v. 4, n. 12, 2024

Journal of
Agricultural
Sciences
Research

Acceptance date: 25/09/2024

GROWING SEASON FOR MOISTURE AND TEMPERATURE AVAILABILITY, EVALUATED WITH THE THORNTHWAITE WATER BALANCE IN JALISCO, MEXICO

Hugo Ernesto Flores Lopez
CECEAJAL CIRPAC INIFAP
Campo Experimental Centro Altos de Jalisco
Centro de Investigación Regional Pacífico
Centro; Instituto Nacional de Investigaciones
Forestales, Agrícolas y Pecuarias

Irma Julieta Gonzalez Acuña
CESIX CIRPAC INIFAP
Campo Experimental Santiago Ixcuintla
Centro de Investigación Regional Pacífico
Centro; Instituto Nacional de Investigaciones
Forestales, Agrícolas y Pecuarias

DOI https://doi.org/10.22533/at.ed.9734122419095

Abstract: In Mexico, corn is the most important crop produced under rainfed conditions. In this condition, the planning of agricultural operations is highly dependent on rainfall, with lower yields and high risk of crop loss. In recent years, Mexico has been facing increasingly severe, frequent and intense droughts, with important impacts on all economic sectors, but with greater influence on agriculture and livestock. This is the reason that motivates the evaluation of water availability in the growing season (GS) of rainfed crops and to have a quantitative basis to propose management technologies to cushion its effects. The objective of the present work was to evaluate the GS due to the availability of adequate moisture and temperature for crops by means of the Thornthwaite model for Jalisco, Mexico. The study used the water balance model of Thornthwaite and Mather (1957). The characteristics of GS were obtained: onset, termination and duration, according to FAO criteria. The GS characteristics were mapped using interpolation procedure in IDRISI Selva and generating the final presentation in ARCVIEW GIS. The results show that the GS begins before June 10 in the central and western zones of the state; it continues with delays in the north of the state and the highlands of Jalisco until after June 30. The termination of the GS was irregular; it ended in the north and highlands of Jalisco before October 15; it continued in the rest of Jalisco until October 31. The duration of GS was shortest in the extreme north and highlands with less than 115 days, up to less than 160 days in the coast and south of Jalisco.

Keywords: Water balance, rainfed, Jalisco.

INTRODUCTION

In Mexico during 2023, the agricultural area planted with irrigation was 1.906 million hectares and only 1.865 million hectares were harvested, representing a loss of 41 thousand hectares; in rainfed agriculture, 7.395 million hectares were planted and only 6.278 million hectares were harvested, indicating losses of 1.117 million hectares (SIAP-SADER, 2024). The above implies that, in rainy season, in addition to having lower yields, the risk of crop loss is great. According to INEGI (2018), the main cause of crop loss is due to the effect of climatic phenomena not controlled by man, such as droughts, floods, frost and hailstorms. In recent years, Mexico has been facing increasingly severe, frequent and intense droughts, with significant impacts on all economic sectors, but with greater influence on agriculture and livestock (Banco de México, 2022). This is the reason why the availability of water for rainfed crops must be evaluated and have a quantitative basis to propose management technologies that cushion its effects (Bradford et al., 2017; Shaw, 1976).

Moisture availability for rainfed crops can be expressed in terms of deficiency, excess or optimum water conditions for plants (Wilhite and Glantz, 1985). Wang (1963) pointed out that drought or excess moisture (or even flooding) is caused by hydrological imbalances involving regional characteristics such as drainage, runoff, topography, soil structure, animal and plant species of the area, as well as meteorological factors. He also indicated that, due to the impossibility of having complete control of drought or excess moisture, protective and preventive measures must be taken to minimize damage to agricultural production. One action is the probabilistic evaluation of the occurrence of these meteorological phenomena.

Under rainfed conditions, crop growth and development is modified when moisture deficiencies occur according to the degree of intensity of the phenomenon. In such a situation, a more accelerated crop development is observed and the accumulation of physiological time is altered. For this reason, Doorenbos and Kassam (1986) affirm that the lack of attention to the satisfaction of the water needs of a crop, expressed by water deficits, can cause negative effects on growth and yield.

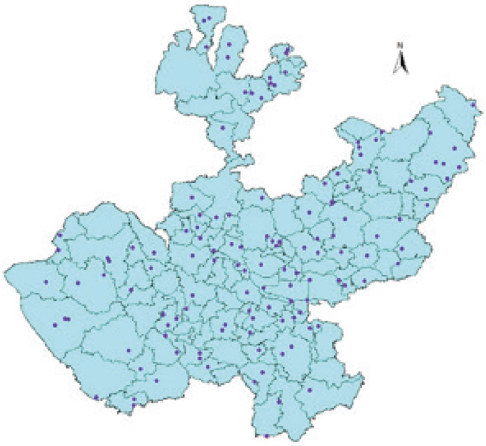
The degree to which plant water requirements are met can be assessed by a soil water balance (Chang, 1968; Shaw, 1976; Baier and Robertson, 1966; Smith *et al.*, 1985). The soil water balance can be expressed by the equation: $PP + Irr = ET \pm \Delta HS + PER + RUN$, where PP is rainfall, Irr is crop irrigation, ET is crop evapotranspiration, ΔHS is soil moisture changes in the root zone, PER is water percolation out of the root zone and *RUN* is water runoff over the soil (Chang, 1968; Smith *et al.*, 1985; Reddy, 1983; Allen et al., 1991).

Quantifying the water required for the growth and development processes of rainfed agricultural crops is a critical part of agronomic management in the field. One of the methods available to estimate the edaphic water balance is that of Thornthwaite and Mather (Thornthwaite and Mather, 1957). Although this method is one of the simplest and most robust, it is feasible to apply it with monthly or decadal or daily data (Thornthwaite and Mather, 1957), it only requires temperature information to calculate the ETP. This method offers the possibility of estimating the water balance at basin (Mammoliti et al., 2021; Moghaddam and Mohammadkhan, 2017), regional (Umar and Yusuf, 2019), global (Mintz and Serafini, 1992; Willmott et al., 1985) scales for any point on the earth's surface (Cardoso do Vale et al., 2022; Umar and Yusuf, 2019), but can also be applied for climate classifications, to define the hydrology of an area and the planning of water use by crops (Fathurrahman et al., 2022; Fernández-Long et al.,2012; Calvo, 1986).

The use of ETP proposed by Thornthwaite (1948) is based on temperature, with good performance in continental and tropical climates of North America where it was developed; however, its application is limited in arid and semi-arid conditions (Ward and Robinson, 2000). Another approach for calculating ETP is with the use of evaporation measured in the evaporimeter tank type "A", which allows measuring the effects of solar radiation, wind, temperature and air humidity integrated in the evaporation measurement of a free water surface, which analogous to the plant responds to the same climatic factors (Allen et al., 2006; Doorenbos and Pruit, 1977). For these reasons, to improve the performance of the Thornthwaite water balance, the calculation of ETP by evaporation has been proposed (Sabziparvar et al., 2010; Steenhuis and Van der Molen, 1986). To give spatial expression to point characteristics of the water balance, interpolation methods provide accurate estimation at intermediate points (Hartkamp et al., 1999); one of the most widely used is Inverse Distance Weighting (IDW) (Li and Heap, 2011). The objective of the present work was to evaluate the GS for availability of adequate moisture and temperature for crops by means of the Thornthwaite model for Jalisco, Mexico.

MATERIALS AND METHODS

Monthly normal evaporation and precipitation data from 130 climatological stations in the state of Jalisco were used, with distribution shown in Figure 1. These data were obtained from the National Water Commission and published as climatological normals by Flores et al. (2022). This publication also includes the date of first frost, information that was used to correct the duration of the GS.



Geographical location of the 130 climatological stations in the State of Jalisco used in this study.

In the present study, the water balance model of Thornthwaite and Mather (1957) was used, expressed by the following equation: $P - ETP \pm \Delta RH + DEF - EXC = 0$, where P is precipitation, ETP is potential evapotranspiration, ΔRH is the change in soil moisture reserve, DEF is the water deficit and EXC is excess water. ETP was calculated based on monthly evaporation (EVAP) corrected by the vat coefficient of 0.8, according to the expression: $ETP=kp*EVAP$. Actual evapotranspiration (ETR) was consumed by the crop. PPutil is equal to (PP - ETP) and indicates the amount of ETP consumed. Soil moisture reserves (RES) occur if the soil storage capacity defined by its physical characteristics (SC) and PP + ETP is not exceeded. Excess water (EXC) was defined when PP + RH exceeded ETP + SC. Water deficit (DEF) occurred when ETP was greater than PP + RH. This procedure was implemented in the EXCEL spreadsheet, as shown in Table 1.

The characteristics of CD: onset, termination and duration were determined according to the FAO definition, expressed by the following conditions: 1) the onset of GS when $PP > 0.5$ ETP, 2) the termination of GS when $PP + RH < 0.5$ ETP, adjusted with the date of first frost (1FRO), so that if the 1FRO occurred when moisture was still present it marked the termination of the GS and 3) the duration of the GS is the difference between the termination and the beginning of the GS (Arteaga-Ramírez et al., 2006). The GS characteristics were mapped using IDW interpolation procedure in IDRISI Selva and generating the final presentation in ARCVIEW GIS.

RESULTS AND DISCUSSION

Figure 2 shows the onset of GS (GSons) for Jalisco. This figure shows that the ECini begins before June 10 in the central and western zones of Jalisco, and continues from June 10 to 20 in the coastal, southern, central, southern and middle zones of the highlands region of Jalisco. The GSons is delayed in the north and highlands of Jalisco until after June 30. These results show a trend similar to those reported by Ruíz et al. (2000), who analyzed the characteristics of the GS for Jalisco in two periods: from 1947 to 1971 and 1972 to 1997, although differences can be attributed to the historical series used, the normal data used and the method for defining GSons.

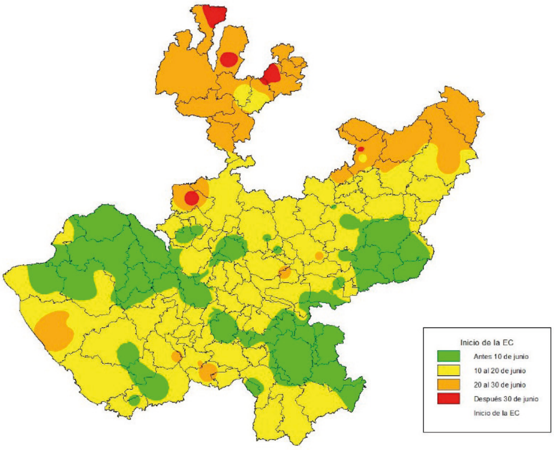


Figure 2. Beginning of the growing season by moisture availability and temperature for Jalisco.

MES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DEC
EVAP	125.4	149	209.9	239.6	255.9	189.3	156.7	141.1	121.1	117.7	113.2	104.9
PP	17.6	14.6	6.2	5.5	34	174.6	227.7	194	147.9	60.5	13.6	11.5
ETP	100.3	119.2	167.9	191.7	204.7	151.4	125.4	112.9	96.9	94.2	90.6	83.9
ETR	17.6	14.6	6.2	5.5	34	151.4	125.4	112.9	96.9	94.2	51.1	11.6
Useful	-82.7	-104.6	-161.7	-186.2	-170.7	23.2	102.3	81.1	51.0	-33.7	-77.0	-72.4
RES	0	0	0	0	0	23.2	71.2	71.2	71.2	37.5	0	0
DEF	82.7	104.6	161.7	186.2	170.7	0	0	0	0	0	39.5	72.3
EXC	0	0	0	0	0	0	0	54.3	81.1	51	0	0

Table 1. Parameters used in the Thornthwaite water balance.

Figure 3 shows the termination of GS (GSter) in Jalisco. The GSter is more irregular than the beginning of the GS; the end of the GS begins in northern and northeastern areas of Jalisco before October 15; it continues in the rest of northern, highlands and southern areas of Jalisco until October 31. For the Central, South and Ciénega regions of Jalisco, the GSter ends until November 15. The GSter is delayed until November 30 in the Coast and Southern regions of Jalisco, while some areas of the Coast and Southern Jalisco occur after December 1. Comparison of these results with those reported by Ruíz et al. (2000) shows a similar general trend, but with later dates. These differences are also attributed to the historical series used, the use of normal data and the method for defining GSter.

The duration of the GS (GSdur) in Jalisco is shown in Figure 4. This characteristic is defined by the difference between the beginning and the end of the GS. The GSdur is shorter in the extreme north of the state and some zones of the highlands, with less than 115 days; in the middle part of the north and highlands of Jalisco it ranges from 115 to 130 days; for the southern part of the northeastern zone and the southern part of the northern zone of Jalisco, as well as some zones of the center the GSdur ranges from 130 to 145 days. In the Central, Ciénega, South and Valles zones of Jalisco, the GSdur ranges from 145 to 160 days, while in the coast and south of Jalisco it reaches more than 160 days. These results contrast with those reported by Ruíz et al. (2000), with a wider current GSter.

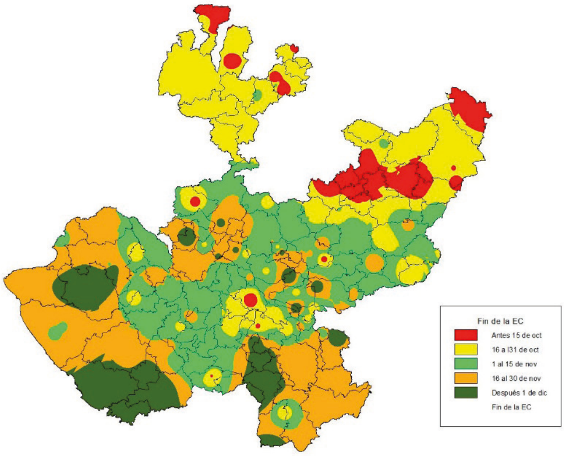


Figure 2. Termination of the growing season by moisture and temperature availability for Jalisco.

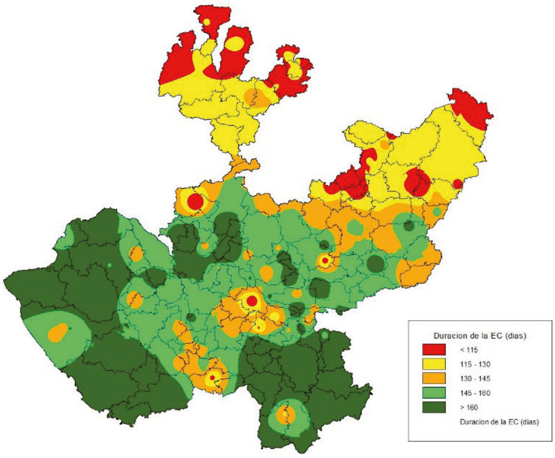


Figure 4. Length of growing season by moisture availability and temperature for Jalisco.

Studies conducted on the characterization of GS show important trends, particularly with the current climate change to reduce the amount of precipitation, but to increase extreme intensity events (Douville et al., 2021). The duration of GS shows tendency to reduce with late onset of GS, but the termination of GS with low correlation with climatic parameters (Ruíz et al., 2016).

The characteristics of GS studied in the present research represent an important complement to the technological information available for agriculture in Jalisco, as it allows identifying the cycle of crop genotypes feasible for production in the different agricultural zones and the average sowing date (INIFAP, 2017).

CONCLUSIONS

The characteristics of the GS (onset, termination and duration) for Jalisco were identified as an important complement to the technological information available for agriculture in Jalisco. Although the results obtained are associated with climate trends reported in other studies, differences arise due to the effect of climate change, the length of the historical series of data used, the use of normal data and the parameters used to estimate the GS.

REFERENCES

Allen, R.G., and W.O. Pruitt. 1991. FAO-24 reference evapotranspiration factors. J. Irrig. Drain. Eng., ASCE 117(5):758–773.

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 2006. Evapotranspiración del cultivo. Guías para la determinación de los requerimientos de agua de los cultivos. FAO, Estudio FAO Riego y Drenaje 56. Roma, Italia. 298 pág.

Arteaga-Ramírez, R., Vázquez-Peña, M. A., Coras-Merino, P. M., & Ángeles-Montiel, V. 2006. Componentes de la estación de crecimiento, variación temporal y espacial en Chapingo, México. *Tecnología Y Ciencias Del Agua*, *21*(2), 57-68.

Baier, W., and G.W. Robertson. 1966. A new versatile soil moisture budget. Can. J. Plant Sci., 46:299-315.

Banco de México. 2022. Sequía en México y su Potencial Impacto en la Actividad Económica. Tomado de:https://www.banxico.org.mx/publicaciones-y-prensa/informes-trimestrales/recuadros/%7B3A0127A1-D0C9-7D61-C9AE-E57E127FB39B%7D.pdf Fecha de acceso: 01-05-2023

Bradford, J.B., D.R. Schlaepfer, W.K. Lauenroth, C.B. Yackulic, M. Duniway, S. Hall, G. Jia, K. Jamiyansharav, S.M. Munson, S.D. Wilson, and B. Tietjen. 2017. Future soil moisture and temperature extremes imply expanding suitability for rainfed agriculture in temperate drylands. Scientific Reports, 7:12923, DOI:10.1038/s41598-017-13165-x

Calvo, J.C. 1986. An evaluation of Thornthwaite's water balance technique in predicting stream runoff in Costa Rica, Hydrological Sciences Journal, 31:1, 51-60, DOI: 10.1080/02626668609491027

Cardoso do Vale, T.M., M.H. Constantino-Spyrides, J.B. Cabral-Júnior, L.M. Barbosa-Andrade, B. Guedes-Bezerra, D. Tôrres-Rodrigues, and P. Rodrigues-Mutti. 2022. Climate and water balance influence on agricultural productivity over the Northeast Brazil. Research Square Preprint. DOI: https://doi.org/10.21203/rs.3.rs-1445346/v1

Chang, J.H. 1968. Climate and agriculture. An ecological survey. Aldine Publishing Company. Chicago, U.S.A. 304 pág.

Doorenbos, J., and Kassam, A.H. 1986. Efecto del agua sobre el rendimiento de los cultivos. Estudio FAO. Riego y Drenaje núm. 33. Roma, Italia. 212 pág.

Doorenbos, J., and Pruitt, W. O. 1977. Crop evapotranspiration. *FAO Irrigation and Drainage Paper No. 24*, FAO, Rome, Italy, 194 pág.

Douville, H., K. Raghavan, J. Renwick, R.P. Allan, P.A. Arias, M. Barlow, R. Cerezo-Mota, A. Cherchi, T.Y. Gan, J. Gergis,D. Jiang, A. Khan, W. Pokam Mba, D. Rosenfeld, J. Tierney, and O. Zolina, 2021: Water Cycle Changes. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Pean, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekci, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,pp. 1055–1210, doi:10.1017/9781009157896.010.

Fathurrahman, Abd. Syakur, Rio Marthadi, Inrianto Kadeko, and Ramal Yusuf. 2022. Estimation of planting season for food crops based on water balance model at center of food crops, Parimo Regency, Central Sulawesi Province. IOP Conf. Series: Earth and Environmental Science 1036, 012111 doi:10.1088/1755-1315/1036/1/012111

Fernandez Long, M.E., Spescha, L., Barnatán, I. y G. Murphy. 2012. Modelo de Balance Hidrológico Operativo para el Agro (BHOA). Rev. Agronomía & Ambiente 32(1-2): 31-47. FA-UBA, Buenos Aires, Argentina.

Flores L., H.E, Chávez D., A.A., Pérez D., J.F. e Ireta M., J. 2022. Estadísticas climatológicas normales, propiedades de suelo y requerimientos agroclimáticos de genotipos de maíz para Jalisco. Libro Técnico Núm. 1. SADER, INIFAP, CIRPAC, Campo Experimental Centro Altos de Jalisco. Tepatitlán de Morelos, Jalisco, México. 94 pág.

Hartkamp, A.D., De Beurs, K., Stein, A., and White, J. W. 1999. Interpolation techniques for climate Variables. NRG-GIS, Series 99-01. CIMMYT. México, D.F. 26 pág.

INEGI. 2018. ENCUESTA NACIONAL AGROPECUARIA (ENA) 2017. Tomado de: https://www.inegi.org.mx/contenidos/saladeprensa/boletines/2018/ena/ena2018_07.pdf Fecha de acceso: 01-05-2023

Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). 2017. AGENDA TÉCNICA AGRÍCOLA JALISCO. Ciudad de México. 264 PÁG.

Li, J., and A.D. Heap. 2011. A review of comparative studies of spatial interpolation methods in environmental sciences: Performance and impact factors. Ecological Informatics 6:228–241.

Mack, A.R., and W.S. Ferguson. 1968. A moisture stress index for wheat by means of a modulated soil moisture budget. Can. J. Plant Sci., 48:535543.

Mammoliti, E., Fronzi, D., Mancini, A.; Valigi, D.;,Tazioli, A. 2021. WaterbalANce, aWebApp for Thornthwaite–MatherWater Balance Computation: Comparison of Applications in Two European Watersheds. Hydrology, 8:34. https://doi.org/10.3390/hydrology8010034

Mintz, Y, and Y, V, Serafini. 1992. A global monthly climatology of soil moisture and water balance. Climate Dynamics, 8:13-27.

Moghaddam, T.E, and S. Mohammadkhan. 2017. An estimation of Thornthwaite monthly water-balance in Mighan sub-basin. Natural Environment Change, 3:71-80 DOI: 10.22059/jnec.2017.216461.54

Mohajerani, H., D.A. Zema, M. E. Lucas-Borja, and M. Casper. 2021. Chapter 9 Understanding the water balance and its estimation methods, Pp 193-221. In: Precipitation (Jesús Rodrigo-Comino editor). Elsevier: Amsterdam, The Netherlands, DOI: 10.1016/B978-0-12-822699-5.00019-7

Reddy, S.J. 1983. A simple method of estimating the soil water balance. Agric. Meteorol., 28:1-17.

Ruíz C., J. A.; Ramírez, D. J. L.; Flores, M. F. J. y Sánchez, G. J. J. 2000. Cambio climático y su impacto sobre la estación de crecimiento de maíz en Jalisco, México. Rev. Fitotec. Mex. 23(2):169-181.

Ruíz C., J.A., G. Medina G., H.E. Flores L., J.L. Ramírez D., L. De la C. Larios, J.F. Villalpando I., C. De La Mora O., N. Durán P., G.E. García R. y O. Ruiz A. 2016. Impacto del cambio climático sobre la estación de crecimiento en el estado de Jalisco, México. Revista Mexicana de Ciencias Agrícolas, 13:2627-2638.

Sabziparvar, A.A., H. Tabari, A. Aeini, and M. Ghafouri. 2010. Evaluation of Class A Pan Coefficient Models for Estimation of Reference Crop Evapotranspiration in Cold Semi-Arid and Warm Arid Climates. Water Resour Manage (2010) 24:909–920 DOI 10.1007/s11269-009-9478-2

Shaw, R.H. 1976. Moisture stress effects on corn in Iowa in 1974. Iowa State Journal Research. 50(4):335-343.

SIAP-SADER. 2024. Anuario Estadístico de la Producción Agrícola. Tomado de: https://nube.siap.gob.mx/cierreagricola/ Fecha de acceso: 19 de julio de 2024.

Smith., R.C.G., J.L. Steiner, W.S. Meyer y D. Erskine. 1985. Influence of season to season variability in

Steenhuis, T.S., and W.H. Van der Molen. 1986. The Thornthwaite-Mather procedure as a simple engineering method to predict recharge. J. Hydrol., 84:221-229.

Thornthwaite, C.W., and J. R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. Drexel Institute of Technology Laboratory of Climatology. Publications in Climatology, VOLUME. X NUMBER 3:185-311. Centerton, New Jersey. USA

Umar, R., and M. Yusuf. 2019. Determination of the Growing Season for Dry Land Agriculture Based on Thornthwaite Method in Bulukumba Regency, South Sulawesi Province. Journal of Physics: Conf. Series 1244. doi:10.1088/1742-6596/1244/1/012032

van Wart, J., L.G.J. van Bussel, J. Wolf, R. Licker, P. Grassini, A. Nelson, H. Boogaard, J. Gerber, N. D. Mueller, L. Claessens, M.K. van Ittersum, and K. G. Cassman. 2013. Use of agro-climatic zones to upscale simulated crop yield potential. Field Crops Research 143:44–55.

Wang, J.Y. 1963. Agricultural meteorology. Pacemaker Press. Milwaukee, Wisconsin, E.U.A. 693 pág.

Wang, J.Y., M.D. Bruton, C.E. Luchessa, and T.J. Roper. 1982. The grower's weather guide for farming practices. Milieu Information Service, Inc. San Jos,, California, E.U.A., 61 pág.

Ward, R.C., and M. Robinson. 2000. Principles of hydrology. Fourth edition. McGraw-Hill Publishing Company. Berkshire, England. 450 pág.

Wilhite, D.A., and Glantz, M.H. 1985. Understanding the drought phenomenon: the role of definitions. Water International, 10(3):111-120.