IV COMEII 2018

IV CONGRESO NACIONAL DE RIEGO Y DRENAJE

Del 15 al 18 de Octubre del 2018, Aguascalientes, Ags.

ESTIMATION OF PEAK IRRIGATION REQUIREMENTS FOR DESIGN PURPOSES AFFECTED BY THE TYPE OF IRRIGATION SYSTEM

(LA ESTIMACIÓN DE LOS REQUERIMIENTOS PICO DE RIEGO CON FINES DE DISEÑO AFECTADO POR EL TIPO DE SISTEMA DE RIEGO)

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Outline

- **Introduction**
- **Materials and Methods**
- **Results and Discussion**
- **Conclusion**

Introduction

- A key variable in an irrigation system design is estimation of the amount of water to be applied through the crop cycle. → peak demand required to design a water network for critical conditions.
- Different irrigation systems must supply water in quantities and at times needed to meet irrigation requirements and schedules.

Center Pivot Irrigation. http://www.valleyirrigation.com/equipment/center-pivots

Study objective:

- Determination of the Design Daily Irrigation Requirement (DDIR), for various return periods in four different crops.
- To analyze the effect of the irrigation system (surface, sprinkler and drip) on the estimation of the maximum irrigation requirements as well as the impact of the precipitation for design purposes.




Materials and Methods

- Study area

The climate is temperate and semi-arid with a median temperature of 15.9 °C, and limited frosts. Most rains come during June and October.

Most Texcoco soils used for agriculture are loamy.

Figure 1. Texcoco location in Mexico.

Determination of the Evapotranspiration

Table 1a. Crop cycle, planting, and harvesting dates commonly presented at Texcoco, Mexico.

Crop	Planting date	Harvest	Crop cycle Total (days)
Maize	April-01	July-09	100
Bean	May-01	Aug-18	110
Oat	Sep-01	Dec-19	110
Tomato	March-01	May-14	75

Table 1b. Continuation of the crops data.

Crop	Rooting depth (m)	Crop height (m)	Critical depletion (fraction)
Maize	1.0	2.0	0.55
Bean	0.9	0.6	0.45
Oat	1.5	1.0	0.55
Tomato	1.0	0.5	0.40

The Penman-Monteith equation

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

Where ET_0 is the reference evapotranspiration (mm/day), Rn is the net radiation (MJ/(m^2·d)), G is the soil heat flux density (MJ/(m^2·d)), U_2 is the wind speed (m/s) at a height of 2 m, e_s is the saturated vapor pressure (kPa), e_a is the actual vapor pressure of the air at standard screen height (kPa), γ is the psychrometer constant (kPa/°C), Δ is the slope of the saturation vapor pressure curve between the average air temperature and dew point (kPa/°C), and T is the mean daily air temperature (°C) (Allen et al., 1998).

Crop evapotranspiration ET_c

$$ET_c = K_c * ET_0$$

Where K_c is the crop coefficient. See Table 2 for K_c values of the crops utilized.

Table 2. K_c values corresponding to the different growing stages for the crops utilized.

Crop	Stage		
	Initial	Mid-season	Final
	Kc	Kc	Kc
Corn	0.7	1.2	0.6
Bean	0.15	1.15	0.35
Oat	0.3	1.15	0.25
Tomato	0.3	1.1	0.86

Determination of the Design Daily Irrigation Requirement (DDIR)

$$DDIR = \frac{AD}{II_{min}}$$

Where the *AD* is the allowed depletion of soil water between irrigation (mm), and II_{min} is the minimum irrigation interval during the irrigation season (days). Although *AD* equals typically *RAW* (Readily available water), the *AD* may exceed *RAW* for deficit irrigation strategies.

$$RP = \frac{100}{P}$$

Where *RP* is the return period (years) and *P*, the probability of occurrence (percent).

Frequency analysis

$$P = \left(1 - \frac{R}{M+1}\right)100$$

Where *P* is the probability that a given value will be exceeded in percent, *R* is the rank of DDIR on a list of DDIR values in ascending order (*R* for the smallest DDIR value = 1), and *M* is the number of DDIR values.

$$W = log\left[-log\left(\frac{P}{100}\right)\right]$$

Where *W* is the Weibull transform of *P*.

Frequency analysis

The utilization of the frequency analysis to determine design daily irrigation requirements (DDIR) for various return periods was carried out using the following steps

- DDIR data were arranged in ascending order (See results in Table 3).
- *P* was computed for each DDIR using Eq. 5.
- *W* was calculated for each DDIR using Eq. 6.
- *W* was plotted versus DDIR (Fig. 6).
- *W* values for *P* values were computed in a 50, 20, 10, and 5 percent,
- DDIR values from the plot for *W* values were read corresponding to *P* values of 50, 20, 10, and 5 percent (2, 5, 10, and 20 year return periods) for the given 30 years of DDIR values:

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Results and Discussion

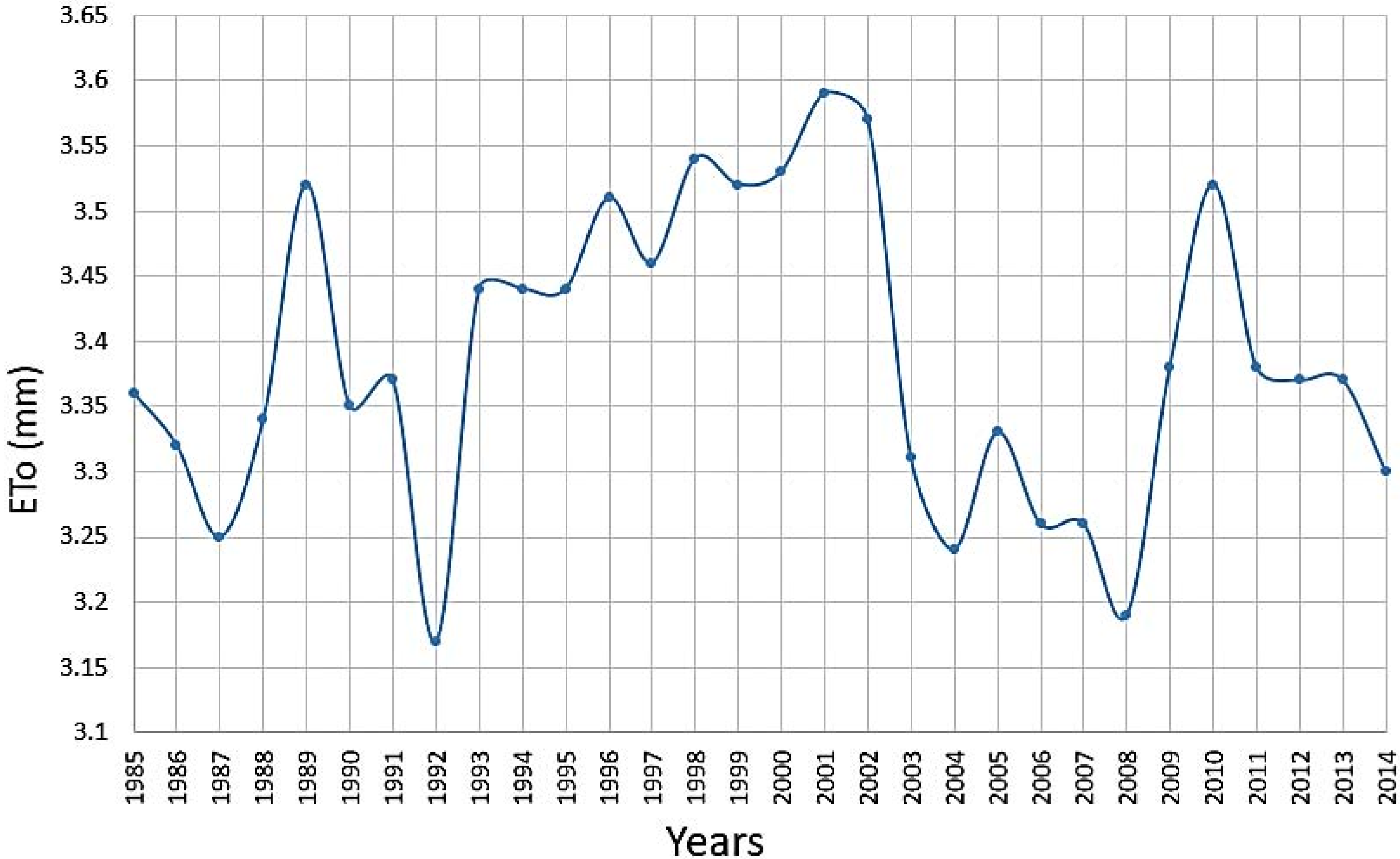

Figure 2. ET_0 (mm) variation during the 30-year analyzed period.

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Results and Discussion

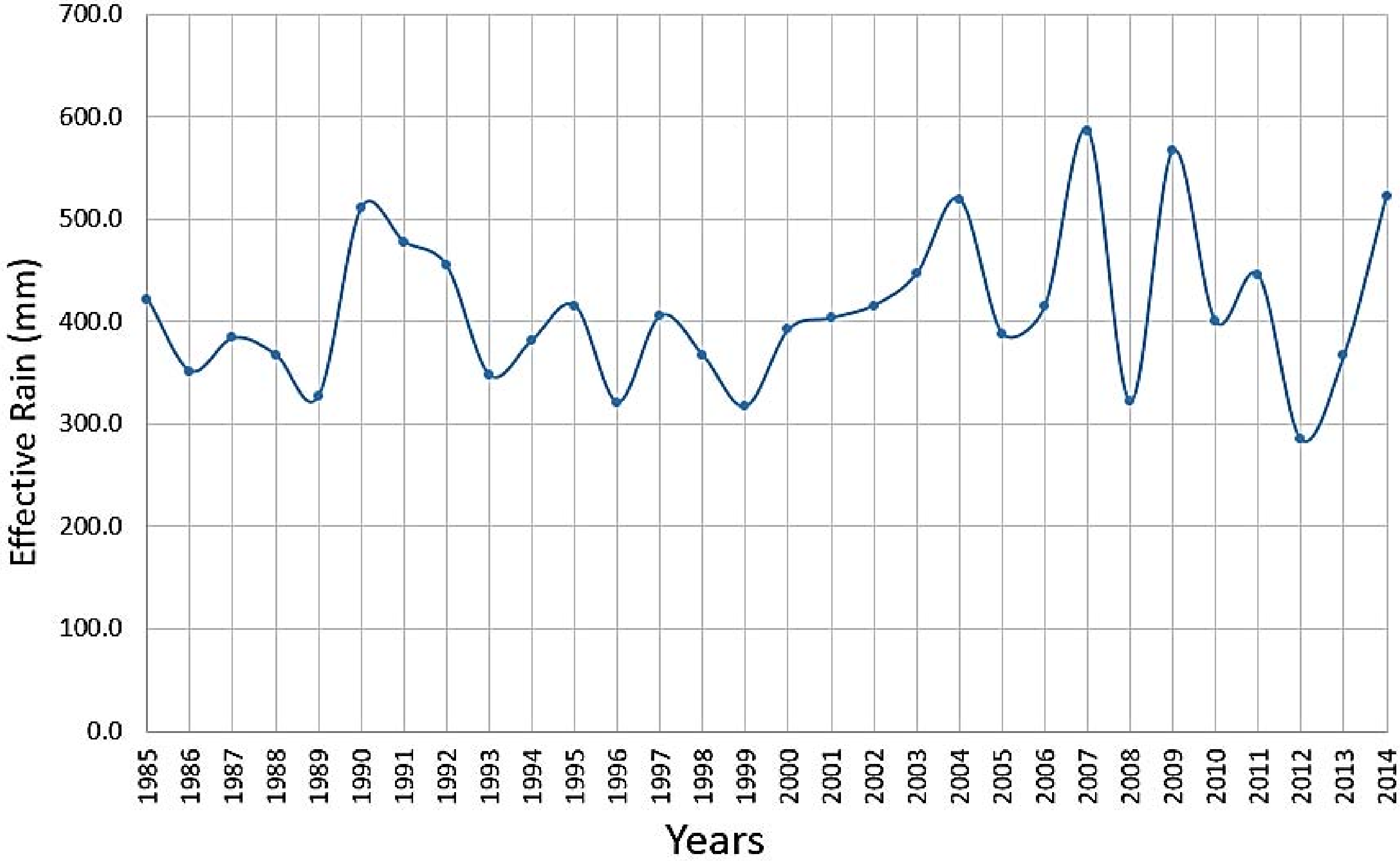

Figure 3. Effective Rain (mm) variation during the 30-year analyzed period.

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Design Daily Irrigation Requirement (DDIR)

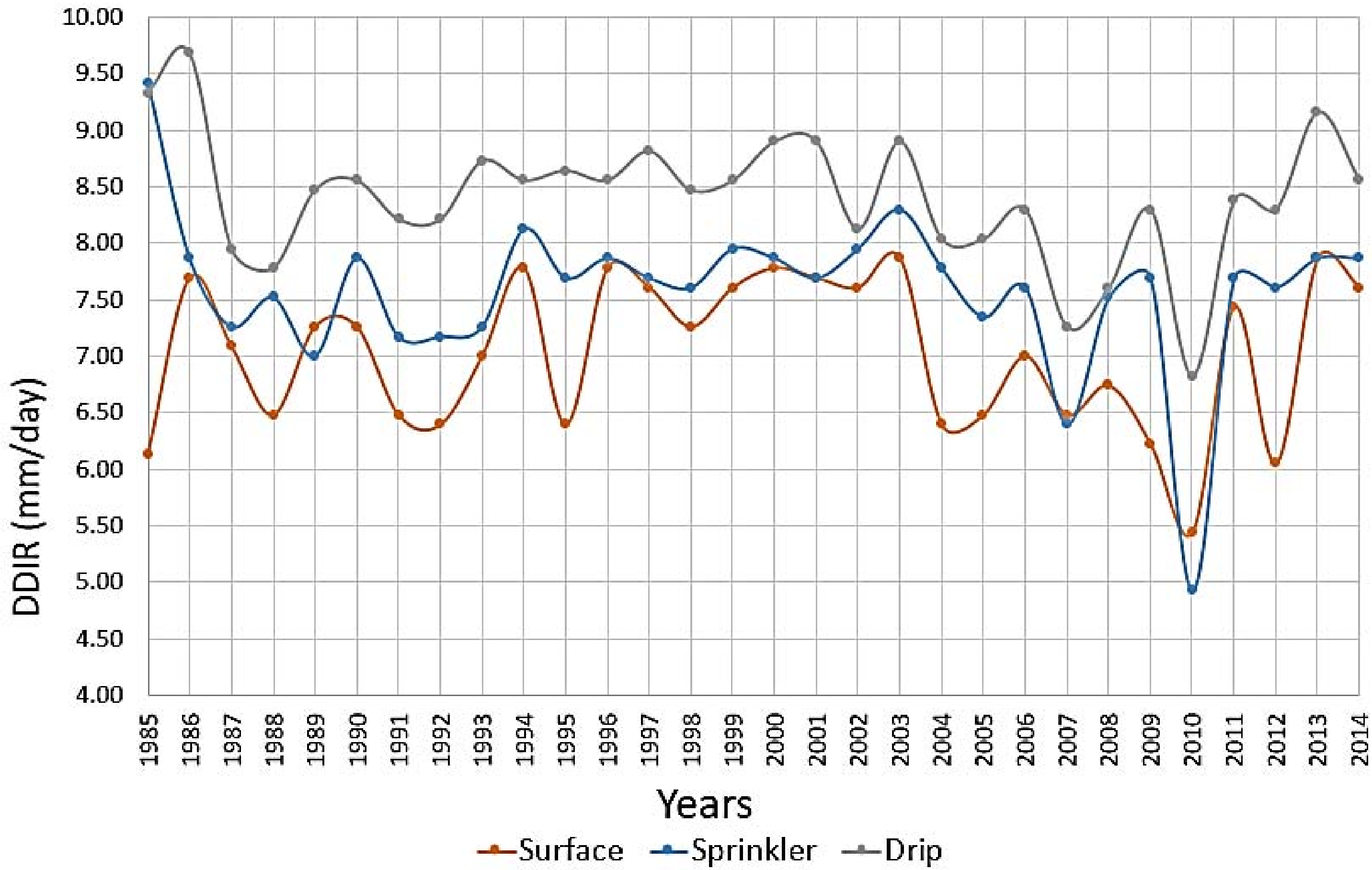


Figure 4. DDIR (mm/day) variation during the 30-year period analyzed for maize crop with three irrigation systems (surface, sprinkler, and drip).

Design Daily Irrigation Requirement (DDIR)

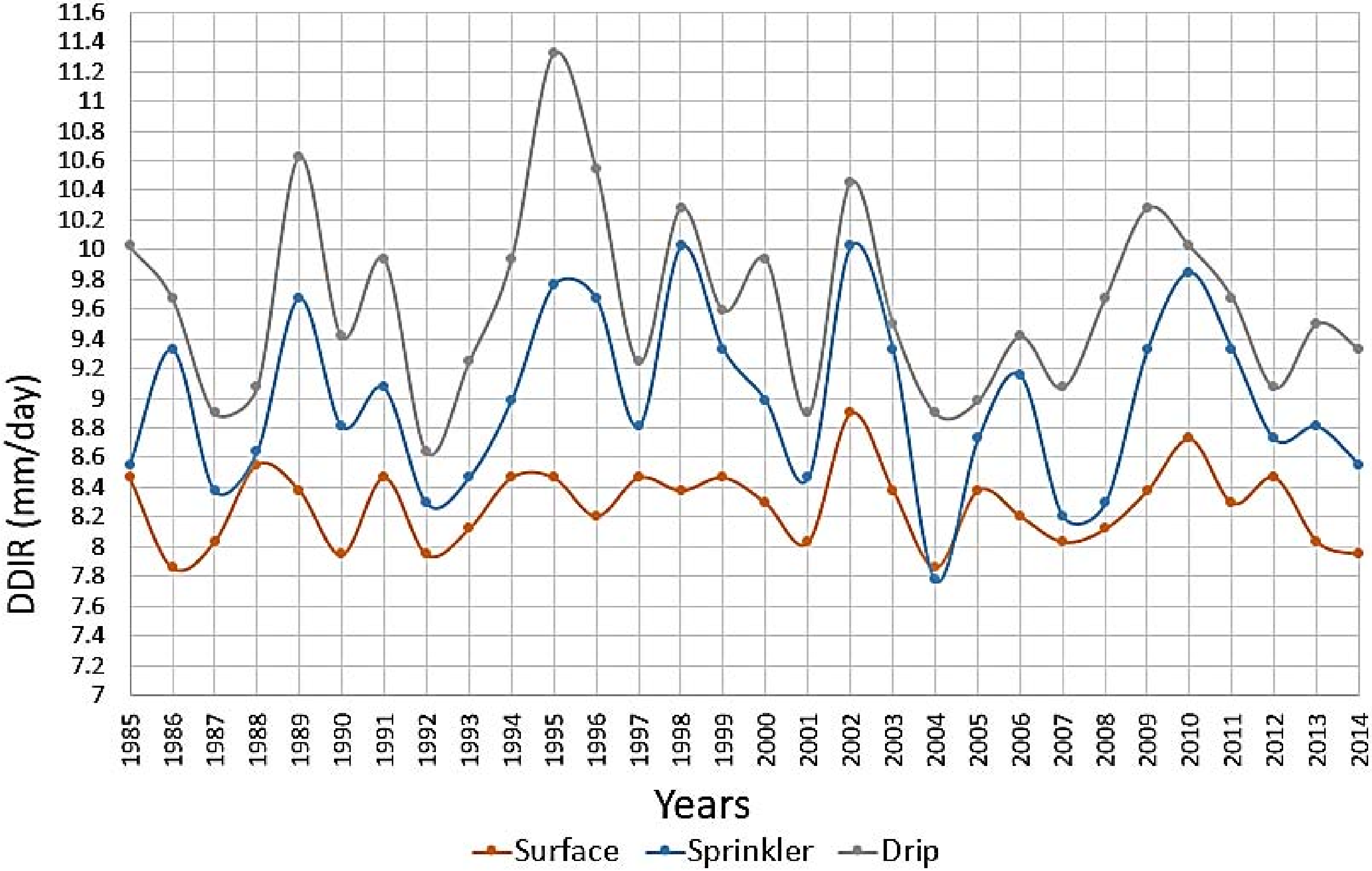


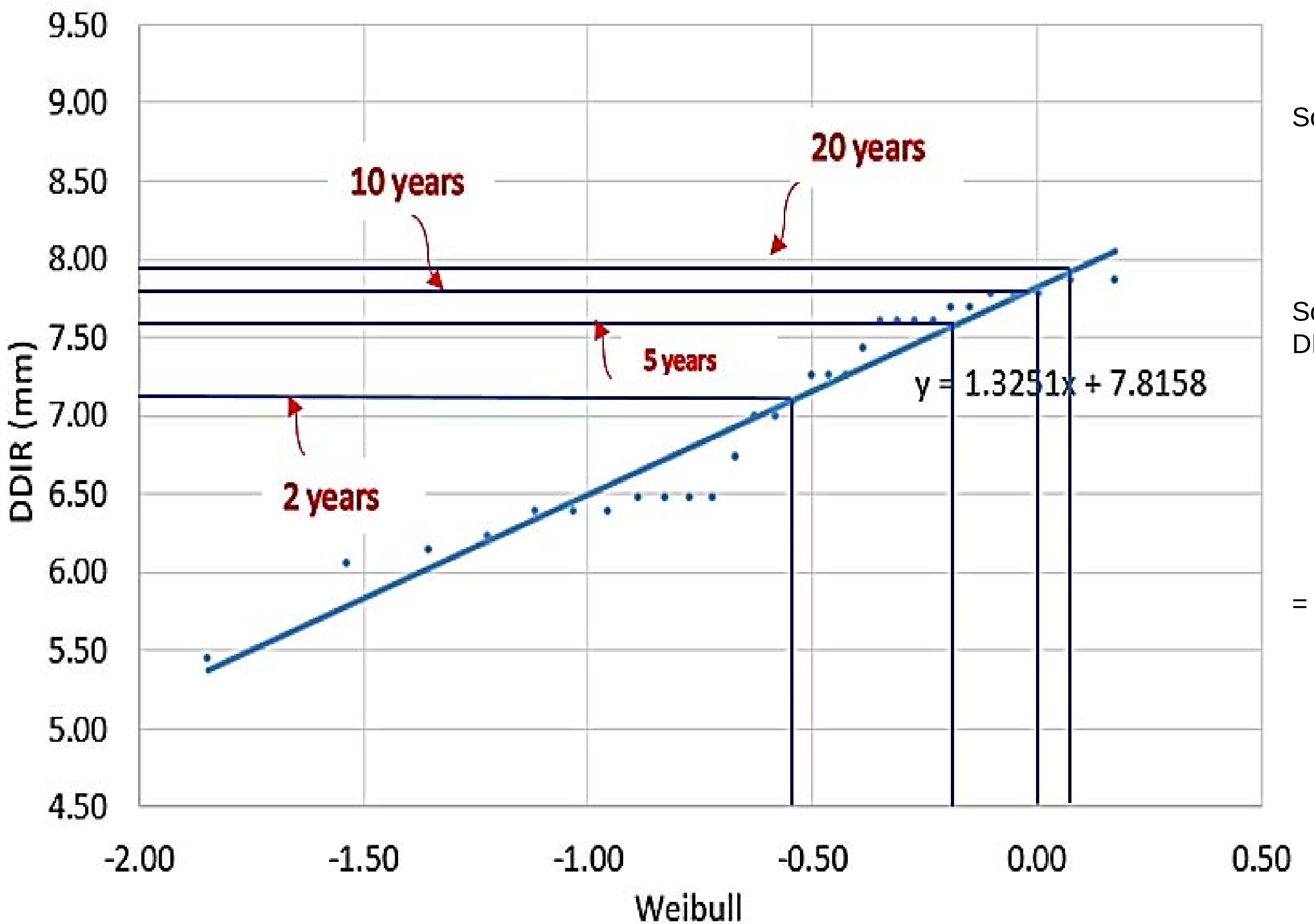
Figure 5. DDIR (mm/day) variation during the 30-year period analyzed without rainfall for maize crop with three irrigation systems (surface, sprinkler, and drip).

Frequency analysis to determine DDIR for various return periods

- The following table summarizes solution steps 1-3 for maize crop irrigated with a surface irrigation system with precipitation. (Similar tables were developed for the other three crops as well as without consideration of precipitation).

Table 3. Solution steps 1-3 for maize crop irrigated with surface irrigation.

DDIR (mm)	Rank (R)	P	RP (years)	W
7.86	1	96.77	1.03	-1.85
7.86	2	93.55	1.07	-1.54
7.95	3	90.32	1.11	-1.35
7.95	4	87.10	1.15	-1.22
7.95	5	83.87	1.19	-1.12
8.04	6	80.65	1.24	-1.03
8.04	7	77.42	1.29	-0.95
8.04	8	74.19	1.35	-0.89
8.04	9	70.97	1.41	-0.83
8.12	10	67.74	1.48	-0.77
8.12	11	64.52	1.55	-0.72
8.21	12	61.29	1.63	-0.67
8.21	13	58.06	1.72	-0.63
8.29	14	54.84	1.82	-0.58
8.29	15	51.61	1.94	-0.54
8.38	16	48.39	2.07	-0.50
8.38	17	45.16	2.21	-0.46
8.38	18	41.94	2.38	-0.42
8.38	19	38.71	2.58	-0.38
8.38	20	35.48	2.82	-0.35
8.47	21	32.26	3.10	-0.31
8.47	22	29.03	3.44	-0.27
8.47	23	25.81	3.88	-0.23
8.47	24	22.58	4.43	-0.19
8.47	25	19.35	5.17	-0.15
8.47	26	16.13	6.20	-0.10
8.47	27	12.90	7.75	-0.05
8.55	28	9.68	10.33	0.01
8.73	29	6.45	15.50	0.08
8.90	30	3.23	31.00	0.17



Solution for step 5
W for (P = 50%) = -0.52
W for (P = 20%) = -0.16
W for (P = 10%) = 0
W for (P = 5%) = 0.11

Solution step 6
DDIR for:
P = 50% (RP = 2 years) = 7.17 mm/day
P = 20% (RP = 5 years) = 7.68 mm/day
P = 10% (RP = 10 years) = 7.77 mm/day
P = 5% (RP = 20 years) = 7.86 mm/day

Figure 6. Solution to step 4. *W* versus DDIR for the 30-year period

Table 4. DDIR values that will be exceeded 50%, 20%, 10% and 5% for maize crop

Maize DDIR (mm/day)				
Precipitation				
P	**50%**	**20%**	**10%**	**5%**
W	**-0.52**	**-0.16**	**0**	**0.11**
RP (years)	**2**	**5**	**10**	**20**
Surface	7.17	7.68	7.77	7.86
Sprinkler	7.68	7.86	8.10	8.79
Drip	8.46	8.88	9.10	9.13
Without Precipitation				
P	**50%**	**20%**	**10%**	**5%**
W	**-0.52**	**-0.16**	**0**	**0.11**
RP (years)	**2**	**5**	**10**	**20**
Surface	8.33	8.46	8.54	8.80
Sprinkler	8.89	9.60	9.84	10.02
Drip	9.54	10.22	10.53	10.93

Table 5. DDIR values that will be exceeded 50%, 20%, 10% and 5% for bean crop.

Bean DDIR (mm/day)				
Precipitation				
P	**50%**	**20%**	**10%**	**5%**
W	**-0.52**	**-0.16**	**0**	**0.11**
RP (years)	**2**	**5**	**10**	**20**
Surface	5.05	5.35	5.67	5.74
Sprinkler	6.13	6.54	6.73	6.73
Drip	7.17	7.32	7.43	7.72
Without Precipitation				
P	**50%**	**20%**	**10%**	**5%**
W	**-0.52**	**-0.16**	**0**	**0.11**
RP (years)	**2**	**5**	**10**	**20**
Surface	6.04	6.79	6.91	6.98
Sprinkler	6.82	7.08	7.25	7.91
Drip	7.77	8.57	8.96	9.27

Table 6. DDIR values that will be exceeded 50%, 20%, 10% and 5% for oat crop.

Oat DDIR (mm/day)				
Precipitation				
P	**50%**	**20%**	**10%**	**5%**
W	**-0.52**	**-0.16**	**0**	**0.11**
RP (years)	**2**	**5**	**10**	**20**
Surface	9.73	9.76	9.84	9.86
Sprinkler	11.31	11.49	11.56	11.70
Drip	12.05	12.52	12.67	12.82
Without Precipitation				
P	**50%**	**20%**	**10%**	**5%**
W	**-0.52**	**-0.16**	**0**	**0.11**
RP (years)	**2**	**5**	**10**	**20**
Surface	9.76	9.83	9.89	9.92
Sprinkler	11.35	11.53	11.60	11.77
Drip	12.18	12.68	12.87	12.96

Table 7. DDIR values that will be exceeded 50%, 20%, 10% and 5% for tomato crop.

Tomato DDIR (mm/day)				
Precipitation				
P	**50%**	**20%**	**10%**	**5%**
W	**-0.52**	**-0.16**	**0**	**0.11**
RP (years)	**2**	**5**	**10**	**20**
Surface	7.51	8.20	8.46	7.65
Sprinkler	7.77	8.10	8.44	8.92
Drip	9.46	9.74	9.84	9.90
Without Precipitation				
P	**50%**	**20%**	**10%**	**5%**
W	**-0.52**	**-0.16**	**0**	**0.11**
RP (years)	**2**	**5**	**10**	**20**
Surface	7.77	8.27	8.85	8.89
Sprinkler	7.80	8.93	8.94	8.98
Drip	9.50	9.80	9.92	9.97

Conclusions

- We can notice that the maximum values of DDIR are found on drip irrigation systems, followed by sprinkler irrigation, and finally surface irrigation. This is because of the interval between irrigations.
- The analysis of the effect of the irrigation system on the estimation of the maximum irrigation requirements was carried out for design purposes in four different crops cultivated in Texcoco, Mexico, to take account what is the peak demand required to dimension the water network during critical conditions, considering the impact of the precipitation. The Design Daily Irrigation Requirements (DDIR) were determined from several years of daily irrigation requirement data obtained with the software CROPWAT, and then a frequency analysis of 30 years DDIR values were made to account for year-to-year variations in climate. Such analysis allowed us to get a probability of occurrence to be assigned to each DDIR.

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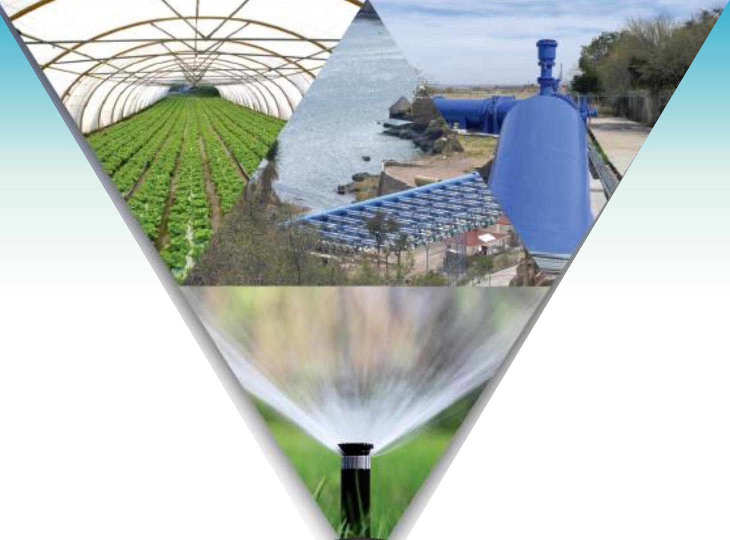
References:

- Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56, United Nations – Food and Agricultural Organization, Rome, Italy, p. 300.
- Cachón Ayora, L.E., Nery Genes H., & Cuanalo de la Cerda, H.E. (1974). Los suelos del área de influencia de Chapingo. Escuela Nacional de Agricultura (Mexico). Colegio de Postgraduados. Sección de Pedología.
- FAO, 1992. CROPWAT A computer program for irrigation planning and management. In: FAO Irrigation and Drainage Paper 46. Rome: FAO, 126.
- FAO, 1979. Yield response to water. In: FAO Irrigation and Drainage Paper No. 33. Rome: FAO, 112–113.
- Haan, C.T. (1977). Statistical Methods in Hydrology. Iowa University Press, Ames, 378 pp.
- IMTA. 2007. Manual para diseño de zonas de riego pequeñas. Instituto Mexicano de Tecnología del Agua. 2ª Edición. Jiutepec, Morelos. México.
- James, Larry G. 1993. Principles of Farm Irrigation System Design. Washington State University. Krieger Pub. Co.
- Jensen, M. E., R. D. Burman, y R. G. Allen. 1990. Evapotranspiration and irrigation water requirements. ASCE Manuals and Reports on Engineering Practice No 70. 332. Pp.
- Martínez E., R. 1991. Riego Localizado: Diseño y Evaluación. Universidad Autónoma Chapingo, Chapingo, Edo. Méx., México.
- Martínez E., R. 1996. Relaciones Agua Suelo Planta Atmosfera. Universidad Autónoma Chapingo, Chapingo, Edo. Méx., México.
- Ojeda, B. W., Martínez, E. R., Carrillo, G. M. 2004 Calendarización del riego: teoría y práctica. Instituto Mexicano de Tecnología del Agua. Jiutepec, Mor., México.
- Palacios, V. E. 1998. ¿Por qué y cuándo y cuánto y cómo regar? Colegio de Postgraduados. Montecillo, México. 163 Pp.
- Reyes E., Rocio G. 2015. Efecto del tipo de sistema de riego en la estimación de la demanda máxima de riego. Tesis profesional. Departamento de Irrigación. Chapingo, Texcoco, Edo. De México.
- Ruíz G, Agustín. 2005. Sistema computacional para la calendarización del riego basado en internet. Tesis profesional. Departamento de Irrigación. Chapingo, Texcoco, Edo. de México.
- Smith M, 1992. CROPWAT, A computer program for irrigation planning and management. In: FAO Irrigation and Drainage Paper 46. Rome: FAO. 1–65.
- Texcoco, State of Mexico – Wikipedia. https://en.wikipedia.org/wiki/Texcoco,_State_of_Mexico (accessed September 26, 2018).



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