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# Increasing water productivity of irrigated crops under limited water supply at field scale

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ABSTRACT

Borkhar district is located in an arid to semi-arid region in Iran and regularly faces widespread drought. Given current water scarcity, the limited available water should be used as efficient and productive as possible. To explore on-farm strategies which result in higher economic gains and water productivity (WP), a physically based agrohydrological model, Soil Water Atmosphere Plant (SWAP), was calibrated and validated using intensive measured data at eight selected farmer fields (wheat, fodder maize, sunflower and sugar beet) in the Borkhar district, Iran during the agricultural year 2004–2005. The WP values for the main crops were computed using the SWAP simulated water balance components, i.e. transpiration $T$, evapotranspiration ET, irrigation $I$, and the marketable yield $Y_M$ in terms in terms of $Y_M T^{-1}$, $Y_M\,ET^{-1}$ and $Y_M\,I^{-1}$.

The average WP, expressed as $\$\,T^{-1}$ (US $\$\,m^{-3}$) was 0.19 for wheat, 0.5 for fodder maize, 0.06 for sunflower and 0.38 for sugar beet. *This indicated that fodder maize provides the highest economic benefit in the Borkhar irrigation district.* Soil evaporation caused the average WP values, expressed as $Y_M\,ET^{-1}$ (kg $m^{-3}$), to be significantly lower than the average WP, expressed as $Y_M\,T^{-1}$, i.e. about 27% for wheat, 11% for fodder maize, 12% for sunflower and 0.18 for sugar beet. Furthermore, due to percolation from root zone and stored moisture content in the root zone, the average WP values, expressed as $Y_M\,I^{-1}$ (kg $m^{-3}$), had a 24–42% reduction as compared with WP, expressed as $Y_M\,ET^{-1}$.

The results indicated that during the limited water supply period, on-farm strategies like *deficit irrigation scheduling* and *reduction of the cultivated area* can result in higher economic gains. Improved irrigation practices in terms of irrigation timing and amount, increased WP in terms of $Y_M\,I^{-1}$ (kg $m^{-3}$) by a factor of 1.5 for wheat and maize, 1.3 for sunflower and 1.1 for sugar beet. Under water shortage conditions, *reduction of the cultivated area* yielded higher water productivity values as compared to *deficit irrigation*.



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# 1. Introduction

In the period 2000–2002 the Iranian Agricultural Engineering Research Institute (IAERI), together with the International Water Management Institute (IWMI), did several quantitative studies on water resources and the irrigated agricultural sector in the Zayande Roud basin (Sally et al., 2001; Salemi et al., 2000; Droogers et al., 2001; Gieske et al., 2002a,b). Although these studies give a good description of the hydrology and the management of the major irrigation systems in the Zayande Roud basin, *there is a general lack of field scale research on crop and water management strategies under water limited conditions*.

Under current water scarcity conditions, the limited available water should be used more efficiently (Bessembinder et al., 2005). Taking into account that photosynthesis (and thus dry matter yield) and transpiration are related through the diffusion process of $CO_2$ and $H_2O$, the efficiency of crop water use can be defined as:

$$\text{Water use efficiency} = \frac{\text{Dry matter growth rate}}{\text{Transpiration rate}} = \frac{Y\,(\text{kg}\,\text{ha}^{-1}\,\text{d}^{-1})}{T\,(\text{mm}\,\text{d}^{-1})} \quad (1)$$

In daily irrigation practices, 'water productivity' WP is a more relevant term for Eq. (1), where the meaning depends on the application. In the case that we integrate the rate of dry matter yield and transpiration over time, i.e. the growing season, denoted as *Y* and *T* respectively. The efficiency of water used by the crop can then be expressed as water productivity $WP_T$:

$$WP_T = \frac{Y(\text{kg ha}^{-1})}{T(\text{mm})} \rightarrow \frac{Y(\text{kg ha}^{-1})}{T(\text{m}^3\ \text{ha}^{-1})} \rightarrow \text{kg m}^{-3} \quad (2)$$

where 1 mm is equivalent with $10\,\text{m}^3\,\text{ha}^{-1}$. When applying irrigation at field scale, it is generally difficult to distinguish plant transpiration *T* (mm) from soil evaporation *E* (mm). Hence, instead of $WP_T$, $WP_{ET}$ may be used (Molden, 1997; Molden et al., 2001; Droogers and Bastiaanssen, 2002; Kijne et al., 2003):

$$WP_{ET} = \frac{Y\,(\text{kg}\,\text{ha}^{-1})}{ET\,(\text{m}^3\,\text{ha}^{-1})} \rightarrow \text{kg m}^{-3} \quad (3)$$

where ET is the evapotranspiration of 'crop + soil'. Total dry matter yield *Y* may also be transformed into marketable yield, i.e. $Y_M$.

If the amount of irrigation + precipitation water is considered as 'water use of the crop' then $WP_{I+P}$ may be used:

$$WP_{I+P} = \frac{Y(\text{kg}\,\text{ha}^{-1})}{[I+P](\text{m}^3\,\text{ha}^{-1})} \rightarrow \text{kg m}^{-3} \quad (4)$$

where *I* stands for amount of seasonal irrigation and *P* for the seasonal precipitation.

Under condition of very low precipitation like arid regions, $WP_{I+P}$ may be converted to $WP_I$:

$$WP_I = \frac{Y(\text{kg}\,\text{ha}^{-1})}{I(\text{m}^3\,\text{ha}^{-1})} \rightarrow \text{kg}\,\text{m}^{-3} \quad (5)$$

As the farmer is mainly interested in the economic yield of the crop, WP may be expressed in terms of money as:

$$WP_\$ = \frac{(\$\,\text{kg}^{-1})\ (\text{kg}\,\text{ha}^{-1})}{ET\,(\text{m}^3\,\text{ha}^{-1})} \rightarrow \$\,\text{m}^{-3} \quad (6)$$

where 1 US \$ is equivalent with 1 \$.

WP indicators express the benefit derived from the consumption of water and can be used for assessing the impact of on-farm strategies under water scarce conditions. They provide a proper vision of where and when water could be saved. WP indicators are also useful for looking at the potential increase in crop yield that may result from increased water availability (Singh et al., 2006).

Quantitative information on WP indicators is therefore necessary to plan an efficient irrigation water management under water scarce conditions. In order to explore which farm strategies help us to achieve 'more crop per drop', we need to understand the interactions between soil, atmosphere, crop and water. Taking in account the spatial variability of the soil and the land use properties, as well as crop growth development, simulation of the water balance components will certainly increase our ability to improve water productivity under water shortage conditions.

In the past 30 years, physically based agrohydrological models such as the Soil Water Atmosphere Plant (SWAP) model (Kroes and van Dam, 2003) have been developed to simulate crop growth and soil water processes. Simulation models are strong in scenario analyses and thus permit to explore viable ways of crop and water management which may help to mitigate the impact of drought (Ines and Droogers, 2002). However, agrohydrological models use a large number of input parameters which may cause low performance and large uncertainty in simulation results such as actual evapotranspiration, deep percolation and dry matter yield (Singh et al., 2006).

In this paper, a methodology will be presented for evaluation of on-farm strategies under water-limited conditions. The SWAP model will be calibrated and validated for the main crops in the Borkhar irrigation district using measurements from farmer's fields. Most of the input parameters collected from these fields will be used directly in the calibration procedures. The remaining unknown soil hydraulic parameters, irrigation depths and crop parameters will be determined indirectly by an inverse modelling technique (Jhorar, 2002; Ritter et al., 2003).

With the help of automated runs using the link between SWAP and the Parameter ESTimation model PEST (Doherty et al., 1995), WP-water consumption curves will be presented for the main crops and for different irrigation practices. On-farm strategies like deficit irrigation scheduling and cropped area reduction will be evaluated using WP indicators. The maximum possible increases in WP indicators will be derived graphically from the WP curves.

# 2. Methodology

## 2.1. Study area

As study area the Borkhar irrigation district was selected, which is located North of the ancient town of Esfahan in the