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# Benchmark irrigated under cover agriculture crops

E. Kitta[a], T. Bartzanas[a], N. Katsoulas[b], C. Kittas[b*]

*[a]Centre fro Research and Technhology-Hellas, Dimitriados 95 & P. Mela, Volos 38333, Greece*
*[b]University of Thessaly, School of Agricultural Sciences, Fytokou St, Volos 38446, Greece*

## Abstract

Managing water sustainably in a 'green' economy means using water more efficiently in all sectors and ensuring that ecosystems have the quantity and quality of water needed to function effectively. Despite the increasing demand for water and its scarcity in some regions in Europe and the Mediterranean basin, "water use efficiency" or Water Productivity, is claimed to be unsatisfactory. In many Southern European regions up to 85% of the water is consumed by agriculture. The expected climate change will worsen the situation as it will lead to hotter summers. In this paper an initial study to benchmark agricultural irrigation practices– here, protected cultivation - with the objective of evaluating and comparing the systems through performanceindicators that can be obtained from data routinely available at the field and farm level were presented and discussed. Benchmarking, a systematic process for detecting inefficiencies based on comparisons between similar systems, is a potential tool for identifying andtargeting problem areas. The benchmarking tool was based on the results of an FP7 EU-SIRRIMED. In the present study we use this tool in order to assess the performance of two contrasted production strategies (i) hi-tech horticultural production, exemplified by soil-less greenhouse-grown tomato crops with closed, semi closed and open irrigation techniques and (ii) low-tech screenhouse production, exemplified by soil grown sweet pepper under screenhouses having different shading factors. We found that a large margin of progress in water and fertilisers use efficiency is at hand of farmers, provided they can integrate to their farming practices innovative technologies (i.e closed hydroponic systems) or structures that are well adapted to the local climatic and biotic conditions (e.g. screenhouses).

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*Keywords: irrigation and management, screenhouses, greenhouses*

## 1. Introduction

With a fast growing world population, climate change impacts, an increasing competition for fresh water, water scarcity approaching critical levels in many developing countries. Irrigated agriculture is the largest water-consuming sector and it faces competing demands from other sectors, such as the industrial and the domestic sectors. The agricultural sector faces the challenge to produce more food with less water by increasing crop water productivity. In the agricultural sector, this has been expressed as “more crop and higher value per drop” (FAO, 2000).

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* Corresponding author. Tel.: +3024210 93158 .*E-mail address*: ckittas@uth.gr

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Despite the increasing demand for water and its scarcity in some regions in Europe and the Mediterranean basin, "water use efficiency" (WUE), is not satisfactory. Most of the irrigation systems in current use have low WUE, whereas the use of more efficient systems is still relatively low, such as drip irrigation and travelling irrigators that distribute water directly without sprinklers. Additionally, most farmers are managing irrigation empirically with little or no knowledge of soil and crop water status, resulting in low WUEs. It is estimated that between 30 to 50% of the water applied to major cultivated crops is simply wasted.

Farmers have only just begun to adopt water-saving practices and adoption has been low, possibly because farmers do not benefit directly by saving water. In addition, the current extension system charged with promoting the adoption of water-saving technologies or practices faces poor incentives and low budgets to carry out this work.

The surface area of greenhouses used for vegetable production is expanding rapidly throughout the Mediterranean Basin. For similar levels of production, crop water requirements are considerably less in greenhouses thanin open fields (FAO, 2000). This is a consequence of the much lower evapotranspiration inside greenhouses on account of there being considerably less wind, reduced solar radiation, and higher atmospheric humidity (Katsoulas et al. 2006). Therefore, greenhouse crops have appreciably higher water use efficiency (WUE). However even in greenhouse crops growers routinely apply more irrigation water to the crops than the estimated water consumption. Capture and recycling of the excess irrigation water that drains out of the root zone is possible in closed-cycle soilless growing systems and might considerably improve the water use efficiency in greenhouse crops (Savvas, 2002).

Apart from greenhouses, the area of agricultural cultivation of vegetable crops and orchards in screenhouses and under screens is constantly increasing in Mediterranean basin, as they meet the needs of consumers for products grown with low inputs of pesticides, as screening materials exclude insects that attack crops, downgrading their productivity and quality. The porous screens provide protection from unfavorable climatic conditions; they modify the crop’s microclimate and consequently its water requirements (Möller and Assouline, 2007). The screenhouse enclosure not only modifies the physical climate by altering the radiative and the flow field components, but it also amplifies the two-way interaction between crops and their microclimate. Unlike the ‘open-field’ setup, the water vapor and heat fluxes originating from the crops within the partially enclosed area can substantially alter the micro-environment, which in turn, alters these fluxes. It is precisely this intensified two-way coupling between the plants and their microclimate in protected environments that can lead to a more sustainable use of irrigated water.

In the last decade the EU Commission produced several documents addressing the integration of environmental concerns into the agricultural policy. Agriculture both creates pressures on the environment and plays an important role in maintaining many cultural landscapes and semi natural habitats. Where the causes of environmental change associated with agriculture are understood, usually they can be traced to changes in farm management and land use. To assess the extent to which environmental concerns are integrated into agriculture policy, it is necessary to understand the environmental pressures and impacts that arise as a result of agricultural activity and its interaction with the environment. The relationship between agriculture and environment can be described by indicator groups that relate to driving forces, pressures, state, impact and responses. Although the need for reliable indicators to monitor, measure and evaluate the real impact of proposed innovation on the environmental sustainability is evident, there is still a lack of that indicators that farmers and water authorities can use to achieve their goals. Benchmarking tools and performance indicators can be efficient used for this purpose.

Benchmarking in not something new. In 4th Century B.C., in Greece, Xenephon wrote: “You (Socrates) have discovered the reasons why some farmers are so successful that husbandry yields them all they need in abundance, and others are so inefficient that they find farming unprofitable. I should like to hear the reasons in each case, in order that we may do what is good and avoid what is harmful”. The term ‘benchmarking’ is used to cover a number of practices found in farming andfood that are designed to highlight the good and make it possible to avoid the harmful. The first task is to clarify what is meant by benchmarking in each of these practices, before assessing their contribution to the development of sustainable change in these industries. In general business practice, benchmarking is used to signify a particular systematic approach in which a business evaluates its own operations and procedures through a detailed comparison with those of another business, in order to establish best practice and to improve performance

## 2. Materials and Methods

### *2.1. Greenhouse facilities, plant material and measurement*

The experiments were performed in a single span, arched roof, polyethylene covered greenhouses (Fig.1), N-S oriented, located at the University of Thessaly near Volos, (Velestino: Latitude 39º 22΄, longitude 22º 44΄, altitude 85 m) on the continental area of eastern Greece, from January to June of 2011. The geometrical characteristics of the greenhouse were as follows: eaves height of 2.4 m; ridge height of 4.1 m; total width of 8 m; total length of 20 m; ground area of 160 m2, and volume of 572 m3. The greenhouse was equipped with two side roll-up vents and a flap roof vent. Greenhouse soil was totally covered by white (water permeable) mulch.

The tomato crop (*Licopersiconesculentum*, cv. Belladonna) was transplanted in rockwool slabs (1 m long, 0.15 m wide, 0.07 m height) placed in 6 independent closed-cycle hydroponic installations (experimental units). Three treatments differing in the management of the DS were applied:

- a standard open (free-drainage) hydroponic system (O), the drainage solution (DS) was constantly discharged throughout the experiment,
- a completely closed hydroponic system (C), the entire volume of DS was captured and recycled in the next watering cycle throughout the experiment and
- a semi-closed hydroponic system (SC), the DS was recycled as long as both electrical conductivity (EC) and Na concentration were lower than 5 dS m-1 and 15 mM, respectively. As soon as one of the thresholds exceeded, the drainage solution was discharged.

Air temperature, relative humidity and solar global radiation were measured inside and outside the greenhouse.

### *2.2. Screenhouses plant material and measurement*

The three screenhouses (Fig. 1) are located in the same farm with the greenhouses. The geometrical characteristics of the screenhouses were as follows: length of 20 m, width of 10 m and height of 3.2 m. The distance between two adjacent screenhouses was 8 m. Three different screens were used: (a) a white anti-thrip net (50-mesh) with a shading factor of about 20% (IP20) (AntiVirusTM, Meteor Agricultural Nets Ltd, Israel), (b) a white anti-thrip net (50-mesh) with shading intensity of about 40% (IP40) (BioNetTM, Meteor Agricultural Nets Ltd, Israel) and (c) a green shading net with shading intensity of about 40% (S40) (Thrace Plastics Co S.A. Xanthi, Greece). Thus, IP20 and IP40 had same porosity but different shading intensity while IP40 and S40 had similar shading intensity but different porosity. S40 had larger size holes than the 50-mesh screens IP20 and IP40. The shading intensities indicated were measured in the laboratory over 350 nm -1100 nm range band by means of a spectroradiometer (model LI-1800, LI-COR, Lincoln, NE, USA) equipped with a 10 W glass halogen lamp and an external integrating sphere (model LI-1800-12S, LI-COR, Lincoln, NE, USA).

Sweet pepper plants (Capsicum annuum L., cv. Dolmi) were transplanted on May 31, 2011 and measurements were performed until October 30, 2011. Plants were laid out 0.5 m apart in the row, in five double rows with a distance between the double rows of 1.2 m and a distance between the two rows of a double row of 0.5 m. To compare with open field

The following climatic data were recorded in the centre of each screenhouse and outside: (a) air temperature and vapour pressure deficit, (b) global solar radiation, (c) leaf temperature, by means of copper-constantan thermocouples and wind speed and direction in the ambient environment. All of the above-mentioned measurements were recorded in a data logger system (model DL3000, Delta-T Devices, Cambridge, U.K.). Measurements took place every 30 seconds and used to compute 10-minute average values


Experimental greenhouse Experimental screenhouse

Fig. 1 The experimental greenhouse and screenhouse

### 2.3. Benchmarking approach

Benchmarking as "a systematic process for securing continualimprovement through comparison with relevant and achievable internal or external normsand standards".The overall aim of benchmarking is to improve the performance of an organisation asmeasured against its mission and objectives. A complex process flow can bebenchmarked as well against ex ante or ex post results or indicators, or against fixedtargets. The key of a benchmarking exercise is comparison, either internally with previousperformance and desired future targets, or externally against similar organisations, ororganisations performing similar functions. Therefore, benchmarking is mainly amanagement tool.At first, the benchmarking technique was developed and applied to finance and business sectors.

Guidelines for benchmarking in the irrigation sector were proposed recently (Malano et al., 2004; Farmani et al., 2003). Performance assessment is based on performance indicators that are specifically identified to enable the comparison and to monitor progress towards closing the identified performance gap. Comparison between performance indicators is widely used in irrigation systems, very much as a tool for water management policies. Previous applications and checks have shown that performance indicators and benchmarking can be successfully applied using the common general guidelines, taking into account the special features of every zone, because not all irrigation zones of the world are similar. The core of any benchmarking exercise is data collection. In order to enable comparison between irrigation districts, data used for benchmarking need to be consistent and comparable.

In the last decade, it has been used in an important amount of Water User Associations (WUAs) around the world (Degirmenci et al., 2003; Sodal, 2004). It is based on performance indicators usage, which tries to summarize the information available in the data-base of different WUAs. By using these indicators, it is possible to compare different WUAs (Rodríguez et al., 2008) and to be able to identify structural deficiencies, dysfunctions and management problems specific to each irrigation districts

Benchmarking has been scarcely applied to farming systems. Some countries (e.g. Australia) recently implemented a methodology of farm benchmarking (Wilson et al 2005). Available information from leading farm business consultants and related researchers has been brought together and the most commonly used physical and financial performance indicators are highlighted. Aim of the present paper is to develop and use suitable benchmarking indicators for under cover crops targeting to a more environmental friendly agricultural production

### 2.4. Benchmarking indicators

To facilitate the irrigation performance indicators calculation and the benchmarking exercise, an application package has been developed in the frame of the Sirrimed EU project (http://www.sirrimed.eu/). The tool considers six specific categories: Conveyance & Distribution, Water Utilisation, Water Use and Productivity, Economical and Financial, Socio Economic, Environment. Each basic category contains various sub-fields that can be selected at the start of the analysis. In each subfield, a set of indicators is proposed to the user. The latter selects the performance indicators he thinks the most pertinent to his assessment objectives. In the present study, the subfield "Water

Utilisation" was selected, and the following indicators were calculated

(i) Water Use Efficiency (WUE, kg dry matter /m3) is ratio of harvested dry matter to the volume of applied irrigation water

$$\text{WUE}= \frac{\text{Harvested dry mass}}{\text{Applied Water}}$$

(ii) Economic productivity indicator (EPI): The economic productive efficiency of irrigation water use (€/m$^3$) can be compared with thewater price paid by farmers (€/m3) to test the profitability of irrigation water use.

$$\text{EPI} = \frac{\text{Production value } (\notin)}{\text{Irrigation water } (\text{m}^3)}$$

Before the analysis a benchmark value was set for each indicator. The reference values were based either to out experimental measurements or to values related to open field tomato and sweet pepper crop. For the water use efficiency the value of 18 kg m$^{-3}$ was adopted for the greenhouse and the value for 6 kg m$^{-3}$ for the screenhouses. For the economic productivity indicator the value of 100 €/m$^3$was selected for both cases.

## *2.5. Performance indicators*

One of the most widely used performance indicators for agricultural systems is water use efficiency (WUE), also termed water productivity (WP, see Molden et al, 2003). The WUE (WP) concept can be applied at different spatial scales, from catchments to individual farms (e.g. greenhouse crops, orchards), passing by irrigation schemes (Droogers and Kite, 2001). WUE refers to different processes and ratios in the literature, and is generally considered as the ratio of yield to water used during crop growth. It is often used as a performance indicator of parts (field efficiency) or totality (farm efficiency) of the farming system (Ref). The FAO has popularised this concept by expressing it as "more crop and higher value per drop" (FAO, 2000).

## *2.6. Specificity of horticultural protected systems*

Although greenhouse crops are considered as the most water efficient agricultural systems (FAO, 2000) growers routinely apply more irrigation water to the crops than the estimated water consumption. Improper irrigation management practices not only waste scarce and expensive water resources but also decrease marketable yield and economic return (Katsoulas et al., 2006). Capture and recycling of the excess irrigation water that drains out of the root zone is possible in closed-cycle soilless growing systems and might considerably improve the water use efficiency in greenhouse crops (Savvas, 2002).

Besides greenhouses, screenhouses are becoming popular among growers in the Mediterranean region, because they meet the needs of consumers for products grown with low inputs of pesticides, as screening materials exclude insects that attack crops, downgrading their productivity and quality. Furthermore, they are of low cost compared to conventional greenhouses (Möller and Assouline, 2007).

The specific objectives of the present paper are to apply the benchmarking approach for WUE to two types of horticultural production systems:

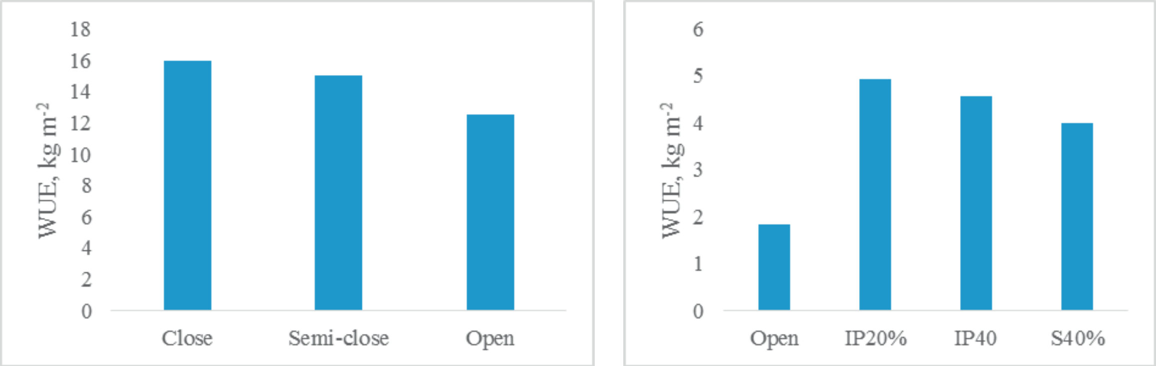
(a) a high-technology input strategy, illustrated by climate controlled greenhouses with hydroponic systems (open, close and semi-close) and

(b) a low-technology input strategy, consisting in simple screenhouses systems with soil-grown crops and free-drainage.

## 3. Results

Final harvest was not significant different between the three hydroponic systems. Total mass was 14% higher in close than in open greenhouse system, the difference percentage being reduced to 5% in semi-close system. The total water supplied to the tomato crop was significantly higher in the open system, followed by the semi-close while it was further reduced when the plants were grown in the close system. Consequently, the water use efficiency was higher in close system, followed by semi-close whereas the lower value was obtained in the open system. The values of WUE for the greenhouse systems (Fig. 2a), with respect to the tomato benchmark value (18 kg $m^{-3}$) indicated that close system was the most efficient (WUE ≈90% of the reference value), followed by semi-close (≈80%) and open (≈65%).

Of the four different tested systems (open field and three different screenhouses) IP20 achieved the highest final yield, which was. 35% higher than that observed for the open field crop. The other two screenhouse (IP40, S40) presented similar yields, with a 22% increase with respect to the open field crop (Table 2). The superior of screenhouse crop in comparison to open field crops in terms of water use efficiency is evident in Fig. 2b. All the three screenhouse systems achieved a water use efficient index almost double than the open field crop.



(a) Water use efficiency in greenhouse (b) Water use efficiency in screenhouse

Fig.2 Water use efficiency for different hydroponic systems and different screenhouses.

The modernization of the irrigation systems offers the farmers a number of possibilities to expand the economic productivity of water. Benchmarking in economics usually refers to some baseline scenario against which the effects of some intervention are evaluated. The scope of the economic productivity indicator (EPI), used in this analysis, is to facilitate the assessment of the actual output (physical and/or economic) of irrigated crops compared to the actual water used for the irrigation of these crops, linking thus water to the economy. In this way, the current status of irrigation practices in terms of efficiency can be implicitly identified, as well as the possibilities for further improvement. In irrigated agriculture the greatest challenge is not developing new irrigation technology, but finding ways to reduce the large differences in technical efficiency, yield and water productivity that can be found among and within irrigated systems (EEA, 2012).

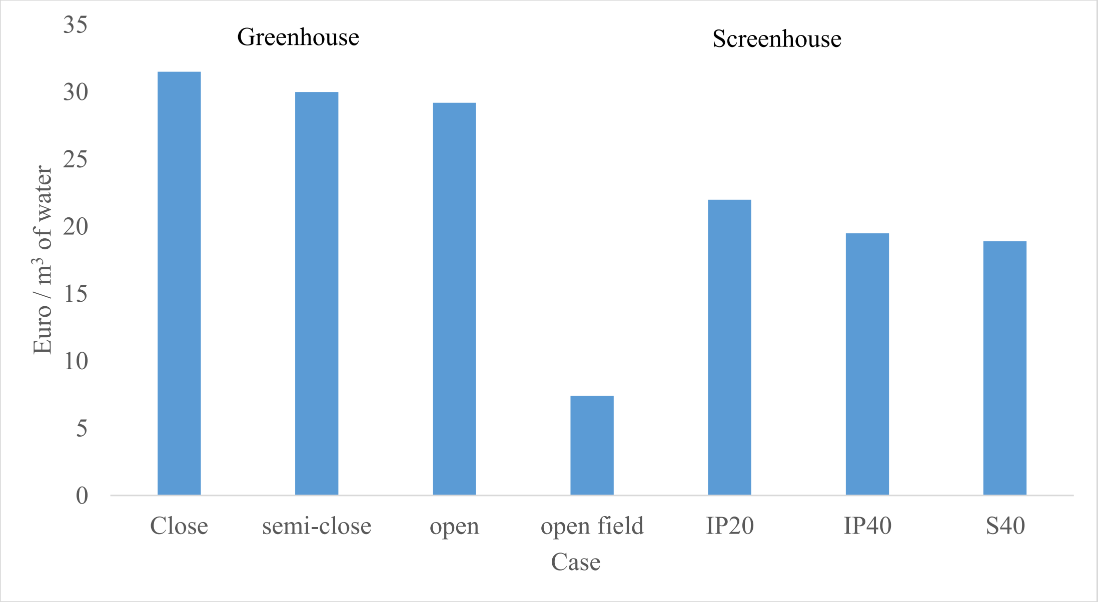


Fig.3. Water economic productivity indicator for greenhouse and screenhouses cases

Fig. 3 presents the water productivity indicator for greenhouse and screenhouses cases. The low value of open field (i.e 7.4. €/m3) indicates clearly the superiority of protected cultivation (undependably if they are greenhouse or screenhouse crops). In the opposite site the close greenhouse hydroponic systems achieves the highest value of this indicator. When we are comparing the greenhouse cases although the three tested hydoponic systems succeeded to maintain similar (and high) values of water economic productivity the close system achieves the highest value and the open the lowest as it was expected. No significant difference were found between the three different with screenhouses.

The proposed benchmarking tool and the calculated indicators are addressed the farmers who benefit from applying to their farming practices innovative technologies (i.e close hydroponic systems) and techniques driven by sustainable management principle (screenhouses). These indicators can be used by farmers to identify ways to reduce inputs such as fertiliser, or to more effectively use water to increase production. Apart from direct benefits in terms of the reduction of water and fertilisers use there also indirect benefits. The acceptance of products in international markets is becoming increasingly dependent upon demonstrably clean and sustainable production systems. International standards, like e.g. the Global Gap, are increasingly influencing the retailers' selection criteria for providers: application of basic sustainable agriculture practices is now the only way to have secured access to the richest markets in western countries. In addition, farmers now have to demonstrate sustainable management in order to comply with government policies and legislative requirements, particularly conditions placed on resource consents. By having a good monitoring and reporting system, farmers may also be able to present a strong case showing the actual environmental effect of an activity for which they have a resource consent. This could result in influencing changes to resource consent conditions that had previously been imposed based on more generalised and conservative information. Examples of this could be the nitrogen application limits for discharge consents, and maximum abstraction rates from a water supply.

## 4. Conclusions

This work is a preliminary intent in the benchmarking of specific protected agrosystems, with the objective of assessing their performances by way of accessible indicators, calculated from input data that can be easily recollected at the field and farm level. Our study highlights that, even in water efficient systems like greenhouses and screenhouses, a large margin of progress in water and fertilisers use efficiency is at hand of farmers, provided they can integrate to their farming practices innovative technologies (but some are very expensive, e.g. closed hydroponic systems) and structures that are well adapted to the local climatic and biotic conditions (e.g. screenhouses, more affordable to growers). We also demonstrated that the benchmarking methodology is likely to provide useful information to environmental issues related with water and fertilisers use in agriculture.

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