflower	35	50	40	15	140	Sept	Calif. Desert, USA
Celery	25 25 30	40 40 55	95 45 105	20 15 20	180 125 210	Oct April Jan	(Semi)Arid Mediterranean (Semi)Arid
Crucifers[1]	20 25 30	30 35 35	20 25 90	10 10 40	80 95 195	April February Oct/Nov	Mediterranean Mediterranean Mediterranean
Lettuce	20 30 25 35	30 40 35 50	15 25 30 45	10 10 10 10	75 105 100 140	April Nov/Jan Oct/Nov Feb	Mediterranean Mediterranean Arid Region Mediterranean
Onion (dry)	15 20	25 35	70 110	40 45	150 210	April Oct; Jan.	Mediterranean Arid Region; Calif.
Onion (green)	25 20 30	30 45 55	10 20 55	5 10 40	70 95 180	April/May October March	Mediterranean Arid Region Calif., USA
Onion (seed)	20	45	165	45	275	Sept	Calif. Desert, USA
Spinach	20 20	20 30	15/25 40	5 10	60/70 100	Apr; Sep/Oct November	Mediterranean Arid Region
Radish	5 10	10 10	15 15	5 5	35 40	Mar/Apr Winter	Medit.; Europe Arid Region
b. Vegetables – Solanum Family *(Solanaceae)*							
Egg plant	30 30	40 45	40 40	20 25	130\140	October May/June	Arid Region Mediterranean
Sweet peppers (bell)	25/30 30	35 40	40 110	20 30	125 210	April/June October	Europe and Medit. Arid Region
Tomato	30 35 25 35 30	40 40 40 45 40	40 50 60 70 45	25 30 30 30 30	135 155 155 180 145	January Apr/May Jan Oct/Nov April/May	Arid Region Calif., USA Calif. Desert, USA Arid Region Mediterranean
c. Vegetables - Cucumber Family *(Cucurbitaceae)*							
Cantaloupe	30 10	45 60	35 25	10 25	120 120	Jan Aug	Calif., USA Calif., USA
Cucumber	20 25	30 35	40 50	15 20	105 130	June/Aug Nov; Feb	Arid Region Arid Region
Pumpkin, Winter squash	20 25	30 35	30 35	20 25	100 120	Mar, Aug June	Mediterranean Europe
Squash, Zucchini	25 20	35 30	25 25	15 15	100 90	Apr; Dec. May/June	Medit.; Arid Reg. Medit.; Europe

* Lengths of crop development stages provided in this table are indicative of general conditions, but may vary substantially from region to region, with climate and cropping conditions, and with crop variety. The user is strongly encouraged to obtain appropriate local information.

1 Crucifers include cabbage, cauliflower, broccoli, and Brussel sprouts. The wide range in lengths of seasons is due to varietal and species differences.

Table II.1 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	*Mid* (L_{mid})	*Late* (L_{late})	Total	Plant Date	Region
Sweet melons	25 30 15 30	35 30 40 45	40 50 65 65	20 30 15 20	120 140 135 160	May March Aug Dec/Jan	Mediterranean Calif., USA Calif. Desert, USA Arid Region
Water melons	20 10	30 20	30 20	30 30	110 80	April Mat/Aug	Italy Near East (desert)
d. Roots and Tubers							
Beets, table	15 25	25 30	20 25	10 10	70 90	Apr/May Feb/Mar	Mediterranean Mediterranean & Arid
Cassava: year 1 year 2	20 150	40 40	90 110	60 60	210 360	Rainy season	Tropical regions
Potato	25 25 30 45 30	30 30 35 30 35	30/45 45 50 70 50	30 30 30 20 25	115/130 130 145 165 140	Jan/Nov May April Apr/May Dec	(Semi)Arid Climate Continental Climate Europe Idaho, USA Calif. Desert, USA
Sweet potato	20 15	30 30	60 50	40 30	150 125	April Rainy seas.	Mediterranean Tropical regions
Sugarbeet	30 25 25 50 25 45 35	45 30 65 40 35 75 60	90 90 100 50 50 80 70	15 10 65 40 50 30 40	180 155 255 180 160 230 205	March June Sept April May Novembe r Novembe r	Calif., USA Calif., USA Calif. Desert, USA Idaho, USA Mediterranean Mediterranean Arid Regions
e. Legumes (*Leguminosae*)							
Beans (green)	20 15	30 25	30 25	10 10	90 75	Feb/Mar Aug/Sep	Calif., Mediterranean Calif., Egypt, Lebanon
Beans (dry)	20 15 25	30 25 25	40 35 30	20 20 20	110 95 100	May/June June June	Continental Climates Pakistan, Calif. Idaho, USA
Faba bean, broad bean - dry - green	15 20 90 90	25 30 45 45	35 35 40 40	15 15 60 0	90 100 235 175	May Mar/Apr Nov Nov	Europe Mediterranean Europe Europe
Green gram, cowpeas	20	30	30	20	110	March	Mediterranean
Groundnut	25 35 35	35 35 45	45 35 35	25 35 25	130 140 140	Dry season May May/June	West Africa High Latitudes Mediterranean
Lentil	20 25	30 35	60 70	40 40	150 170	April Oct/Nov	Europe Arid Region
Peas	15 20 35	25 30 25	35 35 30	15 15 20	90 100 110	May Mar/Apr April	Europe Mediterranean Idaho, USA
Soybeans	15 20 20	15 30/35 25	40 60 75	15 25 30	85 140 150	Dec May June	Tropics Central USA Japan

continued…

Table II.1 continued.

Crop	Init. (L_{ini})	Dev. (L_{dev})	*Mid* (L_{mid})	*Late* (L_{late})	Total	Plant Date	Region
f. Perennial Vegetables (with winter dormancy and initially bare or mulched soil)							
Artichoke	40 20	40 25	250 250	30 30	360 325	Apr (1st yr) May (2nd yr)	California (cut in May)
Asparagus	50 90	30 30	100 200	50 45	230 365	Feb Feb	Warm Winter Mediterranean
g. Fibre Crops							
Cotton	30 45 30 30	50 90 50 50	60 45 60 55	55 45 55 45	195 225 195 180	Mar-May Mar Sept April	Egypt; Pakistan; Calif. Calif. Desert, USA Yemen Texas
Flax	25 30	35 40	50 100	40 50	150 220	April October	Europe Arizona
h. Oil Crops							
Castor beans	25 20	40 40	65 50	50 25	180 135	March Nov.	(Semi)Arid Climates Indonesia
Safflower	20 25 35	35 35 55	45 55 60	25 30 40	125 145 190	April Mar Oct/Nov	California, USA High Latitudes Arid Region
Sesame	20	30	40	20	100	June	China
Sunflower	25	35	45	25	130	April/May	Medit.; California
i. Cereals							
Barley/Oats/ Wheat	15 20 15 40 40 20	25 25 30 30 60 50	50 60 65 40 60 60	30 30 40 20 40 30	120 135 150 130 200 160	Novembe r March/Ap r July Apr Nov Dec	Central India 35-45 °L East Africa Calif. Desert, USA
Winter Wheat	20[2] 30 160	60[2] 140 75	70 40 75	30 30 25	180 240 335	December Novembe r October	Calif., USA Mediterranean Idaho, USA
Grains (small)	20 25	30 35	60 65	40 40	150 165	April Oct/Nov	Mediterranean Pakistan; Arid Reg.
Maize (grain)	30 25 20 20 30 30	50 40 35 35 40 40	60 45 40 40 50 50	40 30 30 30 30 50	180 140 125 125 150 170	April Dec/Jan June October April April	East Africa (alt.) Arid Climate Nigeria (humid) India (dry, cool) Spain (spr, sum.); Calif. Idaho, USA
Maize (sweet)	20 20 20 30 20	20 25 30 30 40	30 25 50/30 30 70	10 10 10 10[3] 10	80 80 90 110 140	March May/June Oct/Dec April Jan	Philippines Mediterranean Arid Climate Idaho, USA Calif. Desert, USA
Millet	15 20	25 30	40 55	25 35	105 140	June April	Pakistan Central USA

continued…

[2] These periods for winter wheat will lengthen in frozen climates according to days having zero growth potential and wheat dormancy . Under general conditions and in the absence of local data, fall planting of winter wheat can be presumed to occur in northern temperate climates when the 10-day running average of mean daily air temperature decreases to 17° C or December 1, whichever comes first. Planting of spring wheat can be presumed to occur when the 10-day running average of mean daily air temperature increases to 5° C. Spring planting of maize-grain can be presumed to occur when the 10-day running average of mean daily air temperature increases to 13° C.

[3] The late season for sweet maize will be about 35 days if the grain is allowed to mature and dry.

Table II.1 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Sorghum	20 20	35 35	40 45	30 30	130 140	May/June Mar/April	USA, Pakis., Med. Arid Region
Rice	30 30	30 30	60 80	30 40	150 180	Dec; May May	Tropics; Mediterranean Tropics
j. Forages							
Alfalfa, total season[4]	10	30	var.	var.	var.		last -4°C in spring until first -4°C in fall
Alfalfa[4] 1st cutting cycle	10 10	20 30	20 25	10 10	60 75	Jan Apr (last -4° C)	Calif., USA. Idaho, USA.
Alfalfa[4], other cutting cycles	5 5	10 20	10 10	5 10	30 45	Mar Jun	Calif., USA. Idaho, USA.
Bermuda for seed	10	25	35	35	105	March	Calif. Desert, USA
Bermuda for hay (several cuttings)	10	15	75	35	135	---	Calif. Desert, USA
Grass Pasture[4]	10	20	--	--	--		7 days before last -4°C in spring until 7 days after first -4°C in fall
Sudan, 1st cutting cycle	25	25	15	10	75	Apr	Calif. Desert, USA
Sudan, other cutting cycles	3	15	12	7	37	June	Calif. Desert, USA
k. Sugar Cane							
Sugarcane, virgin	35 50 75	60 70 105	190 220 330	120 140 210	405 480 720		Low Latitudes Tropics Hawaii, USA
Sugarcane, ratoon	25 30 35	70 50 105	135 180 210	50 60 70	280 320 420		Low Latitudes Tropics Hawaii, USA
l. Tropical Fruits and Trees							
Banana, 1st yr	120	90	120	60	390	Mar	Mediterranean
Banana, 2nd yr	120	60	180	5	365	Feb	Mediterranean
Pineapple	60	120	600	10	790		Hawaii, USA
m. Grapes and Berries							
Grapes	20 20 20 30	40 50 50 60	120 75 90 40	60 60 20 80	240 205 180 210	April Mar May April	Low Latitudes Calif., USA High Latitudes Mid Latitudes (wine)
Hops	25	40	80	10	155	April	Idaho, USA
n. Fruit Trees							
Citrus	60	90	120	95	365	Jan	Mediterranean
Deciduous Orchard	20 20 30	70 70 50	90 120 130	30 60 30	210 270 240	March March March	High Latitudes Low Latitudes Calif., USA

continued…

4 In climates having killing frosts, growing seasons can be estimated for alfalfa and grass as:
alfalfa: last -4°C in spring until first -4°C in fall (Everson, D.O., M. Faubion and D.E. Amos 1978. "Freezing temperatures and growing seasons in Idaho." Univ. Idaho Agric. Exp. station bulletin 494. 18 p.)
grass: 7 days before last -4°C in spring and 7 days after last -4°C in fall (Kruse E.G. and Haise, H.R. 1974. "Water use by native grasses in high altitude Colorado meadows." USDA Agric. Res. Service, Western Region report ARS-W-6-1974. 60 pages)

Table II.1 continued

Crop	Init. (L_{ini})	Dev. (L_{dev})	Mid (L_{mid})	Late (L_{late})	Total	Plant Date	Region
Olives	30	90	60	90	270[5]	March	Mediterranean
Pistachios	20	60	30	40	150	Feb	Mediterranean
Walnuts	20	10	130	30	190	April	Utah, USA
o. Wetlands - Temperate Climate							
Wetlands (Cattails, Bulrush)	10 180	30 60	80 90	20 35	140 365	May November	Utah, USA; killing frost Florida, USA
Wetlands (short veg.)	180	60	90	35	365	November	frost-free climate

[5] Olive trees gain new leaves in March. See footnote 24 of Table 12 for additional information, where the K_c continues outside of the "growing period".

Primary source: FAO Irrigation and Drainage Paper 24 (Doorenbos and Pruitt, 1977), Table 22.

Annex III: Indicative values for soil salinity tolerance for some agriculture crops

References

Ayers, R.S. and D.W. Westcot. 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper N° 29. Rome, Italy. 174 p.

Allen, R., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper N° 56. Rome, Italy. 300 p.

Table III-1. Salt tolerance[4] of common agriculture crops with indication of the lower (ECe_n) and upper (ECe_x) thresholds[5] for salinity stress, and the slope of reduction in crop yield with increasing salinity beyond ECe_n

Agriculture crop	ECe_n	ECe_x	Yield decline
	dS/m	dS/m	%/(dS/m)
Extremely sensitive crops			
Apricot	1.6	5.8	24.0
Blackberry	1.5	6.0	22.0
Boysenberry	1.5	6.0	22.0
Peaches	1.7	6.5	21.0
Beans	1.0	6.3	19.0
Almonds	1.5	6.8	19.0
Sensitive crops			
Plum, prune	1.5	7.1	18.0
Strawberries	1.3	7.3	17.0
Onions	1.2	7.5	16.0
Citrus (Grapefruit)	1.8	8.1	16.0
Citrus (Orange)	1.7	8.0	16.0
Carrots	1.0	8.1	14.0
Peas	1.5	8.6	14.0
Rice	3.0	11.3	12.0
Moderately sensitive crops			
Groundnut (Peanut)	3.2	6.6	29.0
Trefoil, big	2.3	7.6	19.0
Squash (scallop)	3.2	9.5	16.0
Peppers	1.6	9.3	13.0
Pumpkin, winter squash	1.2	8.9	13.0
Lettuce	1.5	9.8	12.0
Potato	1.7	10.0	12.0
Flax	1.7	10.0	12.0
Maize	1.7	10.0	12.0
Maize, sweet corn	1.7	10.0	12.0

[4] The ranking is based on the ECe of the upper and lower threshold (Gullentops, C. 2010 – Introducing soil salinity in AquaCrop. Master research, Interuniversity programme in water Resources Engineering (IUPWARE), Belgium).
[5] ECe means average root zone salinity as measured by electrical conductivity of the saturation extract of the soil. ECe_n is the lower thresholds at which crop growth starts to be affected and ECe_x is the upper threshold at which crop growth ceases.

Clover (alsike, ladino, red)	1.5	9.8	12.0
Cabbage	1.4	10.1	11.9
Spinach	2.6	12.2	11.9
Cowpea (forage)	2.5	11.6	11.0
Vetch, common	3.0	12.1	11.0
Radishes	1.6	12.0	10.3
Cucumber	1.8	12.8	10.0
Sweet potato	2.0	12.0	10.0
Brussels sprouts	1.8	12.1	9.7
Celery	2.2	14.1	9.6
Broadbean (fababean)	1.6	12.0	9.6
Foxtail	1.5	11.9	9.6
Grapes	1.5	12.0	9.6
Broccoli	2.8	13.7	9.2
Tomato	1.7	12.8	9.0
Turnip	0.9	12.0	9.0
Lovegrass	2.0	13.9	8.4
Maize (forage)	1.8	15.3	7.4
Alfalfa	2.0	15.7	7.3
Sesbania	2.3	16.6	7.0
Sphaerophysa	2.2	16.5	7.0
Cauliflower	1.8	17.9	6.2
Orchardgrass	1.5	17.6	6.2
Sugar cane	1.7	18.6	5.9
Clover, Berseem	1.5	19.0	5.7
Moderately tolerant crops			
Soybeans	5.0	10.0	20.0
Sorghum	6.8	13.1	16.0
Cowpea	4.9	13.2	12.0
Squash, Zucchini	4.7	14.7	10.0
Trefoil, narrowleaf birdsfoot	5.0	15.0	10.0
Beets, red	4.0	15.1	9.0
Hardinggrass	4.6	17.8	7.6
Rye-grass (perennial)	5.6	18.8	7.6
Wheat (Triticum aestivum)	6.0	20.1	7.1
Barley (forage)	6.0	20.1	7.1
Wildrye, beardless	2.7	19.4	6.0
Fescue	3.9	21.4	5.8

Sudangrass	2.8	26.1	4.3
Wheatgrass, standard crested	3.5	28.5	4.0
Tolerant crops			
Wheatgrass, fairway crested	7.5	22.0	6.9
Bermuda	6.9	22.5	6.4
Sugar beet	7.0	24.0	5.9
Cotton	7.7	26.9	5.2
Barley	8.0	28.0	5.0
Extremely tolerant crops			
Wheat, durum (Triticum turgidum)	5.8	28.0	4.7
Wheatgrass, tall	7.5	31.3	4.2
Date Palms	4.0	31.8	3.6
Wheat, semidwarf (T. aestivum)	8.6	41.9	3.0
Asparagus	4.1	54.1	2.0

Annex IV: ETo calculation procedures

Calculation methods listed in this annex are outlined in the FAO Irrigation and Drainage Paper n° 56 (Allen et al., 1998).

1. Atmospheric parameters

- **Atmospheric pressure (P)**

The atmospheric pressure, P, is the pressure exerted by the weight of the earth's atmosphere:

$$P = 101.3\left(\frac{293 - 0.0065\,z}{293}\right)^{5.26} \qquad \text{(Eq. 1)}$$

where P atmospheric pressure [kPa],
z elevation above sea level [m].

- **Psychrometric contant (γ)**

The psychrometric constant, γ, is given by:

$$\gamma = \frac{c_p\ P}{\varepsilon\ \lambda} = 0.664742\,x10^{-3}\ P \qquad \text{(Eq. 2)}$$

where γ psychrometric constant [kPa °C^{-1}],
P atmospheric pressure [kPa],
λ latent heat of vaporization, 2.45 [MJ kg^{-1}],
c_p specific heat at constant pressure, 1.013 10^{-3} [MJ kg^{-1} °C^{-1}],
ε ratio molecular weight of water vapour/dry air = 0.622.

The value of the latent heat varies as a function of temperature. As λ varies only slightly over normal temperature ranges a single value of 2.45 MJ kg^{-1} is considered in the program. This corresponds with the calculation procedure for the FAO Penman-Monteith equation. The fixed value for λ is the latent heat for an air temperature of about 20°C.

2. Air temperature

- **Mean air temperature (T_{mean})**

The mean air temperature is given by:

$$T_{mean} = \frac{T_{max} + T_{min}}{2} \qquad \text{(Eq. 3)}$$

where T_{mean} mean air temperature [°C],
T_{min} minimum air temperature [°C],
T_{max} maximum air temperature [°C].

- **Calculation rules**

- if T_{max} and T_{min} are available, the mean air temperature (T_{mean}) is calculated by Eq. 3 and the specified mean air temperature is disregarded,
- if T_{mean} and only T_{max} or T_{min} are available, the missing minimum or maximum air temperature is estimated by rearranging Eq. 3,
- if T_{max} or T_{min} is missing and cannot be derived, ET_o cannot be calculated,
- if no temperature data is available, ETo can not be calculated.

3. Air humidity

- **Saturation vapour pressure as a function of air temperature (e°(T))**

$$e^o(T) = 0.6108 \exp\left[\frac{17.27\ T}{T + 237.3}\right] \qquad \text{(Eq. 4)}$$

where e°(T) saturation vapour pressure at the air temperature T [kPa],
T air temperature [°C],
exp[..] 2.7183 (base of natural logarithm) raised to the power [..].

- **Mean saturation vapour pressure for a day, 10-day, or month (e_s)**

Due to the non-linearity of Eq. 4, the mean saturation vapour pressure for a day, 10-day or month is computed as the mean between the saturation vapour pressure at the mean daily maximum and minimum air temperatures for that period:

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2} \qquad \text{(Eq. 5)}$$

where e_s saturation vapour pressure [kPa],
$e°(T_{max})$ saturation vapour pressure at the mean daily maximum air temperature [kPa],
$e°(T_{min})$ saturation vapour pressure at the mean daily minimum air temperature [kPa].

- **Slope of saturation vapour pressure curve (Δ)**

For the calculation of the reference evapotranspiration, the slope of the relationship between saturation vapour pressure and temperature, Δ, is required. The slope of the curve at a given temperature is given by:

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27\ T}{T + 237.3}\right)\right]}{(T + 237.3)^2} \qquad \text{(Eq. 6)}$$

where	Δ	slope of saturation vapour pressure curve at air temperature T [kPa °C^{-1}],
	T	air temperature [°C],
	exp[..]	2.7183 (base of natural logarithm) raised to the power [..].

- **Actual vapour pressure (e_a) derived from dewpoint temperature**

$$e_a = e^o(T_{dew}) = 0.6108\ \exp\left[\frac{17.27\ T_{dew}}{T_{dew} + 237.3}\right] \qquad \text{(Eq. 7)}$$

where	e_a	actual vapour pressure [kPa],
	T_{dew}	dew point temperature [°C].

- **Actual vapour pressure (e_a) derived from psychrometric data**

$$e_a = e^o(T_{wet}) - \gamma_{psy}(T_{dry} - T_{wet}) \qquad \text{(Eq. 8)}$$

where	e_a	actual vapour pressure [kPa],
	$e°(T_{wet})$	saturation vapour pressure at wet bulb temperature [kPa],
	γ_{psy}	psychrometric constant of the instrument [kPa °C^{-1}],
	T_{dry}-T_{wet}	wet bulb depression, with T_{dry} the dry bulb and T_{wet} the wet bulb temperature [°C].

The psychrometric constant of the instrument is given by:

$$\gamma_{psy} = a_{psy}\ P \qquad \text{(Eq. 9)}$$

where a_{psy} is a coefficient depending on the type of ventilation of the wet bulb [°C^{-1}], and P is the atmospheric pressure [kPa].

- **Actual vapour pressure (e_a) derived from relative humidity data**

The actual vapour pressure can also be calculated from the relative humidity. Depending on the availability of the humidity data, different equations are used:

For RH_{max} and RH_{min}:

$$e_a = \frac{e^o(T_{min})\frac{RH_{max}}{100} + e^o(T_{max})\frac{RH_{min}}{100}}{2} \quad \text{(Eq. 10)}$$

where
- e_a actual vapour pressure [kPa],
- $e°(T_{min})$ saturation vapour pressure at daily minimum temperature [kPa],
- $e°(T_{max})$ saturation vapour pressure at daily maximum temperature [kPa],
- RH_{max} maximum relative humidity [%],
- RH_{min} minimum relative humidity [%].

For RH_{max}:

$$e_a = e^o(T_{min})\frac{RH_{max}}{100} \quad \text{(Eq. 11)}$$

For RH_{mean} (Smith, 1992):

$$e_a = e^o(T_{mean})\frac{RH_{mean}}{100} \quad \text{(Eq. 12)}$$

Eq. 12 differs from the one presented in the FAO Irrigation and Drainage Paper N° 56. Analysis with several climatic data sets proved that more accurate estimates of e_a can be obtained with Eq. 12 than with the equation reported in the FAO paper if only mean relative humidity is available (G. Van Halsema and G. Muñoz, Personal communication).

• Vapour pressure deficit (e_s - e_a)

The vapour pressure deficit is the difference between the saturation (e_s) and actual vapour pressure (e_a) for a given time period.

• Calculation rules

If air humidity data are missing or if several climatic parameters are available with which the air humidity can be estimated, the following calculation rules exist:

- If the mean actual vapour pressure (e_a) is missing and air humidity is specified by means of another climatic parameter, e_a is estimated from (in descending order):
    - the specified mean dew point temperature T_{dew} (Eq. 7),
    - the specified mean dry (T_{dry}) and wet bulb (T_{wet}) temperature (Eq. 8),
    - the specified maximum (RH_{max}) and minimum (RH_{min}) relative humidity, and the specified maximum (T_{max}) and minimum (T_{min}) air temperature (Eq. 10). In case RH_{mean} and only RH_{max} or RH_{min} are available, the program estimates the missing minimum or maximum relative humidity by rearranging Eq. 13:

$$RH_{mean} = \frac{RH_{max} + RH_{min}}{2} \quad \text{(Eq. 13)}$$

  - the specified maximum (RH_{max}) and minimum (T_{min}) air temperature (Eq. 11),
  - the specified mean (RH_{mean}) and mean (T_{mean}) air temperature (Eq. 12).
- If no air humidity data are available, e_a is estimated by assuming that the minimum air temperature (T_{min}) is a good estimate for the mean dew point temperature (T_{dew}). Before using T_{min} in Eq. 7, the number of degrees specified in the ***Data and ETo menu*** (Missing air humidity in the Input data description sheet) will be subtracted from T_{min}.

4. Radiation

- ## Extraterrestrial radiation (Ra)

The extraterrestrial radiation, R_a, for each day of the year and for different latitudes is estimated from the solar constant, the solar declination and the time of the year by:

$$R_a = \frac{24\ (60)}{\pi}\ G_{sc}\ d_r\ \left[\omega_s\ \sin(\varphi)\ \sin(\delta) + \cos(\varphi)\ \cos(\delta) \sin(\omega_s)\right] \qquad \text{(Eq. 14)}$$

where
- R_a extraterrestrial radiation [MJ m^{-2} day^{-1}],
- G_{sc} solar constant = 0.0820 MJ m^{-2} min^{-1},
- d_r inverse relative distance Earth-Sun (Eq. 16),
- ω_s sunset hour angle (Eq. 18) [rad],
- φ latitude [rad] (Eq. 15),
- δ solar declination (Eq. 17) [rad].

The latitude, φ, expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The conversion from decimal degrees to radians is given by:

$$\left[\text{Radians}\right] = \frac{\pi}{180}\ \left[\text{decimal degrees}\right] \qquad \text{(Eq. 15)}$$

The inverse relative distance Earth-Sun, d_r, and the solar declination, δ, are given by:

$$d_r = 1 + 0.033 \cos\left(\frac{2\ \pi}{365}\ J\right) \qquad \text{(Eq. 16)}$$

$$\delta = 0.409\ \sin\left(\frac{2\ \pi}{365}\ J - 1.39\right) \qquad \text{(Eq. 17)}$$

where J is the number of the day in the year between 1 (1 January) and 365 or 366 (31 December).

The sunset hour angle, ω_s, is given by:

$$\omega_s = \arccos\ \left[-\tan(\varphi) \tan(\delta)\right] \qquad \text{(Eq. 18)}$$

- ## Daylight hours (N)

The daylight hours, N, are given by:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \qquad \text{(Eq. 19)}$$

$$N = \frac{24}{\pi}\, \omega_s \qquad \text{(Eq. 20)}$$

where ω_s sunset hour angle in radians given by Eq. 18.

- **Solar radiation (R_s)**

If the solar radiation, R_s, is not measured, it can be calculated with the Angstrom formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

where
- R_s solar or shortwave radiation [MJ m^{-2} day^{-1}],
- n actual duration of sunshine [hour],
- N maximum possible duration of sunshine or daylight hours [hour],
- n/N relative sunshine duration [-],
- R_a extraterrestrial radiation [MJ m^{-2} day^{-1}],
- a_s regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0),
- a_s+b_s fraction of extraterrestrial radiation reaching the earth on clear days (n = N).

The default values for a_s and b_s are 0.25 and 0.50. If the user has site specific information, calibrated values for a_s and b_s can be specified in the ***Data and ETo menu*** (Calculation method and coefficients).

- **Clear-sky solar radiation (R_{so})**

The calculation of the clear-sky radiation, R_{so}, when n = N, is required for computing net longwave radiation. Depending on the option selected in the ***Data and ETo menu*** (Calculation method and coefficients) Eq. 21 or 22 is used

When adjustment for station elevation is requested:

$$R_{so} = \left(0.75 + 2\ 10^{-5}\ z\right) R_a \qquad \text{(Eq. 21)}$$

where
- R_{so} clear-sky solar radiation [MJ m^{-2} day^{-1}],
- z station elevation above sea level [m],
- R_a extraterrestrial radiation [MJ m^{-2} day^{-1}].

When no adjustment for station elevation is requested (calibrated values for a_s and b_s are available):

$$R_{so} = (a_s + b_s)\, R_a \qquad \text{(Eq. 22)}$$

where a_s+b_s fraction of extraterrestrial radiation reaching the earth on clear-sky days (n = N).

- **Net solar or net shortwave radiation (R_{ns})**

The net shortwave radiation resulting from the balance between incoming and reflected solar radiation is given by:

$$R_{ns} = (1 - \alpha) R_s \qquad \text{(Eq. 23)}$$

where R_{ns} net solar or shortwave radiation [MJ m^{-2} day^{-1}],
α albedo or canopy reflection coefficient for the reference crop [dimensionless],
R_s the incoming solar radiation [MJ m^{-2} day^{-1}].

If net solar radiation needs to be calculated when computing ET_o, the fixed value of 0.23 is used for the albedo in Eq. 23.

- **Net longwave radiation (R_{nl})**

$$R_{nl} = \sigma \left[\frac{T_{max,K}{}^4 + T_{min,K}{}^4}{2} \right] \left(0.34 - 0.14 \sqrt{e_a}\right) \left(1.35 \frac{R_s}{R_{so}} - 0.35\right) \qquad \text{(Eq. 24)}$$

where
R_{nl} net outgoing longwave radiation [MJ m^{-2} day^{-1}],
σ Stefan-Boltzmann constant [4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}],
$T_{max,K}$ maximum absolute temperature during the 24-hour period [K = °C + 273.16],
$T_{min,K}$ minimum absolute temperature during the 24-hour period [K = °C + 273.16],
e_a actual vapour pressure [kPa],
R_s/R_{so} relative shortwave radiation (limited to ≤ 1.0),
R_s measured or calculated (Eq. 20) solar radiation [MJ m^{-2} day^{-1}],
R_{so} calculated (Eq. 21, or Eq. 22) clear-sky radiation [MJ m^{-2} day^{-1}].

When maximum and minimum air temperature are missing, $\left[\frac{T^4_{\max,K} + T^4_{\min,K}}{2}\right]$ in Eq. 24 is replaced by $\left[T^4_{mean,K}\right]$.

- **Net radiation (R_n)**

The net radiation (R_n) is the difference between the incoming net shortwave radiation (R_{ns}) and the outgoing net longwave radiation (R_{nl}):

$$R_n = R_{ns} - R_{nl} \qquad \text{(Eq. 25)}$$

- **Calculation rules**

If sunshine or radiation data are missing or if several climatic parameters are available with which radiation can be estimated, the following calculation rules exist:

- If net radiation (R_n) is missing, R_n is cacultated by Eq. 25,
- If Rn and solar radiation (R_s) are missing, R_s is derived from (in descending order):
  - the specified hours of bright sunshine n (Eq. 20),
  - the specified relative sunshine hours n/N (Eq. 20),
  - the maximum (T_{max}) and minimum (T_{min}) air temperature by means of the adjusted Hargreaves' radiation formula:

$$R_s = k_{Rs} \sqrt{(T_{max} - T_{min})}\ R_a \qquad \text{(Eq. 26)}$$

where R_a extraterrestrial radiation [MJ m^{-2} d^{-1}],
T_{max} maximum air temperature [°C],
T_{min} minimum air temperature [°C],
k_{Rs} adjustment coefficient [$°C^{-0.5}$].

The value for the adjustment coefficient k_{Rs} is specified in the ***Data and ETo menu*** (Missing radiation data in the Input data description sheet). Indicative default values are 0.16 for interior locations and 0.19 for coastal locations.

5. Wind speed

- **Adjustment of wind speed to standard height**

To adjust wind speed data obtained from instruments placed at elevations other than the standard height of 2 m:

$$u_2 = u_z \frac{4.87}{\ln(67.8\, z - 5.42)} \qquad \text{(Eq. 27)}$$

where u_2 wind speed at 2 m above ground surface [m s^{-1}],
u_z measured wind speed at z m above ground surface [m s^{-1}],
z height of measurement above ground surface [m].

- **Missing wind speed data**

If wind speed data is missing, the default value for u_2 specified in the ***Data and ETo menu*** (Missing wind speed in the Input data description sheet) is used.

6. Reference evapotranspiration (FAO Penman-Monteith)

The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the ASCE and European studies. The FAO Penman-Monteith equation (Allen et al., 1998) is given by:

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T + 273} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)} \qquad \text{(Eq. 28)}$$

where	ET_o	reference evapotranspiration [mm day^{-1}],
	R_n	net radiation at the crop surface [MJ m^{-2} day^{-1}],
	G	soil heat flux density [MJ m^{-2} day^{-1}],
	T	mean daily air temperature at 2 m height [°C],
	u_2	wind speed at 2 m height [m s^{-1}],
	e_s	saturation vapour pressure [kPa],
	e_a	actual vapour pressure [kPa],
	e_s-e_a	saturation vapour pressure deficit [kPa],
	Δ	slope vapour pressure curve [kPa °C^{-1}],
	γ	psychrometric constant [kPa °C^{-1}].

In Eq. 28, the value 0.408 converts the net radiation R_n expressed in MJ/m^2.day to equivalent evaporation expressed in mm/day. Because soil heat flux is small compared to R_n, particularly when the surface is covered by vegetation and calculation time steps are 24 hours or longer, the estimation of G is ignored in the ETo calculator and assumed to be zero. This corresponds with the assumptions reported in the FAO Irrigation and Drainage Paper n° 56 for daily and 10-daily time periods. Allen et al. (1989) state that the soil heat flux beneath the grass reference surface is relatively small for that time period.

7. Conversion to standard metric unit

To convert a value (***A***) expressed in a non-standard unit to a value (***Y***) expressed in the standard metric unit, the following equations are used in the software:

- **Temperature: standard unit is degree Celsius**

Temperature unit	Equation to convert to standard unit (°C)
degree Fahrenheit (°F)	***Y*** °C = (***A*** °F - 32) 5/9

- **Vapour pressure: standard unit is kilo Pascal**

Vapour pressure unit	Equation to convert to standard unit (kPa)
millibar	***Y*** kPa = 0.1 ***A*** mbar
pound per square inch (psi)	***Y*** kPa = 6.89476 ***A*** psi
atmospheres (atm)	***Y*** kPa = 101.325 ***A*** atm
millimetre of mercury (mmHg)	***Y*** kPa = 0.133322 ***A*** mmHg

- **Wind speed: standard unit is meter per second (m/s)**

Wind speed unit	Equation to convert to standard unit (m/s)
kilometre per day (km/day)	***Y*** m/s = (***A*** /86.40) km/day
nautical mile/hour (knot)	***Y*** m/s = 0.5144 ***A*** knot
foot per second (ft/s)	***Y*** m/s = 0.3048 ***A*** ft/sec

- **Radiation: standard unit is megajoules per square meter per day (MJ/m^2.day)**

Radiation unit	Equation to convert to standard unit (MJ/m^2.day)
watt per m^2 (W/m^2)	***Y*** MJ/m^2.day = 0.0864 ***A*** W/m^2
joule per cm^2 per day (J/cm^2.day)	***Y*** MJ/m^2.day = 0.01 ***A*** J/cm^2.day
equivalent evaporation (mm/day)	***Y*** MJ/m^2.day = 2.45 ***A*** mm/day
calorie per cm^2 per day (cal/cm^2.day)	***Y*** MJ/m^2.day = 4.1868 10^{-2} ***A*** cal/cm2.day

- **Evapotranspiration: standard unit is millimeter per day (mm/day)**

Evaporation unit	Equation to convert to standard unit (mm/day)
equivalent radiation in megajoules per square metre per day (MJ/m^2.day)	***Y***mm/day = 0.408 ***A*** MJ/m^2.day

References

Allen, R., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper N° 56. Rome, Italy.

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Smith, M. 1992. CROPWAT - a computer program for irrigation planning and management. FAO Irrigation and Drainage Paper N°46. Rome, Italy.