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Abstract. This study aims at assessing the feasibility of deficit irrigation of maize and wheat under drought conditions when farmed in selected sprinkler-irrigated fields in Vigia Irrigation District, Southern Portugal. An analysis of the economic water productivity is adopted. Considering a very high climatic demand, various scenarios of water deficits and limited water availability were developed. Various economic water productivities values were calculated using field collected data on yield, production costs, water costs, commodity prices and irrigation performance in order to determine positive economic thresholds. Results show that the main bottleneck for adopting deficit irrigation under drought conditions is the presently low performance of the farm irrigation systems, which leads to low economic water productivities. Limited water deficits for all crops are likely to be viable when improving the irrigation performance. It is concluded that adopting deficit irrigation requires high irrigation performance, and that the application of a water prices policy would be flexible, thus supporting the improvement of the irrigation systems and of drought irrigation management policies.

Keywords. Economic water productivity – Drought – Irrigation performance – Water prices.

Évaluer la faisabilité de l'irrigation déficitaire en vertu des conditions de sécheresse

Résumé. *Cette étude a comme objectif l'évaluation de la faisabilité économique de l'irrigation déficitaire du maïs et du blé en conditions de sécheresse. Les cultures sont irriguées par aspersion et se situent sue le périmètre irrigué de Vigia, au Sud du Portugal. On a adopté l'analyse par la productivité économique de l'eau (EWP). Plusieurs scénarios de déficit en eau et de disponibilité de l'eau ont été considérés pour des conditions de très forte demande en eau. On a calculé plusieurs valeurs pour EWP en utilisant des données de terrain relatives au rendement, aux coûts de production, aux prix de l'eau, aux prix des produits et à la performance de l'irrigation de façon à déterminer les seuils économiques positifs. Les résultats montrent que la difficulté principale pour adopter l'irrigation déficitaire en conditions de sécheresse est la faible performance des systèmes d'irrigation à la parcelle, ce qui conduit à une faible EWP. Des déficits en eau limités peuvent être économiquement faisables si cette performance est améliorée. On a conclu que l'adoption de l'irrigation déficitaire requiert de meilleures performances de l'irrigation et que soit adoptée une politique de prix de l'eau flexible et capable d'appuyer l'amélioration des systèmes d'irrigation et l'application des politiques de gestion des sécheresses.*

Mots-clés. *Productivité économique de l'eau – Sécheresse – Performance de l'irrigation – Prix de l'eau.*

I – Introduction

Deficit irrigation consists in deliberately applying irrigation depths smaller than those required to satisfy the crop water requirements, thus affecting evapotranspiration and yields, but keeping a positive return from the irrigated crop (Kang *et al.*, 2000). However, impacts of irrigation deficits on yields and related economic results may or not be negative, depending upon the adopted irrigation scheduling, irrigation performance, production costs and yield values (Lorite *et al.*, 2007). Support to farmers through the use of simulation models may help them to adopt an irrigation management that controls water deficits in such a way these are applied during the less sensitive crop development stages (Pereira *et al*., 2009b). Increasing the water productivity (WP) may be the best way to achieve efficient water use. Pereira *et al.* (2009a) define WP as the ratio between the yield achieved (Y_a) and the total water use (TWU).

The main goal of this study is the assessment of the economic impacts of water deficits and water costs for deficit irrigation under drought conditions through evaluations of economic water productivities. This approach may allow defining a methodology easily in engineering assessment. The development and testing of this methodology is one of the aims of this study, including the use of the simulation model SIMDualKc (Rolim *et al.*, 2007; Godinho *et al*., 2008). The SIMDualKc model allows the estimation of crop transpiration and soil evaporation and is applied to two sprinkler-irrigated fields in Vigia Irrigation District, Alentejo region (Southern Portugal) and two field crops: maize and wheat. The second main objective is the assessment of the feasibility of deficit irrigation as influenced by irrigation performance and the water costs. With this purpose, the irrigation systems performance was evaluated in those fields, costs were assessed and various scenarios of water demand and irrigation water costs are considered, the latter relating to the application of the European Water Directive to the irrigated agriculture sector.

II – Materials and methods

1. Study area and irrigation systems

The study area is the Vigia Irrigation District, Évora. The meteorological station is located in Évora. The predominant soil types in the area are Mediterranean red and brown soils derived from quartz-diorite rocks and other non-calcareous materials. The unsaturated soil hydraulic properties were determined from a survey and using laboratory methods for the full range of soil water tension. The crops selected for this study are the winter wheat and maize. Some main characteristics of these crops are described by Rodrigues and Pereira (2009).

Field evaluations of irrigation systems in operation were performed through several years (Pereira, 2007). Considering the willingness of the farmers to cooperate, those systems were evaluated twice or more times. For understanding how performance could influence economic results, two case studies relative to poorly performing irrigation systems were selected for this analysis. They correspond to a large and a medium farm, identified respectively as M. Igreja and T-134.

2. Water productivity

There is not a common agreement on the use of the term WP. WP may express a physical ratio between yields and water use or between the value of the product and water use. Concepts may be applied to different scales, from the field to the basin. As analysed by Pereira *et al.* (2009a), WP concepts may be extended to non-agricultural water uses. Therefore, it is important to properly define the concepts used in this study. WP is defined herein as the ratio between the actual crop yield and the total water use, in kg/m^3 (Pereira *et al.*, 2009a), thus:

$$WP = \frac{Y_a}{TWU} \tag{1}$$

When considering the farm irrigation water use (IWU_{Farm}) only, it results the farm irrigation water productivity:

$$WP_{I-Farm} = \frac{Y_a}{IWU_{Farm}} \tag{2}$$

It is important to consider the economic issues relative to water productivity since the objective of a farmer is to achieve the best income and profit. As for this study, the economics of production is considered when expressing both the numerator and the denominator in monetary terms, respectively the yield value and the TWU cost (including the irrigation farming costs), thus yielding the economic water productivity ratio (EWPR):

$$EWPR = \frac{Value(Y_a)}{Cost(TWU)} \qquad (3)$$

Several scenarios for deficit irrigation were simulated with the SIMDualKc model, which allowed estimating the net irrigation requirements (NIR) relative to every scenario. Using these irrigation data with the Stewart model (Stewart *et al.*, 1977), the Y_a values were computed for each scenario. NIR values were converted into gross irrigation depths (GID) using a set of potential application efficiency values representing various scenarios for improving the irrigation performance, starting with those obtained from field evaluations. WP, $WP_{I\text{-}Farm}$ and EWPR were then determined for the various combinations yield – seasonal gross irrigation. Rodrigues and Pereira (2009) assessed the effects of water prices in $EWPR_I$.

3. Irrigation scenarios

The irrigation scenarios simulated were built assuming various restrictions on the seasonal water available for irrigation and different allowed soil water depletion fractions (ASWD). These are defined by a percentage increase of the depletion fraction for no stress "p". These scenarios are described by Rodrigues and Pereira (2009).

The crop net irrigation requirements (NIR) were computed for no restrictions on water availability and ASWD = p. It resulted for each crop a NIR data series relative to the period covered by the weather data set (1965-2009), which were analysed assuming a normal distribution. Hence, the years when NIR are not exceeded with the probabilities of 50, 95 and 97% were identified to represent average (Av), very high (VH) and extreme (Ext) climatic demand. The last two typically identify drought years. All irrigation scenarios were simulated for the all weather conditions. The years of Av, VH and Ext climatic demand for maize are 1969, 1998 and 2004, respectively. For wheat, the years of 1985/86, 1998/99 and 1994/95, for the same climatic demand. The season NIR for those identified years and all scenarios described in were computed adopting irrigation depths of 15 mm per event as usually practiced in the area. They were later transformed into seasonal gross irrigation requirements (GID) considering the observed potential efficiencies defined above: PELQ = 65.5% for M. Igreja (center-pivot system) and PELQ = 61.5% for T-134 (solid set sprinkler system). To consider the upgrading of the irrigation systems and an improvement in management that allow to control wind drift losses, as well as higher distribution uniformity and appropriate irrigation schedules, two improved performance scenarios based upon data suggested by Keller and Bliesner (1990) were considered where PELQ are 70 and 85%.

4. Irrigation costs

The calculation of EWPR requires that the cost of each cubic meter of water is known. Data by Noéme *et al.* (2004) was used by Rodrigues and Pereira (2009) for estimating the investment costs reported to 2003 and using appropriate life time for various types of equipment, which consist of fixed costs, and the operation, maintenance and management (OM&M) costs that consist of variable costs. Data relative to crop practices and used production factors were obtained through questionnaires to farmers, in order to build a database with all the farming costs.

IV – Results

1. Water productivity

For the actual PELQ, a comparison between WP and $WP_{I\text{-}Farm}$ obtained with and without water availability restrictions is presented in Fig. 1.

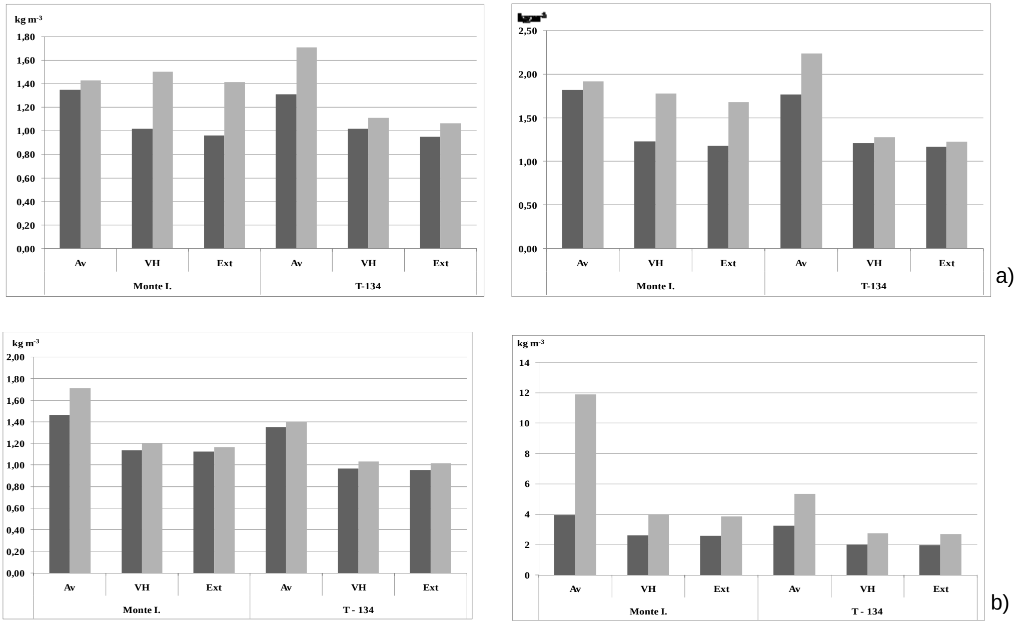

Fig. 1. WP (on left) and WPI-farm (on right) for average (Av), very high (VH) and extreme (Ext) climatic demand with ( ) and without ( ) water availability restrictions for: a) maize and b) wheat under the observed irrigation performance.

Results in Fig. 1a show that adopting a reduced demand scheduling due to limited water availability when farming maize leads to higher WP and $WP_{I\text{-}Farm}$, particularly the latter because it depends only from the irrigation water use. When no restrictions to water use are considered, WP varies from 0.96 to 1.35 kg/m^3, and when water availability is restricted WP ranges 1.06 to 1.71 kg/m^3. Under full irrigation, $WP_{I\text{-}Farm}$ ranges 1.17 to 1.82 kg/m^3, while adopting deficit irrigation it varies from 1.23 to 2.24 kg/m^3. Results show that water productivities are lower under very high climatic demand because crop water requirements are then the highest. Under these conditions, because under deficit irrigation the consequent reduction in yields is larger than the decrease in water use, it results also a decrease in WP.

Fig. 1b compares WP and $WP_{I\text{-}Farm}$ for wheat with and without water restrictions considering the observed irrigation performance conditions. Differently from the summer crops, because irrigation is supplemental of rainfall, which is the main source for wheat water use, results for WP show only a small increase when water restrictions are considered. Instead, $WP_{I\text{-}Farm}$ very much increases when restrictions are applied to the irrigation water, augmenting from a range of 1.98-4 kg/m^3 to 2.7-11.9 kg/m^3. The smaller values correspond to the less performing case (T-134) and to the extreme climatic demand, when irrigation requirements are the highest. The highest values refer to the best performing farm (M. Igreja).

2. Assessing the impacts of farming and water prices

The economic water productivity ratio (EWPR, equation 3) is used to compare the yield values per unit of farming costs considering water costs relative to the three water price scenarios. Analysing the EWPR for maize (Fig. 2a), it may be observed that these ratios are presently in the range 0.41 to 0.56, for the current water prices, 0.04 €/m^3 (lower ratios refer to drought conditions and larger ones to average demand). If these would be maintained, EWPR would increase to 0.42-0.57 if PELQ = 85% is achieved. Results show that farmers have a negative return from farming maize with the currently poor performing irrigation systems with the current commodity prices. If the water prices increase to fully cover the OM&M costs (0.0834 €/m^3), EWPR would decrease to 0.37-0.52 and maize production with the presently poor performance would be even more unprofitable. If system performance would be improved, EWPR would range 0.39-0.53 and farming returns would keep being not profitable under every demand conditions. If full costs are considered (0.1144 €/m^3), then EWPR decrease to 0.35-0.5 for the actual PELQ or to 0.37 to 0.52 with PELQ = 85%. Then, maize production would lead to a negative income to the farmer including for average demand conditions.

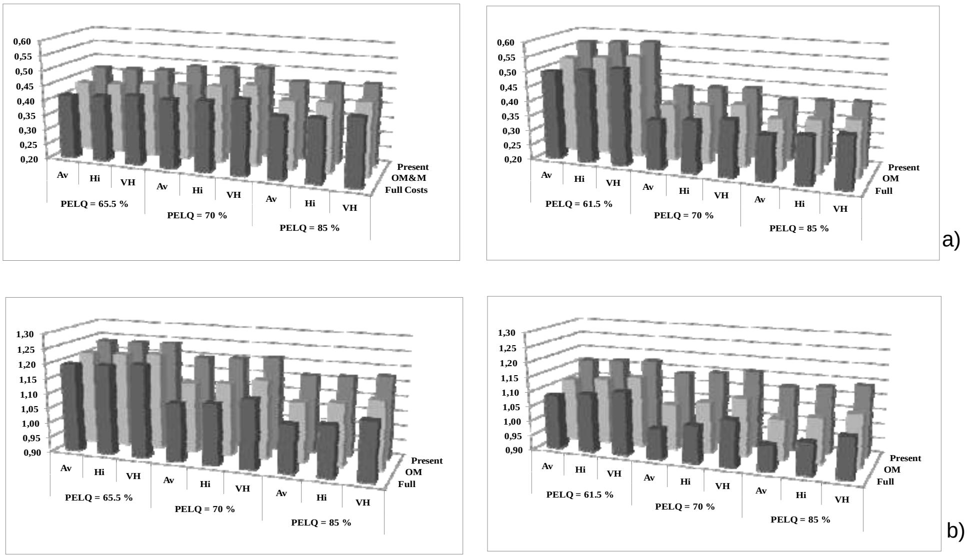

Fig. 2. Economic water productivity ratios relative to farms M. Igreja (on the left) and T-134 (on the right) under deficit irrigation for: a) maize and b) wheat, considering three system performance scenarios and three water costs scenarios (present, OM&M costs and full costs).

Results for wheat (Fig. 2b) show that for the present water price (0.04 €/m^3) EWPR vary from 1.12 to 1.24 for the present PELQ, and from 1.14 to 1.24 with an improved system performance (lower ratios refer to drought conditions and larger ones to average demand). Hence, results show that with current water prices wheat supplemental irrigation is profitable. If water prices rise to 0.0834 €/m^3 EWPR range 1.03-1.21 and 1.08-1.22 respectively for present and improved PELQ, while for water prices that fully cover the total costs (0.1144 €/m^3) EWPR decrease to 0.98-1.19 and 1.04-1.21 for the same performance scenarios. Results show that covering the OM&M costs would lead to positive results if higher performances are achieved but it is not so evident that when prices rise to cover full costs positive returns could be attained due to the fluctuation of commodity prices. Results show that water prices influence the profitability of irrigated agriculture. Moreover, the analysis shows that the variability of crop irrigation water demand due to system performance highly influences the economic water productivity ratio, i.e. the impacts of water costs and prices are tied to the irrigation performance PELQ. In general, results show that using poorly performing irrigation systems do not allow practicing deficit irrigation if water price policies following the European Water Directive are abruptly enforced, i.e., some flexibility must be adopted in view of progressively improving the irrigation performance and the demand for water.

V – Conclusions

This study shows that economic water productivity indicators may be appropriate tools for assessing impacts of deficit irrigation and water costs. Comparing water productivities with or without restrictions in water availability, i.e., with and without crop water stress, may help to assess when deficit irrigation is or not feasible; however, an analysis of economic water productivities is definitely helpful with this purpose. In this study, it is observed that the small differences between water productivities of maize with and without water availability restrictions are not enough to justify when the adoption of deficit irrigation may or not be feasible.

The economic water productivity ratio EWPR, relating the yield values per unit of farming costs with the water prices, reveals adequate to assess the feasibility of deficit irrigation as influenced by the water prices. In case of maize, the analysis confirms that the feasibility of deficit irrigation highly depends upon the system performance, is doubtful when the climatic demand is very high to extreme (drought conditions), and may not be feasible if water prices rise to cover the OM&M costs, mainly if commodity prices fall to former lower levels. Wheat under supplemental irrigation, thus with relatively small irrigation water use, may respond positively to increased water prices if irrigation systems perform well and commodity prices do not fall.

This study shows that analysing deficit irrigation, and consequently defining the corresponding issues for appropriate feasibility, require not only the knowledge of the crop yields responses to water but also to know the structure of the production costs, including relative to the impacts of irrigation costs and performances on the crops profitability. Appropriately modelling is then required since the prices of commodities pay a very important role. The present analysis using EWP and EWPR revealed adequate for assessing the feasibility of deficit irrigation but further developments on the relationships between irrigation practices and economic results are required.

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