

Evapotranspiration Crop Coefficients of Vegetable Crops for a Hot and Arid Climate

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ABSTRACT. Crop coefficients, with reference to alfalfa, were determined for four vegetable crops which could be used in estimating water requirements under the hot and arid conditions of Saudi Arabia. The vegetable crops and alfalfa were grown in lysimeters and the evapotranspiration (ET) was measured. Crop coefficients were obtained from the data. Coefficients, with respect to evaporation from class A pan and Piche evaporimeter were also obtained, which could be used by farmers and irrigationists to estimate water requirements.

The crop coefficients varied at various stages of growth, and hence a single crop coefficient value is not suitable for ET estimation of the crop cycle. The coefficients differed from those obtained by research scientists at other places, under different environmental conditions, suggesting that the coefficients given here are more suitable for ET estimation, under the hot and arid climate of Saudi Arabia.

Crop coefficients, with reference to alfalfa, 20 cm tall, were obtained under a hot and arid climate of Saudi Arabia to help in arriving at reliable estimates of the evapotranspiration of important vegetable crops. These coefficients could be useful in meeting the irrigation needs of crops and in efficient utilization of the scarcely available and costly water in arid areas. They are also used in computerized irrigation programs (Jensen *et al.* 1971).

Crop coefficient is expressed as a ratio of the evapotranspiration of a crop to that of alfalfa, 20 cm tall and in active growth (Wright 1982) or grass, 8-15 cm in height (Doorenbos and Pruitt 1977). Thus, the estimation of ET from crop coefficient involves the estimation of reference ET in conjunction with crop coefficient. Hence, the accuracy with which water requirements are determined, with the help of equations, is related to the accuracy with which the reference ET is obtained. A number of equations are available for estimating reference ET but

each one of them results in a different value, under the same climatic conditions (Saeed 1986). Even the estimates with the most sophisticated equation, *i.e.* the modified Penman Equation (Hansen *et al.* 1980), cannot be regarded to give an accurate estimate, because it renders different estimates with its parameters computed in different ways (Cuenca and Nicholson 1982), thus making it difficult to consider one of them as the best value. To overcome the problem of an accurate estimate of the reference ET, most of the available formulae were calibrated on the basis of actual measurements of weekly ET from a continuous stand of well watered alfalfa, in lysimeters, over the period March 81 to April 1984 (Saeed 1986). The crop coefficients obtained earlier (Abdel-Aziz and Saeed 1986) differed greatly in values from those by Doorenbos and Pruitt (1977) and Wright (1982). This difference is because crop water requirements and hence crop coefficients are affected by variation in climate over time, distance and altitude, size of fields, advection, soil water availability, salinity, method of irrigation and methods and practices in cultivation. This work was conducted to find out suitable crop coefficients, from planting to harvest of some of the vegetable crops, under the severe arid conditions of Saudi Arabia and a supplement to the work carried out earlier where ET coefficients of field crops were given (Abdel-Aziz and Saeed 1986).

Material and Methods

The work was done at the Agricultural Research Station of the College of Agriculture, King Saud University, in Deirab. Sixteen lysimeters of size 2 m × 2 m × 1.25 m were used in the study. The lysimeters were filled with the soil excavated from the site, maintaining the order and density conditions of the surrounding area. A layer of gravel was placed at the bottom of the lysimeters for drainage, and ample clearance at the top was provided. An underground passage enabled access to the drainage water which was measured with calibrated cans. The lysimeters were surrounded on all sides by an alfalfa belt. Three and four lysimeters were used for each crop and alfalfa, respectively. The irrigation water was measured with calibrated flow meters. Two tensiometers were installed in each lysimeter at 15 cm and 30 cm depths and the tension was kept at 25 cb which corresponds to 70% available moisture on the soil. Gravimetric method was used for moisture determination at the start of the study. In March 1985 and thereafter 503 Hydroprobe (Neutron probe) was used. The ET of a crop was determined by balancing the water inputs and outputs to the lysimeters. The soil moisture was calculated from bulk density and moisture contents. A graph was prepared from the actual ET measurements of alfalfa and the relationship between the ET of alfalfa at other stages and the reference ET of alfalfa at 20 cm height was obtained. This relationship was used in arriving at ET₂₀ at various growth stages of alfalfa. Meteorological data used in the study were obtained from the weather station adjacent to the lysimeters.

Results and Discussions

The crop coefficients (*i.e.* the ratio of the ET of a crop to the reference ET, or ET/ET_{20}) during a crop season are shown in Fig. 1. In each case, four different stages occur. These stages are referred to as:

- i) Initial Stage or seedling stage, soon after emergence of a crop.
- ii) Crop development stage, in which the crop grows rapidly and foliage development takes place.
- iii) Mid season which covers most of the flowering stage, and
- iv) Late, in which the yield takes place (Doorenbos and Pruitt 1977). The length of these stages vary with the crop. The crop coefficients vary from one stage to another for all the crops and are given as follows:

i. Initial Stage (Table 1)

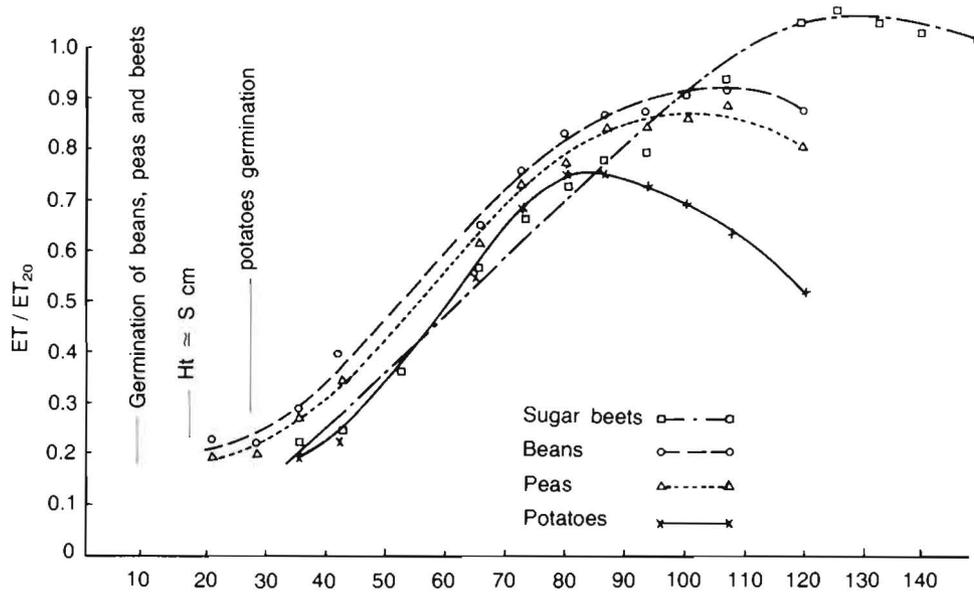


Fig. 1. The variation of ET/ET_{20} of crops at various stages of growth.

Table 1. Crop coefficients during the initial stage.

Crops	Duration (days)		K_c
	Since planting	Since Emergence	
Beans	30	21	0.22
Peas	30	21	0.20
Potatoes	42	15	0.22
Sugar beets	45	30	0.23

ii. Crop Development Stage

The requirements during this stage are not constant. The equation of the curves fitting the data during this stage will give the K_c accurately. It is noted that a straight line relationship closely represents the data. The maximum deviation occurs in sugar beets but this too is within 10%, hence, a straight line relationship is also adopted for sugar beets. The crop coefficients during this stage are as follows:

Table 2. Crop coefficient during development stage.

Crop	Crop Coefficient	Duration 'D' (days) since planting
Beans	$K_c = 0.012 D - 0.13$	30 < D < 90
Peas	$K_c = 0.012 D - 0.16$	30 < D < 90
Potatoes	$K_c = 0.015 D - 0.40$	42 < D < 80
Sugar Beets	$K_c = 0.010 D - 0.19$	45 < D < 115

iii. Flowering and Fruiting Stages (Peak Values)

During these states, the crop coefficient are:

Name of Crop	Coefficient
Beans	0.90
Peas	0.85
Potatoes	0.71
Sugar Beets	1.02

Table 3 shows the comparison of the crop coefficients obtained in this study to those reported by Wright (1982) at different growth stages. It is seen that only the peak coefficients agree, except in potatoes, where the difference is about 10%. At other stages, the coefficients don't agree. Minimum discrepancy is noted in beans and maximum in sugar beets. Except for potatoes, generally the values obtained in this study were higher than those reported by Wright. The differences were quite small for beans and peas, and largest in sugar beets.

Table 4 shows the comparison of peak crop coefficient values obtained, to those given by Doorenbos and Pruitt (1977). The values they reported are higher because they used grass for reference. Assuming that the grass ET is 20% less than that for alfalfa (Hansen *et al.* 1980), it was found that the reduced values were in agreement with those obtained here for beans and peas, but not for potatoes and sugar beets. A similar result was found when the coefficients were compared to those by Wright (1982), suggesting that possibly potatoes and sugar beets behave differently in the hot and dry climate of Saudi Arabia.

Table 3. The comparison of crop coefficients obtained in the study to those from Wright (1982) at various growth stages.

Crop	Time since planting to 'peak ET in percentage							
	25%		50%		75%		100%	
	Obt*	Wright	Obt*	Wright	Obt*	Wright	Obt*	Wright
Beans	0.22	0.17	0.40	0.35	0.70	0.68	0.90	0.92
Peas	0.22	0.17	0.38	0.29	0.66	0.56	0.85	0.9
Potatoes	0.22	0.15	0.23	0.35	0.42	0.66	0.72	0.8
Sugar beets	0.23	0.16	0.42	0.16	0.78	0.34	1.02	1.0

Obt* = Obtained from the study.

Table 4. The comparison of the peak coefficients obtained to those from Doorenbos and Pruitt (1977).

Crop	Beans	Peas	Potatoes	Sugar beets
Obtained	0.9	0.85	0.72	1.02
Doorenbos	1.0	1.10	1.10	1.10
20% less*	0.83	0.9	0.9	0.9

* To convert from grass to alfalfa.

The estimation of crop ET from crop coefficients involves reference ET (ET from 20 cm tall alfalfa), which can either be determined from a formula or obtained through measurements from an alfalfa stand in lysimeter. In the former case, meteorological data will be required which may not be readily available. Values of ET₂₀ of alfalfa, grown in lysimeters have the following limitations:

- a) To monitor periodic variations in the reference ET, the crop has to be grown in lysimeters under ideal set up and will require investment in terms of capital and trained personnel.
- b) Suitable precautions are necessary for creating conditions in lysimeters similar to that of large fields where the crops are actually grown.

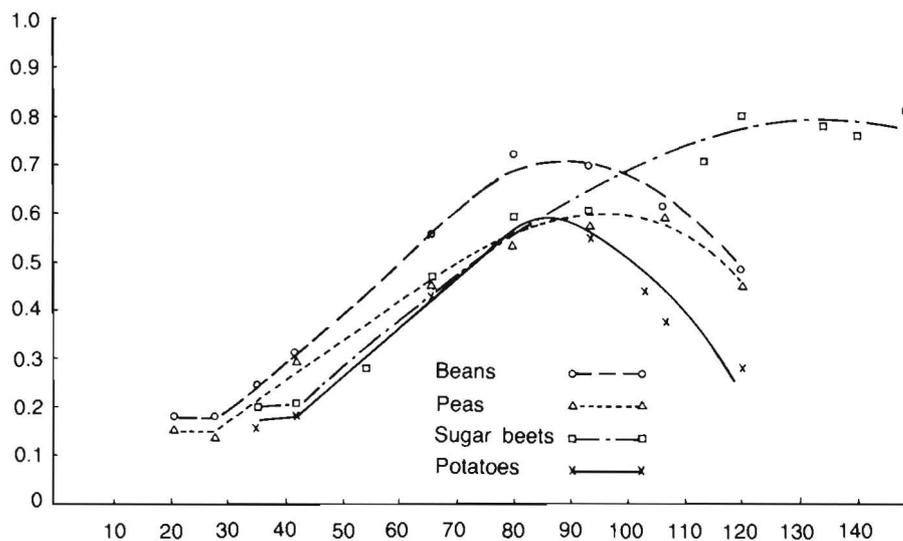
Instead, setting up a USWB Class A pan would be cheaper and convenient to predict climatic variations of a locality and so, K_c based on A pan evaporation (Table 5) will be more meaningful for the purpose of irrigation application.

Table 5. Crop coefficients with reference to class A pan.

Crop	Stages of Growth		
	Initial	Crop Development	Flowering Peak coefficients
Beans	0.18	$0.011 D^* - 0.12$ $30 < D < 90$	0.67
Peas	0.15	$0.007 D - 0.042$ $30 < D < 90$	0.57
Potatoes	0.17	$0.011 D - 0.28$ $42 < D < 80$	0.55 </td
Sugar beets	0.23	$0.008 D - 0.10$ $45 < D < 115$	0.78

*D = days since planting

The variation of the ratio, crop ET to class A pan, with respect to time is shown in Fig. 2. Initially, the ratio is constant but soon starts to change with time as the crop development progresses and reaches the peak at maturity. During the crop development stage, the variation is well represented by a straight line. The crop coefficients are given in Table 5. The variation of the ratio, crop ET to Piche evaporation, with time is shown in Fig. 3.

**Fig. 2.** The variation of ET / EA with days since planting.

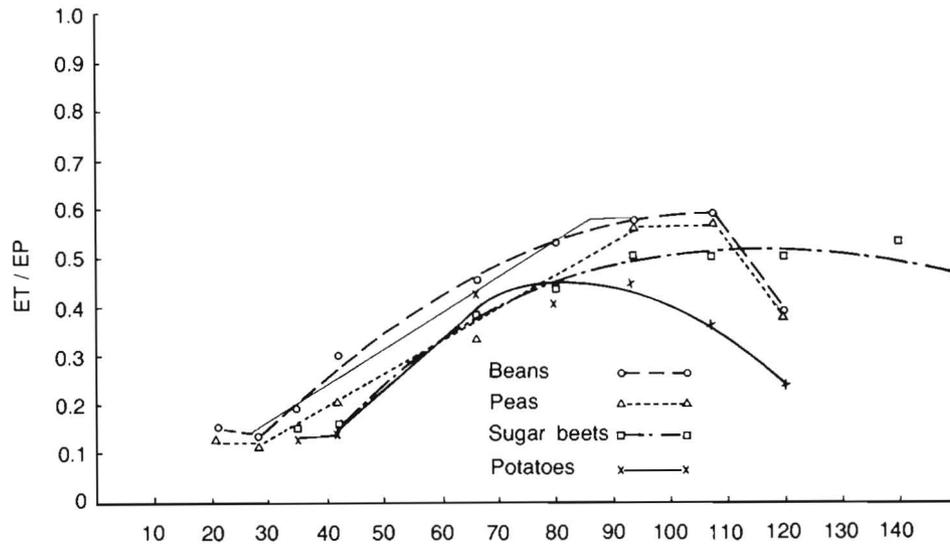


Fig. 3. Variation of ET / EP with days since planting.

Crop Coefficients with respect to Piche evaporimeter are given in Table 6. Due to its small evaporating surface, this evaporimeter predicts drying power of the weather with less accuracy.

Table 6. Crop coefficients based on Piche Evaporimeter.

Crop	Stages of Growth		
	Initial	Crop Development	Flowering Peak coefficients
Beans	0.15	$0.007 D^* - 0.04$ $30 < D < 90$	0.58
Peas	0.12	$0.007 D - 0.07$ $30 < D < 90$	0.57
Potatoes	0.13	$0.007 D - 0.07$ $30 < D < 90$	0.43
Sugar beets	0.15	$0.007 D - 0.14$ $45 < D < 115$	0.50

*D = days since planting

Conclusion

Most of the crops behave differently in hot and arid environment. Consequently, the irrigation water requirements and hence the crop coefficients are different. The values given here are higher than those reported in other studies.

References

- Abdel-Aziz, M.H. and Saeed, M. (1986) Evapotranspiration Crop Coefficients for a Hot and Arid Climate, *Arab Gulf J. scient. Res.* **4**: 373-382.
- Cuenca, R.H. and Nicholson, M.T. (1982) Application of Penman Equation wind function, *Journal of Irrigation and Drainage Division, ASCE* **108** (IR 1): 13-23.
- Doorenbos, J. and Pruitt, W.O. (1977) *Guidelines for Predicting Crop Water Requirements*. F.A.O. Irrigation and Drainage Paper **24**: F.A.O. of the U.N., Rome: 35-46.
- Hansen, V.E., Israelsen, O.W. and Stringham, G.E. (1980) *Irrigation Principles and Practices*, John Wiley & Sons, New York.
- Jensen, M.E., Wright, J.L. and Pratt, B.J. (1971) Estimating soil moisture depletion from climate, crop and soil data, *Transactions of ASAE* **14**: 954-959.
- Saeed, M. (1986) The estimation of evapotranspiration by some equations under hot and arid conditions, *Transactions of ASAE* **29**: 434-438.
- Wright, J.L. (1982) New ET crop coefficients, *Journal of Irrigation and Drainage Division, ASCE* **108** (IR 1): 57-71.

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معامل الإستهلاك المائي لمحاصيل الخضروات تحت ظروف المناطق الحارة الجافة

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تم تقدير معامل الاستهلاك المائي لأربعة محاصيل خضروات مقارنة بالاستهلاك المائي الدال (البرسيم الحجازي بارتفاع ٢٠ سم من سطح الأرض). وقد وجد أن معامل الاستهلاك المائي يختلف إختلافاً بيناً تبعاً لطور النمو ولذلك فقد تم إيجاد المعامل المناسب لأطوار النمو المختلفة (عدد الأيام منذ الزراعة). وبمقارنة معامل الاستهلاك في هذه الدراسة بذلك المقدر بالطرق التجريبية المختلفة، وجد أنه أفضلها جميعاً تحت ظروف المناطق الحارة الجافة.