ANNEX 1
Crop parameters

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.

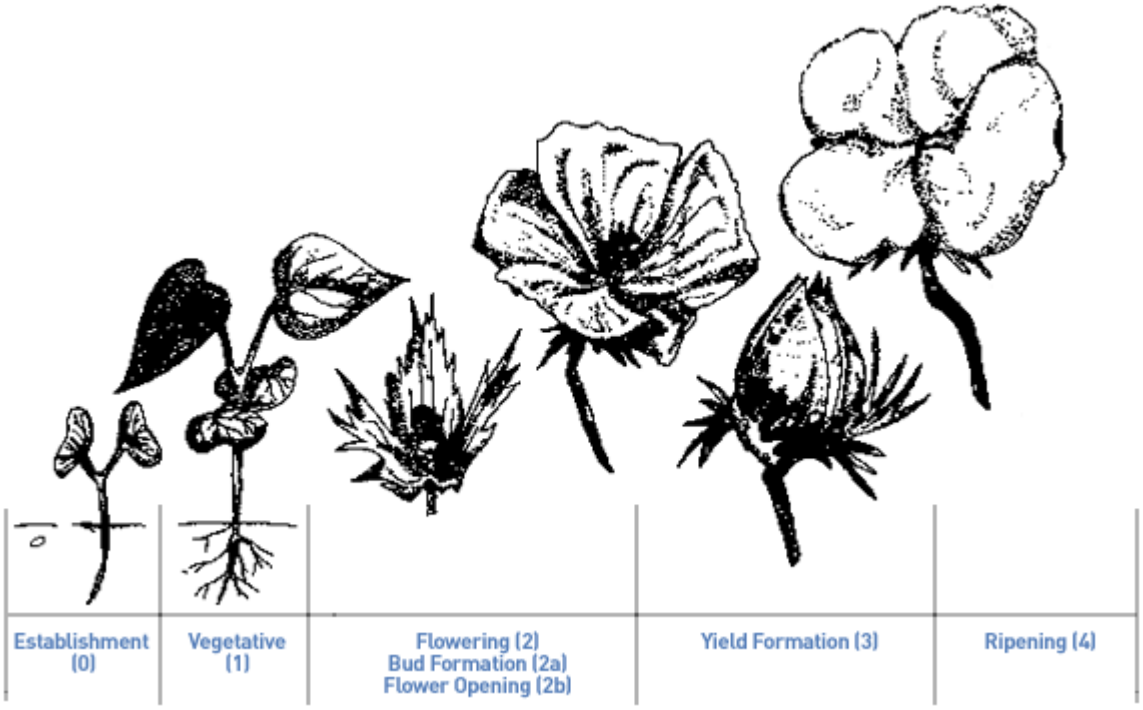
In using the tables the differences in thoroughness of calibration and validation of the parameters for the different crops should be considered. For the better tested crops, the values provided should yield reasonable results, although small adjustments in the parameter values may prove to be desirable. 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 cutout 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 favorable, new flowers and fruits are produced again. Cutout 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.

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 cutout 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 favorable, new flowers and fruits are produced again. Cutout 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 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 2.50
	Shape factor describing root zone expansion	Conservative [1]	1.5

I.1 Cotton continued

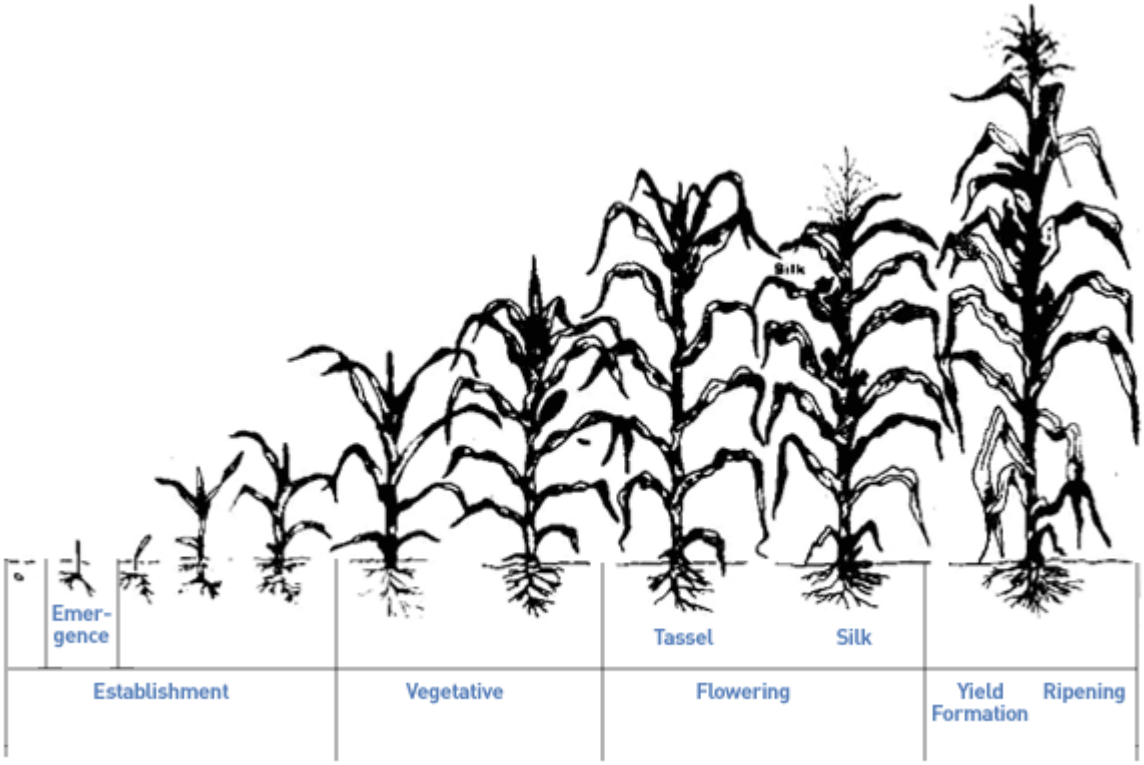
2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.30
	Effect of canopy cover 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]	0.65
	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]	0.75
	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

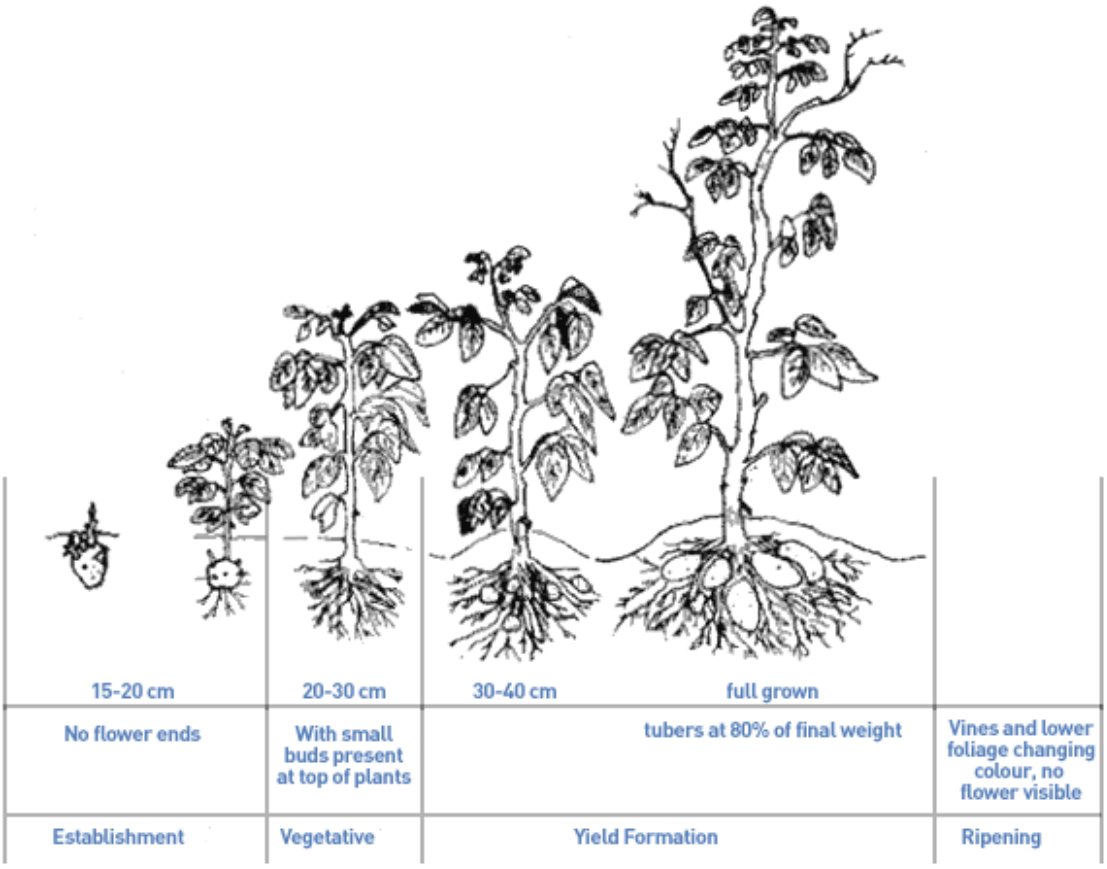
(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

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]	0.55
	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

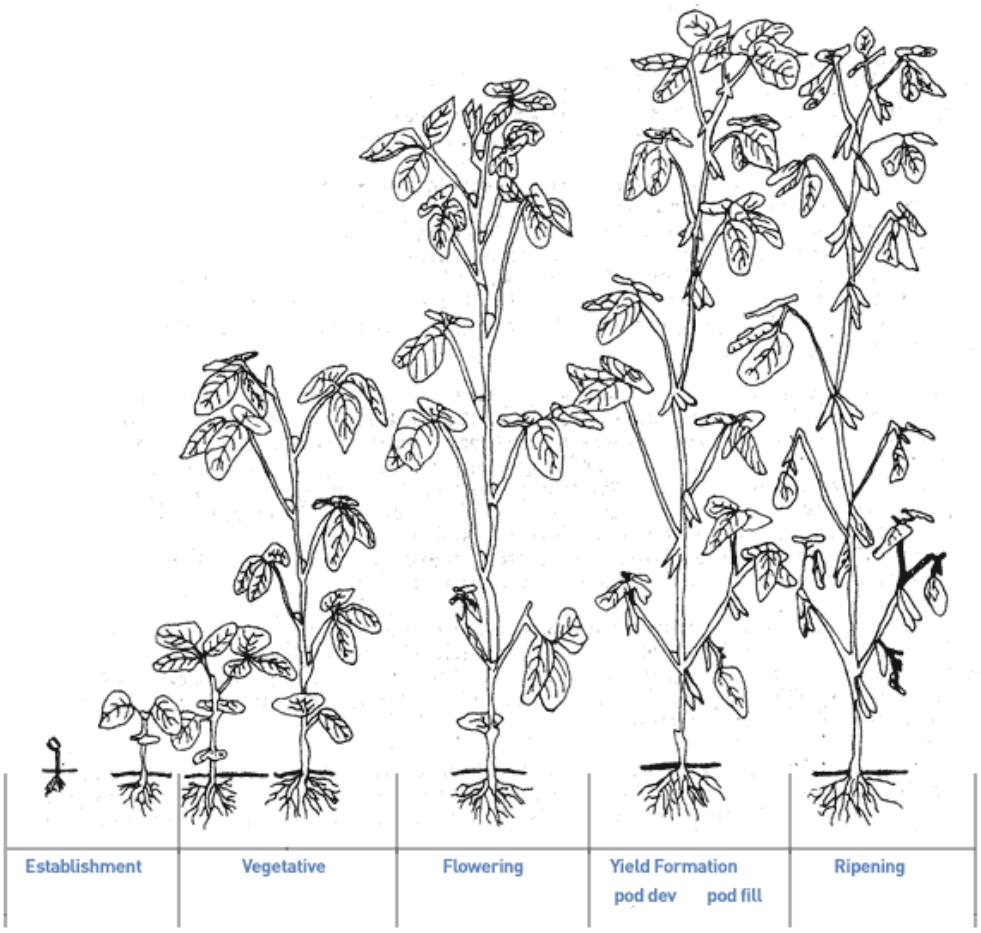
(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

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

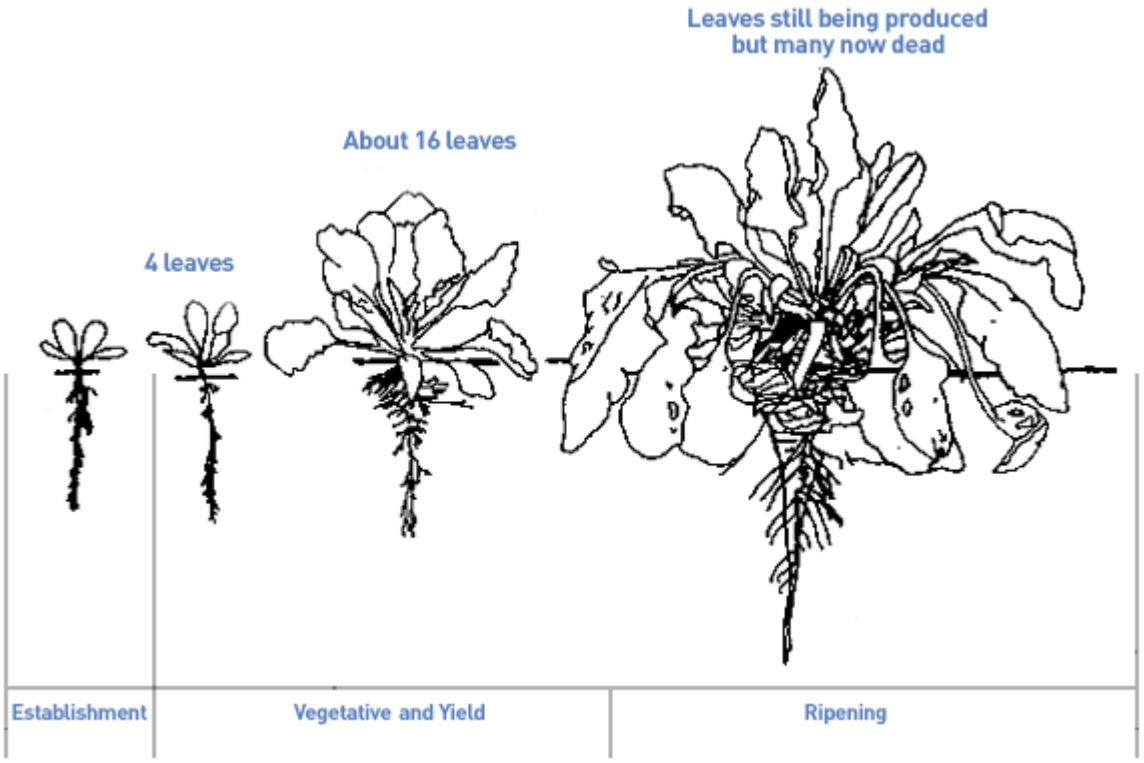
2. Crop transpiration			
Symbol		Type (1), (2), (3), (4)	Values / ranges
$Kc_{Tr,x}$	Crop coefficient when canopy is complete but prior to senescence	Conservative (1)	1.10
	Decline of crop coefficient (%/day) as a result of ageing, nitrogen deficiency, etc.	Conservative (1)	0.30
	Effect of canopy cover 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)]	0.50
	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)]	0.70
	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]	0.25
$p_{exp,upper}$	Soil water depletion threshold for canopy expansion - Lower threshold	Conservative [1]	0.70
	Shape factor for Water stress coefficient for canopy expansion	Conservative [1]	4.0
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]	0.75
	Shape factor for Water stress coefficient for canopy senescence	Conservative [1]	2.5
	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			
ECe_n	Electrical conductivity of the saturated soil-paste extract: lower threshold (at which soil salinity stress starts to occur)	Conservative [1]	7.0
ECe_x	Electrical conductivity of the saturated soil-paste extract: upper threshold (at which soil salinity stress has reached its maximum effect)	Conservative [1]	24.0

I.8 Sunflower

Establishment (0)	Vegetative (1)		Flowering (2)	Yield Formation (3)	Ripening (4)
20 days	early (1a) 30 days	late (1b) 25 days	30 days	25 days	15 days

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 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 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)

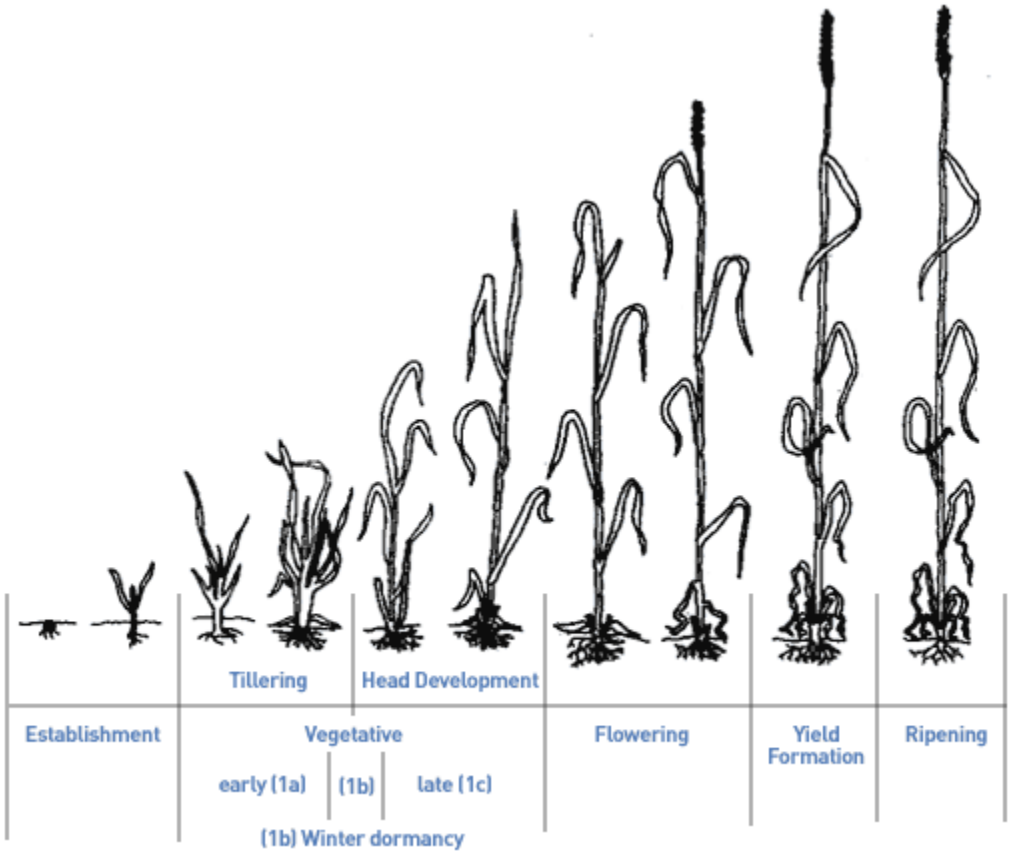
(1) Conservative generally applicable
(2) Conservative for a given specie but can or may be cultivar specific
(3) Dependent on environment and/or management
(4) Cultivar specific

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]	0.7
	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]	0.70
	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)

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	50/30	20	100	Oct/Jan	Arid climate
	30	40	60	20	150	Feb/Mar	Mediterranean
	30	50	90	30	200	Oct	Calif. Desert, USA
Cauliflower	35	50	40	15	140	Sept	Calif. Desert, USA
Celery	25	40	95	20	180	Oct	(Semi)Arid
	25	40	45	15	125	April	Mediterranean
	30	55	105	20	210	Jan	(Semi)Arid
Crucifers[1]	20	30	20	10	80	April	Mediterranean
	25	35	25	10	95	February	Mediterranean
	30	35	90	40	195	Oct/Nov	Mediterranean
Lettuce	20	30	15	10	75	April	Mediterranean
	30	40	25	10	105	Nov/Jan	Mediterranean
	25	35	30	10	100	Oct/Nov	Arid Region
	35	50	45	10	140	Feb	Mediterranean
Onion (dry)	15	25	70	40	150	April	Mediterranean
	20	35	110	45	210	Oct; Jan.	Arid Region; Calif.
Onion (green)	25	30	10	5	70	April/May	Mediterranean
	20	45	20	10	95	October	Arid Region
	30	55	55	40	180	March	Calif., USA
Onion (seed)	20	45	165	45	275	Sept	Calif. Desert, USA
Spinach	20	20	15/25	5	60/70	Apr; Sep/Oct	Mediterranean
	20	30	40	10	100	November	Arid Region
Radish	5	10	15	5	35	Mar/Apr	Medit.; Europe
	10	10	15	5	40	Winter	Arid Region
b. Vegetables – Solanum Family *(Solanaceae)*							
Egg plant	30	40	40	20	130\1	October	Arid Region
	30	45	40	25	40	May/June	Mediterranean
Sweet	25/30	35	40	20	125	April/June	Europe and Medit.
peppers (bell)	30	40	110	30	210	October	Arid Region
Tomato	30	40	40	25	135	January	Arid Region
	35	40	50	30	155	Apr/May	Calif., USA
	25	40	60	30	155	Jan	Calif. Desert, USA
	35	45	70	30	180	Oct/Nov	Arid Region
	30	40	45	30	145	April/May	Mediterranean
c. Vegetables - Cucumber Family *(Cucurbitaceae)*							
Cantaloupe	30	45	35	10	120	Jan	Calif., USA
	10	60	25	25	120	Aug	Calif., USA
Cucumber	20	30	40	15	105	June/Aug	Arid Region
	25	35	50	20	130	Nov; Feb	Arid Region
Pumpkin,	20	30	30	20	100	Mar, Aug	Mediterranean
Winter squash	25	35	35	25	120	June	Europe
Squash,	25	35	25	15	100	Apr; Dec.	Medit.; Arid Reg.
Zucchini	20	30	25	15	90	May/June	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	35	40	20	120	May	Mediterranean
	30	30	50	30	140	March	Calif., USA
	15	40	65	15	135	Aug	Calif. Desert, USA
	30	45	65	20	160	Dec/Jan	Arid Region
Water melons	20	30	30	30	110	April	Italy
	10	20	20	30	80	Mat/Aug	Near East (desert)
d. Roots and Tubers							
Beets, table	15	25	20	10	70	Apr/May	Mediterranean
	25	30	25	10	90	Feb/Mar	Mediterranean & Arid
Cassava: year 1	20	40	90	60	210	Rainy	Tropical regions
year 2	150	40	110	60	360	season	
Potato	25	30	30/45	30	115/130	Jan/Nov	(Semi)Arid Climate
	25	30	45	30	130	May	Continental Climate
	30	35	50	30	145	April	Europe
	45	30	70	20	165	Apr/May	Idaho, USA
	30	35	50	25	140	Dec	Calif. Desert, USA
Sweet potato	20	30	60	40	150	April	Mediterranean
	15	30	50	30	125	Rainy seas.	Tropical regions
Sugarbeet	30	45	90	15	180	March	Calif., USA
	25	30	90	10	155	June	Calif., USA
	25	65	100	65	255	Sept	Calif. Desert, USA
	50	40	50	40	180	April	Idaho, USA
	25	35	50	50	160	May	Mediterranean
	45	75	80	30	230	November	Mediterranean
	35	60	70	40	205	November	Arid Regions
e. Legumes (*Leguminosae*)							
Beans (green)	20	30	30	10	90	Feb/Mar	Calif., Mediterranean
	15	25	25	10	75	Aug/Sep	Calif., Egypt, Lebanon
Beans (dry)	20	30	40	20	110	May/June	Continental Climates
	15	25	35	20	95	June	Pakistan, Calif.
	25	25	30	20	100	June	Idaho, USA
Faba bean,	15	25	35	15	90	May	Europe
broad bean	20	30	35	15	100	Mar/Apr	Mediterranean
- dry	90	45	40	60	235	Nov	Europe
- green	90	45	40	0	175	Nov	Europe
Green gram, cowpeas	20	30	30	20	110	March	Mediterranean
Groundnut	25	35	45	25	130	Dry	West Africa
	35	35	35	35	140	season	High Latitudes
	35	45	35	25	140	May	Mediterranean
						May/June	
Lentil	20	30	60	40	150	April	Europe
	25	35	70	40	170	Oct/Nov	Arid Region
Peas	15	25	35	15	90	May	Europe
	20	30	35	15	100	Mar/Apr	Mediterranean
	35	25	30	20	110	April	Idaho, USA
Soybeans	15	15	40	15	85	Dec	Tropics
	20	30/35	60	25	140	May	Central USA
	20	25	75	30	150	June	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	40	250	30	360	Apr (1st yr)	California
	20	25	250	30	325	May (2nd yr)	(cut in May)
Asparagus	50	30	100	50	230	Feb	Warm Winter
	90	30	200	45	365	Feb	Mediterranean
g. Fibre Crops							
Cotton	30	50	60	55	195	Mar-May	Egypt; Pakistan; Calif.
	45	90	45	45	225	Mar	Calif. Desert, USA
	30	50	60	55	195	Sept	Yemen
	30	50	55	45	180	April	Texas
Flax	25	35	50	40	150	April	Europe
	30	40	100	50	220	October	Arizona
h. Oil Crops							
Castor beans	25	40	65	50	180	March	(Semi)Arid Climates
	20	40	50	25	135	Nov.	Indonesia
Safflower	20	35	45	25	125	April	California, USA
	25	35	55	30	145	Mar	High Latitudes
	35	55	60	40	190	Oct/Nov	Arid Region
Sesame	20	30	40	20	100	June	China
Sunflower	25	35	45	25	130	April/May	Medit.; California
i. Cereals							
Barley/Oats/	15	25	50	30	120	November	Central India
Wheat	20	25	60	30	135	March/Apr	35-45 °L
	15	30	65	40	150	July	East Africa
	40	30	40	20	130	Apr	
	40	60	60	40	200	Nov	
	20	50	60	30	160	Dec	Calif. Desert, USA
Winter Wheat	20[2]	60[2]	70	30	180	December	Calif., USA
	30	140	40	30	240	November	Mediterranean
	160	75	75	25	335	October	Idaho, USA
Grains (small)	20	30	60	40	150	April	Mediterranean
	25	35	65	40	165	Oct/Nov	Pakistan; Arid Reg.
Maize (grain)	30	50	60	40	180	April	East Africa (alt.)
	25	40	45	30	140	Dec/Jan	Arid Climate
	20	35	40	30	125	June	Nigeria (humid)
	20	35	40	30	125	October	India (dry, cool)
	30	40	50	30	150	April	Spain (spr, sum.); Calif.
	30	40	50	50	170	April	Idaho, USA
Maize (sweet)	20	20	30	10	80	March	Philippines
	20	25	25	10	80	May/June	Mediterranean
	20	30	50/30	10	90	Oct/Dec	Arid Climate
	30	30	30	10[3]	110	April	Idaho, USA
	20	40	70	10	140	Jan	Calif. Desert, USA
Millet	15	25	40	25	105	June	Pakistan
	20	30	55	35	140	April	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[1] of common agriculture crops with indication of the lower (ECe_n) and upper (ECe_x) thresholds[2] 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

[1] 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).

[2] 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