Geisenheim Irrigation Scheduling 2021 with kc values using the PENMAN-equation

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The Geisenheim Irrigation Scheduling calculates the frequency and amount of irrigation for open field vegetable crops and some agricultural crops.

Water consumption is calculated from a reference evapotranspiration, which is adjusted with kc values for the crop. **Water consumption** is contrasted with **rainfall** and **amounts of irrigation**.

1. Considering the initial deficit

The **soil moisture at the start of the calculation** must be known and included in the calculation as the **initial deficit.**

The initial deficit can be estimated, determined with soil samples or calculated approximately.

The initial deficit in spring can be calculated if kc values for bare soil (sand kc 0.1, clay kc 0.2) are used from the end of the last crop in the previous year to the new crop. For fields with winter crops, kc values for the respective crop are to be used.

The resulting deficit represents the initial deficit for the following crop. Larger deficits must be compensated with irrigation before starting the cultivation.

2. Amount of water to be applied at each irrigation cycle

Irrigation for vegetable crops starts at soil moisture levels of 60% available field capacity (FC) and fills the soil up to 90% FC. Most agricultural crops do not need to be irrigated until 30-50% FC is reached.

The **amount of water applied** depends on soil texture and rooting depth (Table 1). The amount has to be high enough to ensure that the currently rooted soil layer is soaked. For estimating the crops' rooting depths at their individual stages of development (Table 8) , data from IGZ Großbeeren were used (http://www.igzev.de/publikationen/IGZ_Duengung_im_Freilandgemuesebau.pdf).

Rain and irrigation soak the soil from top to bottom. Only after water saturation has been reached in the upper soil layers does the water penetrate into the next deeper soil layer. Therefore, amounts of water applied must be sized so that the upper rooted layers reach 100% FC and the lowest rooted layer is filled up to 90% FC only. That way, a water storage reserve for rainfall is maintained, the so-called **buffer**, to avoid seepage. If the infiltration capacity of the soil is limited, high amounts of water (e.g. >30 mm) should be spread over several days.

Table 1: The amount of water applied (mm) depending on soil texture and rooting depth

soil texture	buffer (mm)	amount of water applied (mm) for rooting depths of			water content at 100% FC (Vol.%)
		0 - 30 cm	0 - 60 cm	0 - 90 cm	
sand (S)	3	8	19	30	9%
weak loamy sand (lS)	4	12	28	44	13%
strong loamy sand (llS)	5	14	33	52	16%
sandy loam (sL)	6	17	40	63	19%
silty loam (uL)	7	20	47	74	22%
clayey loam (tL)	5	15	35	55	17%
loamy clay (lT)	4	13	30	47	14%
clay (T)	3	9	21	33	10%

Source of the FC values used: https://www.alb-bayern.de

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Table 2: Calculating method: amount of water applied

Calculation	Example: Soil layer of 30 cm depth on weak loamy sand (lS)	
Soil volume	1 m x 1 m x 0,3 m = 0,3 m^3	300 L/m^2
x water content at 100% FC	x 13 Vol.%	= 39 L/m^2
x proportion of FC used for irrigation	x (60 - 90% FC)	= 30% FC
= amount of irrigation water applied	39 L/m^2 x 30%	= 12 mm

Table 3: Calculating the amount of water applied and the buffer (mm) depending on rooting depth: Example: weak loamy sand (lS)
amount of water applied, buffer, remaining soil moisture

soil layer	rooting depth 30 cm	rooting depth 60 cm	rooting depth 90 cm
0-30 cm	0 - 60% FC 12 mm (60 - 90 % FC) 4 mm (90 - 100% FC)	16 mm (60 - 100% FC)	16 mm (60 - 100% FC)
30-60 cm		12 mm (60 - 90% FC) 4 mm	16 mm (60 - 100% FC)
60-90 cm			12 mm (60 - 90% FC) 4 mm
total	= 12 mm	16+12 = 28 mm	16+16+12 = 44 mm

3. Calculating the daily deficit

The **kc value** depends on the kind of vegetable and its stage of development (Table 8). The **reference evapotranspiration** according to the **"Penman equation"** may be calculated from data of an own weather station or obtained from a provider of weather data (e.g. German Weather Service DWD).

Calculation of the daily deficit:

$$Penman\ transpiration \times kc\ vaule - precipitation = daily\ defict$$

Example:
cauliflower stage 1

$$8.0\ mm \quad \times\ 0.5 \quad -\ 2\ mm \quad = 2.0\ mm$$

Example: kc values for cauliflower

stage 1

after transplanting: **kc 0.5**

stage 2

≥ 8 leaves: **kc 0.8**

stage 3

plant length ≥ 70%: **kc 1.2**

4. Calculating the total deficit and deciding to irrigate

The daily deficits are added up to a **total deficit**. If the **total deficit** reaches the sum of the **amount of water applied** and the **buffer** (e.g. 7/27: 12+4 mm), the **amount of water** (e.g. 12 mm) is applied and the buffer is not filled up. If the total deficit on the day of irrigation is significantly higher than the sum of the amount of water applied and the buffer, this total deficit minus the buffer is to be applied.

The actual **amount of water applied** is subtracted from the total deficit and the calculation continues.

If the **precipitation** exceeds the total deficit, e.g. on 7/29, the total deficit is set to zero and the calculation is suspended for two or three days.

Table 4: **Calculating the total deficit:** Example: cauliflower: stage 1, kc 0.5
weak loamy sand, rooting depth 30 cm: amount of water applied 12 mm, buffer 4 mm
from 7/31: stage 2, kc 0.8

Date	Penman transpiration [mm]	kc	Precipitation [mm]	Daily deficit [mm]	Amount of water applied [mm]	Total deficit [mm]
7/20			initial deficit:			0
7/21	8.0	x 0.5	- 2	= 2.0	→	0+2.0 = 2.0
7/22	6.0	0.5		3.0		2.0+3.0 = 5.0
7/23	7.3	0.5		3.7		8.7
7/24	5.3	0.5		2.7		11.4
7/25	4.7	0.5		2.4		13.8
7/26	5.1	0.5		2.6		16.4
7/27	3.2	0.5		1.6	**12**	16.4+1.6-12 = 6.0
7/28	7.7	0.5		3.9		9.9
7/29	5.7	0.5	**35**	-32.2		0.0
7/30	6.9	0.5		3.5		0.0
7/31	6.0	**0.8**		4.8		0.0
8/01	6.9	0.8		5.5		5.5

5. Further aspects

Calculation of the amount of water applied for different soil textures in individual layers.

If individual soil layers differ in their soil texture, the amount of water applied can be calculated individually with the FC values of Table 1.

Table 5: The amount of water applied for different soil textures in individual layers

soil layer	soil texture	water content at 100% FC (Vol.%)	amount of water applied (mm) at rooting depths of 30 cm	60 cm	90 cm
0 - 30 cm	sL	**19%**	**17 mm** (90-60%FC)	23 mm (100-60%FC)	23 mm (100-60%FC)
30 - 60 cm	lS	13%		12 mm (90-60%FC)	16 mm (100-60%FC)
60 - 90 cm	S	9%			8 mm (90-60%FC)
sum			17 mm	35 mm	47 mm
buffer			6 mm	4 mm	3 mm

The amount of water applied with drip irrigation

For calculating the amount of water applied for drip irrigation, the ratio of the width of the soaking zone to the drip line distance has to be considered.

Table 6: Calculation method: Amount of water applied for drip irrigation with dripper distances < 30 cm and soils with good water conductivity

Calculation	Example: 3 drippers/m^2
Amount of water applied for usual irrigation x width of the soaking zone : drip line distance	17 mm x 30 cm : 100 cm
= Amount of water applied for drip irrigation	= 5.1 mm
: dripper per area	: 3 drippers/m^2
= Amount of water applied per dripper	= 1.7 L/dripper

Table 7: Calculation method: Amount of water applied for drip irrigation with dripper distances > 30 cm or soils with poor water conductivity

Calculation	Example: 3 drippers/m^2	
Radius of soaking zone area of soaking zone Proportion of soaked soil surface	0,15 m 3,14 x 0,15 m x 0,15 m x 3 drippers 0,21 m^2/1,0 m^2	 = 0,21 m^2 = 21 %
Amount of water applied for usual irrigation	17 mm	
= Amount of water applied for drip irrigation	17 mm x 21%	= 3,6 mm
: dripper per area		: 3 drippers/m^2
= Amount of water applied per dripper		= 1,2 L/ dripper

Adjusting the water supply

An **adjustment factor** can be used to intentionally irrigate less, e.g., in case of limited water availability or special requirements for product size and quality.

However, reducing water supply could result in a total loss of harvest for the vegetable crop if market quality requirements cannot be met due to drought stress. Therefore, the adjustment factor should not fall below 0.7 and the crop should be intensively monitored if an adjustment factor is used.

Calculation of the daily deficit with the adjustment factor:

Example: cauliflower stage 1

$$\begin{array}{lllllllll} Penman\ transpiration & \times & kc\ vaule & \times & \boldsymbol{adjustment\ factor} & - & precipitation & = & daily\ defict \\ 8.0\ mm & \times & 0.5 & \times & \mathbf{0.7} & - & 2\ mm & = & 0.8\ mm \end{array}$$

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Table 8: Development stages, kc-values and rooting depths of vegetable and some field crops for the Geisenheim Irrigation Scheduling with the **original PENMAN**-equation

species	stage 1	stage 2	stage 3	stage 4
asparagus 1. year	 **developing sprouts** **0.5** **0-60 cm** [2])	 **well-developed cladophylls** from 0.7 to 0.8 [4]) **0-60 cm**	**begin of September** **0** **0-60 cm**	
asparagus ≥ 2. year	 **developing sprouts** **0.6** **0-90 cm**	 **well-developed cladophylls** from 0.8 to 1.1 [4]) **0-90 cm**	**begin of September** **0** **0-90 cm**	
beetroot	**after emergence** **0.4** **BBCH 09** **0-30 cm**	**≥ 4 leaves** **0.8** **BBCH 14** **0-30 cm**	**≥ 8 leaves** **1.2** **BBCH 18** **0-60 cm**	**100% ground-cover** **1.4** **BBCH 39** **0-60 cm**
broccoli [1])	 **after transplanting** **0.5** **BBCH 12 bis 13** **0-30 cm**	 **≥ 8 leaves** **0.8** **BBCH 18** **0-30 cm**	 **≥ 14 leaves** **1.4** **BBCH 114** **0-60 cm**	

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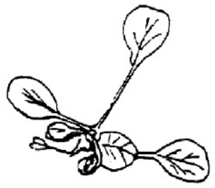
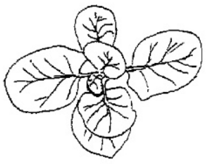
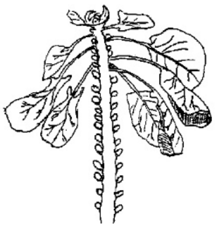
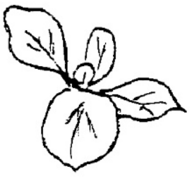
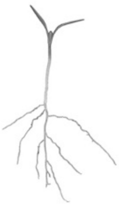
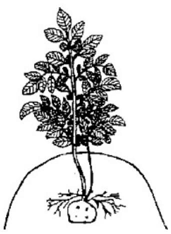
species	stage 1	stage 2	stage 3	stage 4
Brussels sprouts	 **after transplanting** **0.5** **BBCH 12 bis 13** **0-30 cm**	 **≥ 6 leaves** **0.8** **BBCH 16** **0-30 cm**	 **100% ground-cover** **1.2** **BBCH 37** **0-60 cm**	 **developing sprouts** **1.4** **BBCH 41** **0-90 cm**
bush bean [1])	 **after emergence** **0.3** **BBCH 09** **0-30 cm**	 **developing flowers** **0.8** **BBCH 61** **0-60 cm**	 **first fruit reaches maxi-mum length** **1.0** **BBCH 71** **0-60 cm**	
butterhead lettuce	 **after transplanting** **0.5** **BBCH 12 bis 13** **0-30 cm**	 **≥ 8 leaves** **0.8** **BBCH 18** **0-30 cm**	 **≥ 20% of the di-ameter of the head of lettuce** **1.2** **BBCH 42** **0-30 cm**	
cabbage [1])	 **after transplanting** **0.5** **BBCH 12 bis 13** **0-30 cm**	 **≥ 8 leaves** **0.6** **BBCH 18** **0-30 cm**	 **≥ 11 leaves** **0.7** **BBCH 111** **0-60 cm**	 **developing heads** **0.8** **BBCH 41** **0-60 cm**
carrot [1])	 **after emergence** **0.3** **BBCH 09** **0-30 cm**	 **≥ 5 leaves** **0.6** **BBCH 15** **0-30 cm**	 **100% ground-cover** **0.8** **BBCH 43** **0-60 cm**	

species	stage 1	stage 2	stage 3	stage 4
cauliflower [1])	 after transplanting **0.5** BBCH 12 bis 13 0-30 cm	 ≥ 8 leaves **0.8** BBCH 18 0-30 cm	 plant length ≥ 70% **1.2** BBCH 37 0-60 cm	
celeriac	 after transplanting **0.5** BBCH 12 bis 13 0-30 cm	 ≥ 7 leaves **0.8** BBCH 17 0-30 cm	 corm starts to develop **1.1** BBCH 42 0-60 cm	 100% ground-cover **1.4** BBCH 46 0-60 cm
chinese cabbage	 after transplanting **0.5** BBCH 12 bis 13 0-30 cm	 ≥ 6 leaves **0.8** BBCH 16 0-30 cm	 developing heads **1.2** BBCH 41 0-60 cm	
corn, sweet corn	after emergence **0.4** BBCH 09 0-30 cm	height ≥ 0.5 m from 0.4 to 0.5 [3]) BBCH 31 0-30 cm	height ≥ 1.0 m from 0.5 to 0.6 [3]) BBCH 33 0-60 cm	height ≥1.5 m from 0.6 to 0.8 [3]) BBCH 35 0-90 cm
cucumber	 after emergence **0.5** BBCH 09 0-30 cm	 developing flowers **0.8** BBCH 61 0-30 cm	 start of harvest **1.1** BBCH 71 0-30 cm	

species	stage 1	stage 2	stage 3	stage 4
curly kale	 **after transplanting** **0.5** **BBCH 12 bis 13** **0-30 cm**	 **≥ 6 leaves** **0.8** **BBCH 16** **0-30 cm**	 **intensive development of leaves** **1.2** **BBCH 35** **0-60 cm**	 **100% ground-cover** **1.4** **BBCH 39** **0-60 cm**
endive	**after transplanting** **0.5** **BBCH 12 bis 13** **0-30 cm**	**≥ 8 leaves** **0.8** **BBCH 18** **0-30 cm**	**≥ 50% of the di-ameter of the head of lettuce** **1.2** **BBCH 45** **0-60 cm**	
fava bean	 **after emergence** **0.5** **BBCH 09** **0-30 cm**	 **≥ 5 leaves** **0.8** **BBCH 35** **0-30 cm**	 **developing flowers** **1.2** **BBCH 61** **0-60 cm**	 **developing fruits** **1.4** **BBCH 71** **0-90 cm**
fennel [1])	 **after transplanting** **0.5** **BBCH 12 bis 13** **0-30 cm**	 **≥ 5 leaves** **1.0** **BBCH x15** **0-30 cm**	 **≥ 8 leaves** **1.4** **BBCH 18** **0-60 cm**	
grain [1])	 **after emergence** **0.4** **BBCH 09** **0-30 cm**	 **running to seed** **0.7** **BBCH 30** **0-90 cm**	**start of ripening** **0** **BBCH 85**	

species	stage 1	stage 2	stage 3	stage 4
iceberg lettuce	**after transplanting** **0.5** **BBCH 12 bis 13** **0-30 cm**	**≥ 8 leaves** **0.8** **BBCH 18** **0-30 cm**	**developing heads** **1.0** **BBCH 41** **0-30 cm**	**30% of diameter is reached** **1.2** **BBCH 43** **0-30 cm**
leek [1])	 **after transplanting** **0.5** **BBCH 12 bis 13** **0-30 cm**	 **diameter ≥ 13 mm** **0.8** **BBCH 42** **0-30 cm**	 **diameter ≥ 16 mm** **1.2** **BBCH 44** **0-60 cm**	 **diameter ≥ 20 mm** **1.4** **BBCH 46** **0-60 cm**
onion [1])	 **after emergence** **0.5** **BBCH 09** **0-30 cm**	 **≥ 5 leaves** **1.0** **BBCH 15** **0-30 cm**	 **≥ 8 leaves** **1.2** **BBCH 18** **0-60 cm**	 **bending leaves** **0** **BBCH 47** **0-60 cm**
parsley [1])	 **after emergence** **0.3** **BBCH 09** **0-30 cm**	 **≥ 5 leaves** **0.8** **BBCH 15** **0-30 cm**	 **after the 1^{st} yield** **1.0** **0-60 cm**	
potato [1])	 **after emergence** **0.4** **BBCH 09** **0-30 cm**	 **second sprout ≥ 5 cm** **0.6** **BBCH 22** **0-30 cm**	 **100% ground-cover** **0.8** **BBCH 39** **0-60 cm**	**0** **BBCH 91**

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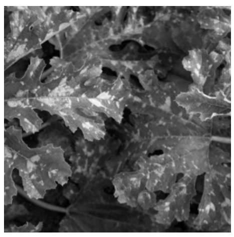
species	stage 1	stage 2	stage 3	stage 4
red radish *Raphanus sativus* var. *sativus*	 **after emergence** **0.5** **BBCH 09** **0-15 cm**	 **≥ 3 leaves** **0.8** **BBCH 13** **0-15 cm**		
whtie radish *Raphanus sativus* var. *niger*	**after emergence** **0.5** **BBCH 09** **0-30 cm**	**beet formation is starting** **0.8** **BBCH 41** **0-30 cm**	**50% beet diameter is reached** **1.0** **BBCH 45** **0-60 cm**	
sugar beet [1])	**after emergence** **0.2** **BBCH 09** **0-30 cm**	**≥ 5 leaves** **0.4** **BBCH 15** **0-30 cm**	**100% ground-cover** **0.6** **BBCH 39** **0-60 cm**	**beet diameter ≥ 12 cm till end of September** **0.8** **BBCH 45** **0-90 cm**
tomato, open field	 **after transplanting** **0.5** **BBCH 15** **0-30 cm**	 **height ≥ 0.75 m** **0.8** **BBCH 17** **0-30 cm**	 **height ≥ 1.0 m** **1.2** **BBCH 19** **0-60 cm**	
zucchini	 **after emergence** **0.5** **BBCH 09** **0-30 cm**	 **first flowers are developing** **0.8** **BBCH 61** **0-60 cm**	 **developing fruits** **1.2** **BBCH 71** **0-60 cm**	

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[1]) crop coeffients recently evaluated

[2]) All rooting depths were estimated with N-sampling depths from the Leibniz-Institut für Gemüse- und Zierpflanzenbau Großbeeren: http://www.igzev.de/publikationen/IGZ_Duengung_im_Freilandgemuesebau.pdf

[3]) depending on the development of plants

[4]) depending on the development of plants and irrigation technique

abscised leaved have to be counted too

diameter: percentage of the maximum value

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  url: http://www.mdpi.com/2311-7524/4/4/49/pdf.

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