Drought impacts on yield potential in rainfed agriculture

Tsakiris G., Vangelis H., Tigkas D.

in

López-Francos A. (comp.), López-Francos A. (collab.).
Economics of drought and drought preparedness in a climate change context

Zaragoza : CIHEAM / FAO / ICARDA / GDAR / CEIGRAM / MARM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 95

2010
pages 191-197

Drought impacts on yield potential in rainfed agriculture

G. Tsakiris, H. Vangelis and D. Tigkas

Centre for the Assessment of Natural Hazards & Proactive Planning,
National Technical University of Athens, Iroon Polytechniou 9, 15773, Athens (Greece)
e-mail: water@survey.ntua.gr

Abstract. In this paper a simplified methodology for the estimation of drought impacts on crop yield in rainfed agriculture is proposed. The methodology is based on empirical models for the estimation of actual to potential evapotranspiration ratio (ET/PET). This ratio is related to the Reconnaissance Drought Index (RDI), an expression of cumulative precipitation to cumulative potential evapotranspiration. The actual to potential evapotranspiration ratio is the basic variable in the simple linear regression functions used for estimating the relative crop yield (actual/potential yield). A case study from Thessaly (Greece) is presented in which a large number of years were analysed to assess production losses.

Keywords. Drought – Crop yield – RDI – Evapotranspiration.

Les impacts de la sécheresse sur le rendement potentiel en agriculture pluviale

Résumé. *Dans cet article on propose une méthodologie simplifiée pour l'estimation des effets de la sécheresse sur le rendement agricole en agriculture pluviale. La méthodologie est fondée sur des modèles empiriques pour l'estimation du ratio d'évapotranspiration réelle sur l'évapotranspiration potentielle (ET/ETP). Ce ratio est lié à l'Indice de Reconnaissance de la Sécheresse (RDI), une expression des précipitations accumulées par rapport à l'évapotranspiration potentielle accumulée. Le ratio d'évapotranspiration réelle sur l'évapotranspiration potentielle est la variable de base dans les fonctions de régression linéaire simple utilisée pour l'estimation du rendement agricole relatif (rendement réel/potentiel). On présente une étude de cas en Thessalie (Grèce) dans laquelle un grand nombre d'années ont été analysées pour évaluer les pertes de production.*

Mots-clés. *Sécheresse – Rendement agricole – RDI – Évapotranspiration.*

I – Introduction

Mediterranean water resources are limited, fragile and threatened. Water shortage, caused mainly by drought and human activities and processes, is placing an increased pressure on an already stressed situation. Water shortage conditions may cause significant social, environmental and economic impacts. Nowadays, the water shortage problem is considered as a major problem in many parts of the world attracting the attention of the international communities of scientists and policy makers.

The most important consumer of water in Greece is irrigated agriculture accounting for about 85% of the total water consumed. The steadily increasing irrigated areas along with the need for more competitive products magnify the problem. In areas as the region of Thessaly in central Greece, where the economy is mainly based in agricultural production, an urgent solution is needed. Replacing crops with crops consuming less and focusing to rainfed agriculture may be such a solution (Pereira, 2007). Since human activities cannot influence the rainfed agricultural system significantly, drought is a key factor regarding the crop yield. Drought impacts can be assessed taking into account the severity of drought and the vulnerability of the agricultural system (Tsakiris and Tigkas, 2007).

In this paper the direct impact of droughts on rainfed agriculture is studied, through a simplified methodology with the aim to reach practical results. The methodology is based on empirical models for the estimation of actual to potential evapotranspiration ratio (ET/PET). Drought severity is represented by the Reconnaissance Drought Index (RDI), which is an expression of cumulative precipitation to cumulative potential evapotranspiration. Finally, the reduction of yield potential in rainfed agriculture in the Thessaly plain is estimated for the historical sample 1995-2002.

II – Methodology

1. Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) can be characterised as a general meteorological index for drought assessment (Tsakiris and Vangelis, 2005; Tsakiris *et al*., 2007). In this paper we will focus on two forms of RDI, the initial α_k and the standardised RDI_{st}.

The initial value (α_k) is presented in an aggregated form using a monthly time step and may be calculated on a monthly, seasonal or annual basis. The α_k for the year *i* and a reference period of *k* (months) is calculated as:

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}} \quad , \quad i = 1\ (1)\ N \tag{1}$$

where P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of month *j* of year *i*, starting from October which is the onset of the hydrological year for most Mediterranean countries and *N* is the total number of years of the available data. The mean annual $\bar{\alpha}_{12}$ is equal to the well-known Aridity Index of the area (UNEP, 1992).

The calculation of RDI_{st} can be performed by fitting the gamma probability density function (pdf) to the given frequency distribution of α_k (Tigkas, 2008; Tsakiris *et al*., 2008). Positive values of RDI_{st} indicate wet periods, while negative values indicate dry periods compared with the normal condition of the area. The severity of drought events increases when RDI_{st} values are lower. Drought severity can be categorised in mild, moderate, severe and extreme levels, with corresponding thresholds of RDI_{st} (-0.5), (-1.0), (-1.5) and (-2.0), respectively.

2. Assessing yield loss caused by droughts

Although RDI is a general index designed mainly to represent meteorological drought, it can be used to assess variables related to agricultural production, especially for rainfed crops. This is due to the fact that a number of empirical crop production functions include the ratio of actual (ET) to potential evapotranspiration (PET) as an independent variable. Many models and methods can be used to estimate the ratio ET/PET using RDI. One of them is described by the following simple equation referring to a certain period (Zhang *et al*., 2004):

$$\frac{ET}{PET} = 1 + \frac{P}{PET} - \left[1 + \left(\frac{P}{PET}\right)^{w}\right]^{1/w} \tag{2}$$

where *P* is the precipitation for the given period. According to Zhang *et al.* (2004) the coefficient *w* depends on the land cover of the region and may vary from 2.84 for areas covered by trees to 2.55 for areas with low vegetation.

Using equation (1) for a period of one hydrological year, equation (2) becomes:

$$\frac{ET}{PET} = 1 + a_{12} - \left[1 + (a_{12})^w\right]^{1/w} \tag{3}$$

Crop yield from a unit of land may be roughly estimated by a simple linear production function:

$$\frac{y}{y_0} = k_y \cdot \frac{ET}{PET} + (1 - k_y) \tag{4}$$

where y/y_0 is the ratio of actual to maximum yield and k_y is a coefficient which depends on the type of crop (e.g. Doorenbos and Kassam, 1979).

Equation (4) is a lumped model for estimating yield loss due to suppression of the ratio of ET/PET. For more analytical approaches the dated production functions should be used. In these functions each growth stage is modelled separately from the other growth stages. Then a simplified multiplicative or additive function is used accounting for the entire growth period resulting in the final loss in crop yield.

Using equation (3), equation (4) is then transformed into the following equation:

$$\frac{y}{y_0} = k_y \cdot \left(a_{12} - \left[1 + (a_{12})^w\right]^{1/w}\right) + 1 \tag{5}$$

Equation (5) can be used firstly to estimate the rainfed yield potential of a certain crop in an agricultural area by inserting the average $\overline{a}_{12}$ for the area based on a significant number of years. Further, by using the α_{12} value of each year of drought we have the estimation of the yield potential of this crop for this specific year. By comparing the above two we can estimate the shrinkage of yield potential for each drought year.

III – Case study

1. Study area

The above methodology was applied to one of the most water deficient agricultural areas of central Greece, the Thessaly plain (Fig. 1). This area suffers from low annual precipitation depths and from frequent and persistent droughts. The high water demands of agriculture makes Thessaly plain one of the most vulnerable areas of Greece in terms of waters scarcity.

Fig. 1. Location of the study area (region of Thessaly).

2. Drought assessment

For the identification of drought years, data from the Greek Meteorological Service were used. Monthly precipitation and temperature (average, minimum and maximum) data were analysed for a period of 47 hydrological years (1955-2002). The potential evapotranspiration (PET) was calculated using Hargreaves methods. Based on these data, the RDI (α values and RDI_{st}) were calculated.

In Fig. 2 the annual values of RDI (α_{12}) are presented. The average of α_{12} which is equal to the Aridity Index of the area is indicated by the dotted line. The RDI_{st} values are shown in Fig. 3, in which it is easier to identify the drought years and the drought severity. As can be seen from Figs 2 and 3, the significant drought events in the area occurred during the hydrological years 1958-59, 1969-70, 1970-74, 1992-94, 1997-98 and 1999-2000.

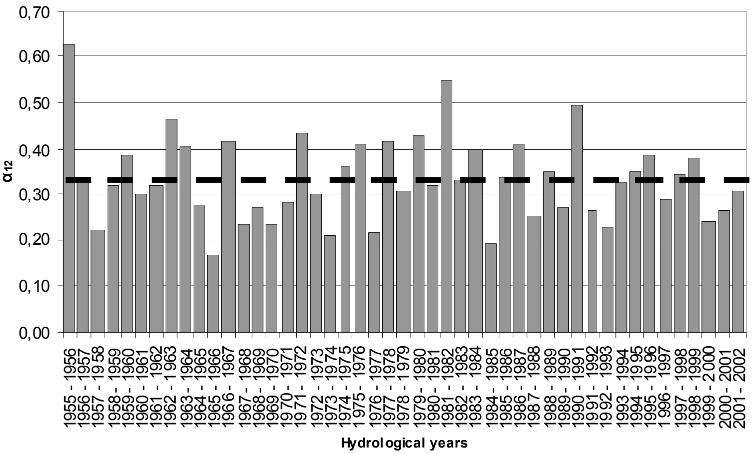

Fig. 2. Annual RDI (α_{12}) for the period 1955-2002 (dotted line indicates average conditions corresponding to the Aridity Index).

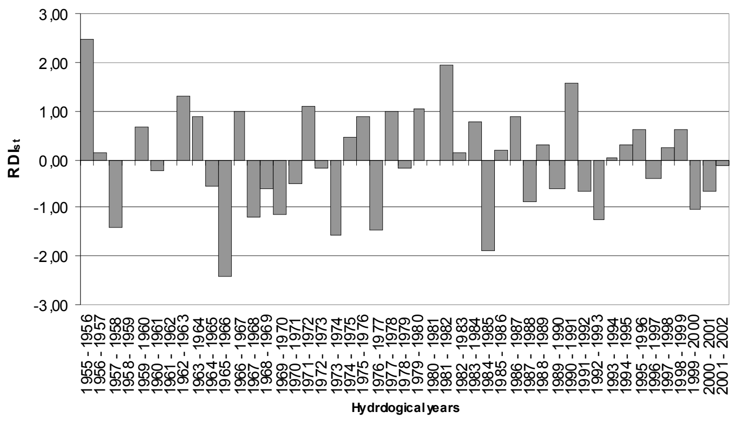

Fig. 3. Annual standardised RDI_{st} values for the period 1955-2002.

3. Relative yield loss

For the assessment of the relative yield loss in the study area, equation (5) was used for three crops: winter wheat (k_y = 1.0), sorghum (k_y = 0.9) and maize (k_y = 1.2) (Doorenbos and Kassam, 1979). The relative yield loss (Δy) is considered only for the years of drought in which $RDI_{st} < 0$:

$$\Delta y_i = \frac{\overline{y} - y_i}{\overline{y}} \quad (6)$$

where y_i is the annual crop yield of the specific year and $\overline{y}$ is the annual yield potential of the specific crop in the area (a_{12} equal to the aridity index $\overline{a}_{12}$).

As presented in Figs 4, 5 and 6, very significant yield losses occurred in the year 1965-66 and 1984-85, while there are 6 more years with crop losses over 40% compared with the yield potential of the area under study.

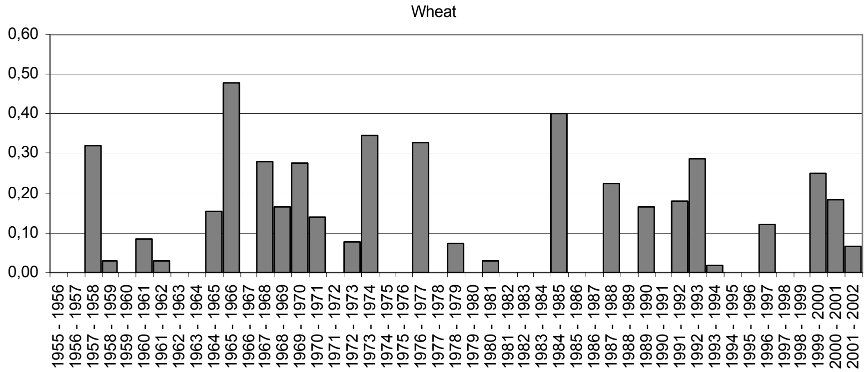

Fig. 4. Relative yield loss for wheat in the area of Larissa in drought years (period 1995-2002).

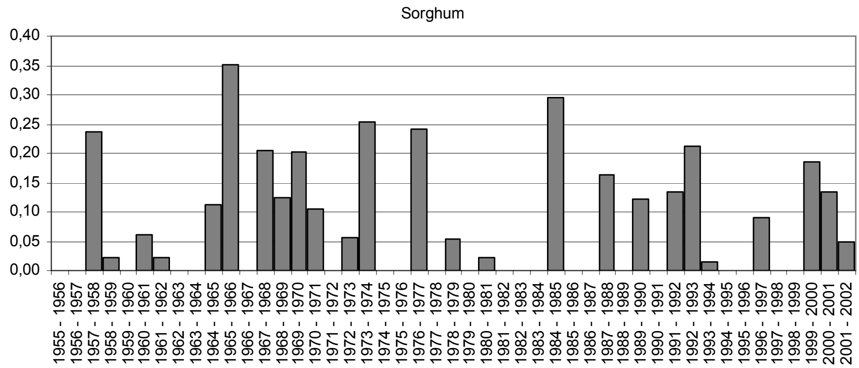

Fig. 5. Relative yield loss for sorghum in the area of Larissa in drought years (period 1995-2002).

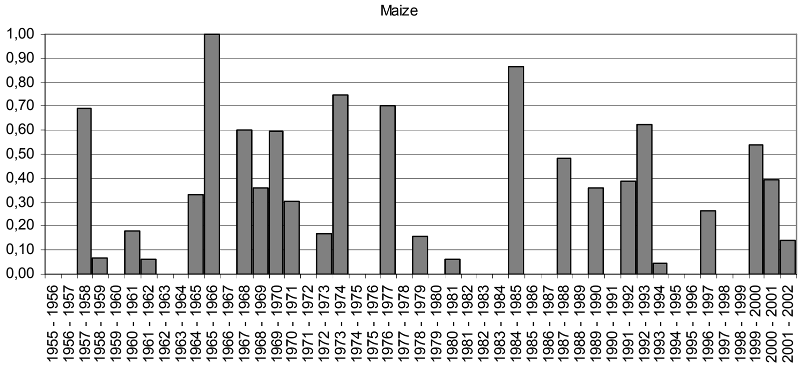

Fig. 6. Relative yield loss for maize in the area of Larissa in drought years (period 1995-2002).

From Figs 4, 5 and 6, it may be also noticed that higher losses occurred for maize and then for wheat, whereas sorghum seems to be more resistant to droughts. The maximum yield loss encountered reached 100% for maize, nearly 50% for wheat and 35% for sorghum.

The above results were compared with the real information on yield losses from Cooperative Agricultural Organisations of the area. Although no crisp figures but qualitative information was available from these organisations, it seems that their records on the years of high losses on the above crops coincide with the years with high losses estimated by the proposed simplified procedure. Needless to say that due to the gross assumptions adopted in this approach, rounded figures should be finally produced.

IV – Concluding remarks

In this paper a simplified procedure for estimating drought impacts on rainfed agriculture was proposed. It was shown that drought indices such as the Reconnaissance Drought Index can be used for estimating the level of crop yield losses for rainfed crops for the drought years. The proposed procedure is based on the crop yield potential of the area under study. Using simplified lumped crop yield functions the negative deviation from the yield potential for the crop and the area is calculated and expressed in relative values.

The importance of the proposed procedure lies in the fact that it is simple and easy to understand and therefore it may be accepted by all interested parties in a preparedness plan for facing drought in rainfed agriculture.

The proposed methodology after customisation and refinement could be also used for devising insurance policies and compensation strategies related to drought episodes.

References

Doorenbos J. and Kassam A.H., 1979. *Yield response to water*. FAO, Irr. and Drain. Paper 33, Rome.

Pereira L.S., 2007. Drought impacts in agriculture: Water conservation and water saving practices and management. In: Rossi G., Vega T. and Bonaccorso B. (eds). *Methods and Tools for Drought Analysis and Management*. The Netherlands: Springer, p. 349-373.

Tigkas D., 2008. Drought characterisation and monitoring in regions of Greece. In: *European Water*, 23/24, p. 29-39.

Tsakiris G., Nalbantis I., Pangalou D., Tigkas D. and Vangelis H., 2008. Drought meteorological monitoring network design for the reconnaissance drought index (RDI). In: López-Francos A. (ed.). Proc. of the 1st Int. Conference "Drought Management: Scientific and Technological Innovations", Zaragoza (Spain), 14-16 June 2008. *Options Méditerranéennes*, Series A, no. 80, p. 57-62.

Tsakiris G., Pangalou D. and Vangelis H., 2007. Regional drought assessment based on the Reconnaissance Drought Index (RDI). In: *Water Resources Management*, 21, p. 821-833.

Tsakiris G. and Tigkas D., 2007. Drought risk in agriculture in Mediterranean regions. Case Study: Eastern Crete. In: Rossi G., Vega T. and Bonaccorso B. (eds). *Methods and Tools for Drought Analysis and Management*. The Netherlands: Springer, p. 399-414.

Tsakiris G. and Vangelis H., 2005. Establishing a drought index incorporating evapotranspiration. In: *European Water*, 9/10, p. 3-11.

UNEP, 1992. *World Atlas of Desertification.* London: Edward Arnold.

Zhang L., Hickel K., Dawes W.R., Chiew F. and Western A., 2004. A rational function approach for estimating mean annual evapotranspiration. In: *Water Resources Research*, 40, W02502, doi:10.1029/2003WR002710.