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Original article

Water footprint and irrigation use efficiency of important crops in Northern Cyprus from an environmental, economic and dietary perspective

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ABSTRACT

Availability of freshwater is currently one of the most important limiting factors for crop production and food security throughout the world. Northern Cyprus is one of the world's most important countries that has been facing drought and salinization problems since the 1970 s. The present study aimed to determine the irrigation use efficiency (IUE), irrigation economic productivity (IEP), irrigation economic efficiency (IEE) and irrigation dietary efficiency (IDE) of some major crops in Northern Cyprus to ensure better planning for sustainable water management, not only for Northern Cyprus but also for all countries facing similar problems. The results of the present study showed that both carob and fig crops require the least amount (24 L) of irrigation to produce 1 kg of fruit, and "open field" lettuce and "greenhouse" eggplant require the least amount (10 and 16 L) of irrigation to produce 1 kg of vegetables in Northern Cyprus. The irrigation economic productivity (IEP) and irrigation dietary efficiency (IDE) of crops were also found to be significantly different and meaningful for different crops. Our results showed that reshaping the distribution of crops based on their water consumption would reduce the use of water resources while continuing to feed the population.

1. Introduction

The human population worldwide is increasing day-by-day, while the available resources for food production are being depleted due to the negative effects of human activity on the ecosystem (Kahramanoğlu, 2017). According to the FAO (2015), approximately 12.5% of the world population was suffering from chronic undernourishment in 2014–2016. One of the most important challenges in the 21st century is global food security (Lal, 2005). Climate change has caused significant impacts on water resources, food security and human health throughout the world (Magadza, 2000). Kang et al. (2009) noted that the availability of water will be one of the most important limiting factors for crop production and food security. Furthermore, Fujihara et al. (2008) noted that even if the demand for irrigation remains the same, water scarcity will occur if the irrigation efficiency rates stay as they are. Approximately ¾ of the earth's surface consists of water, but less than 1% of this amount is fresh water, where 70% of it, is being used in agriculture (Evans and Sadler, 2008).

Water scarcity is a rapidly growing concern around the globe (Kummu et al., 2016) and in Cyprus (EEA, 2009). Since the 1970 s, Cyprus has experienced extended periods of drought, as the increase in population induced water scarcity problems (BBC, 2010; Zikos et al., 2015). Northern Cyprus is experiencing not only "water quantity problems," but also "water quality problems" (Gökçekuş, 2014). Therefore, water must be used effectively to ensure sustainability not only in Northern Cyprus but also around the world. Agriculture is responsible for approximately 75% or more of the total water withdrawals in Northern Cyprus. Depletion of the available water resources combined with the increasing demand for food requires an urgent management plan in agricultural production to improve the productivity per unit of water consumed. To overcome these challenges, researchers, policy makers and farmers urgently need to consider different types of agricultural adaptation (Howden et al., 2007; Rickards and Howden, 2012). Researchers previously mentioned that the modern biotechnology and energy efficient farming are crucial for solving the

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problems of climate change (Tesfahun, 2018). However, to do so, it is of utmost importance to study not only the irrigation use efficiency but also the economical and dietary efficiency of the crops.

Therefore, the present study aimed to determine the irrigation use efficiency (IUE) and water use efficiency (WUE) of some important crops in Northern Cyprus to ensure better planning for sustainable water management. The aim was focused not only on improved planning in Northern Cyprus but also on changing the viewpoint of decision makers and researchers regarding the efficient use of water resources. The irrigation economic productivity (IEP) and irrigation dietary efficiencies (IDEs) of crops in terms of energy, protein, carbohydrate, fibre (total dietary) and total sugar were also calculated by using reference values.

2. Materials and methods

The present study was conducted in Northern Cyprus by collecting data from farmers. The territory has mild winters and warm to hot summers, which corresponds to the semi-arid type Mediterranean climate. The total agricultural land in Northern Cyprus is approximately 187,069 ha (ha), which represents 56.7% of the total territory. Of this total production area, only 5.2% (9.714 ha) is currently irrigated. Agricultural productivity is primarily determined by the level of rainfall and access to water resources. There are a total of 14,633 registered farmers in Northern Cyprus, but 10.798 of them are animal producers or producers of rain-fed temporary crops (cereals, food and feed legumes, green fodder and industrial crops). When considering irrigated land, it is noteworthy that over 48% of the total irrigated land is currently devoted to citrus production, 24% to vegetables and greenhouses, 20% to other fruits and 2% to legumes. The total number of citrus producers is 2.588, and the total number of producers of other crops is 1.247 (Ministry of Agriculture, 2017). Fifty important crops (including citrus) were selected for the present study. The number of farmers for each selected crop (other than citrus) is between 13 (minimum) and 121 (maximum). Data were collected via a survey form from randomly selected farmers. According to the Cochran's sample size formula (Cochran, 1963), a total of 244 farmers are necessary from the total of 1.247 farmers. However, to increase the reliability of the survey, for the selected 49 crops (except citrus), 10 farmers were randomly selected and surveyed (49 * 10 = 490 farmers). Thus, 60 citrus farmers were randomly selected and surveyed.

Efficiency is defined as the ability to produce the desired utility with the minimum input. The irrigation use efficiency (IUE) of the most important crops in Northern Cyprus was measured as the ratio between the economic yield obtained (kg output) and the irrigation water applied (metric ton input):

$$\text{IUE (kg/mt)} = \left(\frac{\text{economic yield obtained (kg/da)}}{\text{irrigation water applied (mt/da)}}\right) \quad (1)$$

The water use efficiency (WUE) of the same crops was also calculated according to Eq. (2) as the ratio between the economic yields obtained and the total water usage (irrigation+rainfall).

$$\text{WUE (kg/mt)} = \left(\frac{\text{economic yield obtained (kg/da)}}{[\text{irrigation water applied (mt/da)}] + [\text{received rainfall (mt/da)}]}\right) \quad (2)$$

The irrigation economic productivity (IEP) of the crops was calculated by dividing the economic value obtained ($) by the irrigation water applied (metric ton) using Eq. (3):

$$IUE\ (kg/mt) = \left(\frac{economic\ yield\ obtained\ (kg/da)}{irrigation\ water\ applied\ (mt/da)}\right) \quad (3)$$

Water economic productivity (WEP) was then calculated by dividing the economic value obtained ($) by the total water usage (irrigation + rainfall) according to Eq. (4):

$$WUE\ (kg/mt) = \left(\frac{economic\ yield\ obtained\ (kg/da)}{[irrigation\ water\ applied\ (mt/da)] + [\text{received rainfall (mt/da)}]}\right) \quad (4)$$

Using only irrigation economic productivity may cause some miscalculations due to the huge differences in the share of irrigation in total costs. Thus, the share of irrigation in total costs was also measured to calculate irrigation economic efficiency (IEE). This variable was calculated for all crops by multiplying the IEP of crops by the share (%) of irrigation in total costs according to Eq. (5):

$$\text{IEE (/mt)} = [(\text{IEP (/mt)}) \times (\text{share (\%) of irrigation cost in total})] \quad (5)$$

On the other hand, the reference values for energy, protein, carbohydrate, fibre (total dietary) and total sugar for the selected crops were taken from the USDA food composition database (USDA, 2018) to calculate the irrigation dietary efficiencies (IDE) of crops. Eqs. (6)–(10) were used for such calculations:

$$\text{IDE - Energy (kcal/L)} = \left(\frac{\text{(yield obtained (kg/da))} \times \text{(USDA ref for Energy (kcal/100g)} \times 10}{\text{irrigation water applied (L/da)}}\right) \quad (6)$$

$$\text{IDE - Protein (g/L)} = \left(\frac{\text{(yield obtained (kg/da))} \times \text{(USDA ref for Protein (g/100g)} \times 10}{\text{irrigation water applied (L/da)}}\right) \quad (7)$$

$$\text{IDE - Carbohydrate (g/L)} = \left(\frac{\text{(yield obtained (kg/da))} \times \text{(USDA ref for Carbohydrate (g/100g)} \times 10}{\text{irrigation water applied (L/da)}}\right) \quad (8)$$

$$\text{IDE - Fibre (g/L)} = \left(\frac{\text{(yield obtained (kg/da))} \times \text{(USDA ref for Fibre (g/100g)} \times 10}{\text{irrigation water applied (L/da)}}\right) \quad (9)$$

$$\text{IDE - Sugar (g/L)} = \left(\frac{\text{(yield obtained (kg/da))} \times \text{(USDA ref for Sugar (g/100g)} \times 10}{\text{irrigation water applied (L/da)}}\right) \quad (10)$$

Data obtained from the surveys were used to calculate the above values. The results were analysed via ANOVA, and mean separations were done using Tukey's test at $P < 0.05$. SPSS 20.0 Software was used for statistical analysis.

3. Results

The total amount of irrigation and irrigation+rainfall requirements for the production of 1 kg of fruits in Northern Cyprus are shown in Fig. 1. It is clear from the figure that carob and fig crops require the least amount of irrigation for the production of 1 kg of fruit. Both require approximately 24 L of water, and these crops are followed by loquat, pear, peach and almond with 47, 68, 71 and 73 L, respectively. When looking at the total amount of water

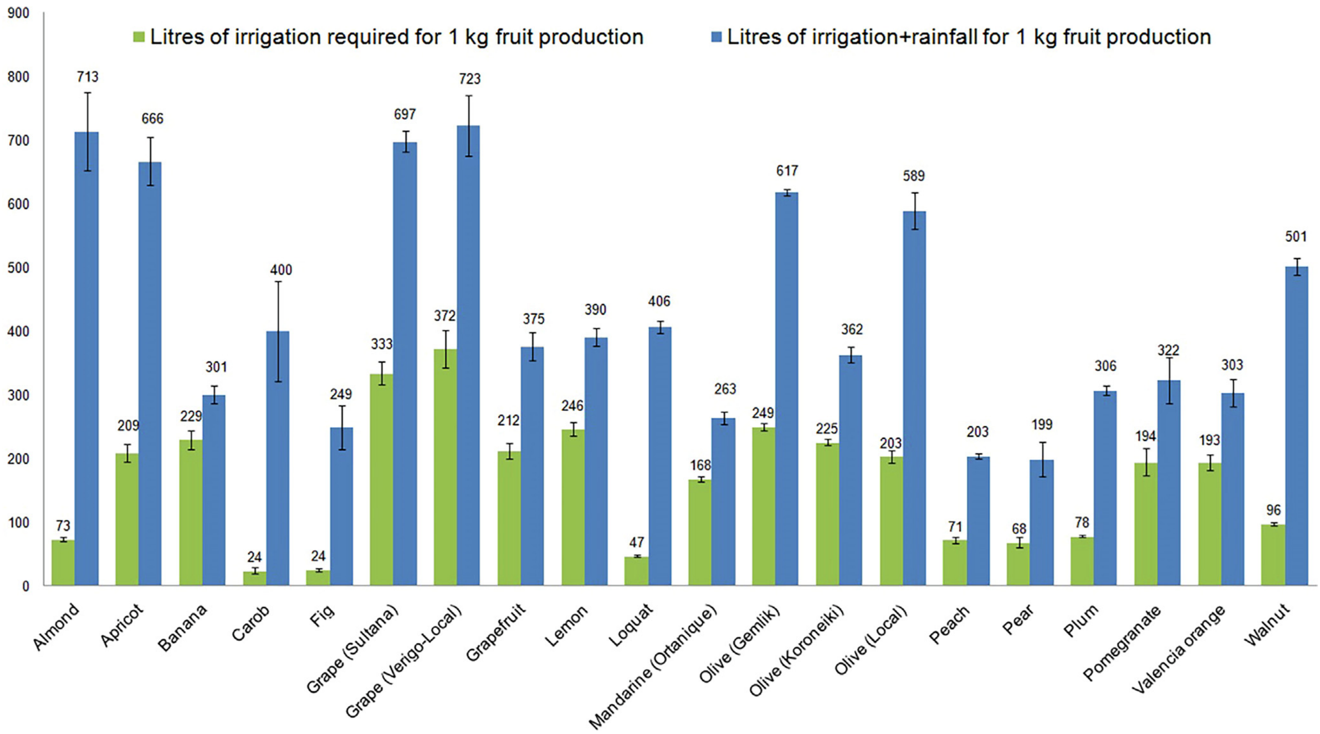

Fig. 1. Litres of irrigation and irrigation+rainfall required for the production of 1 kg of fruit in Northern Cyprus.

(irrigation+rainfall) used for the production of 1 kg of fruit, pear, peach and fig crops hold the first three places with 199, 203 and 249 L. However, carob and loquat are found to need more water in total (approximately 400 L), while almond requires the second highest amount of water (713 L) to produce 1 kg of fruit. On the other hand, grapes required the most irrigation to produce 1 kg of fruit, with a local variety of grape needing 372 L and sultana grape needing 333 L. In some regions of the country, grapes are produced with a small quantity of water, but the production is small, and no reliable information is available from these farms.

According to our results, green bean production, both under sprinkler irrigation and drip irrigation, and green pea production under sprinkler irrigation are found to require the highest amounts of irrigation to produce 1 kg of vegetables (Fig. 2). The amount of

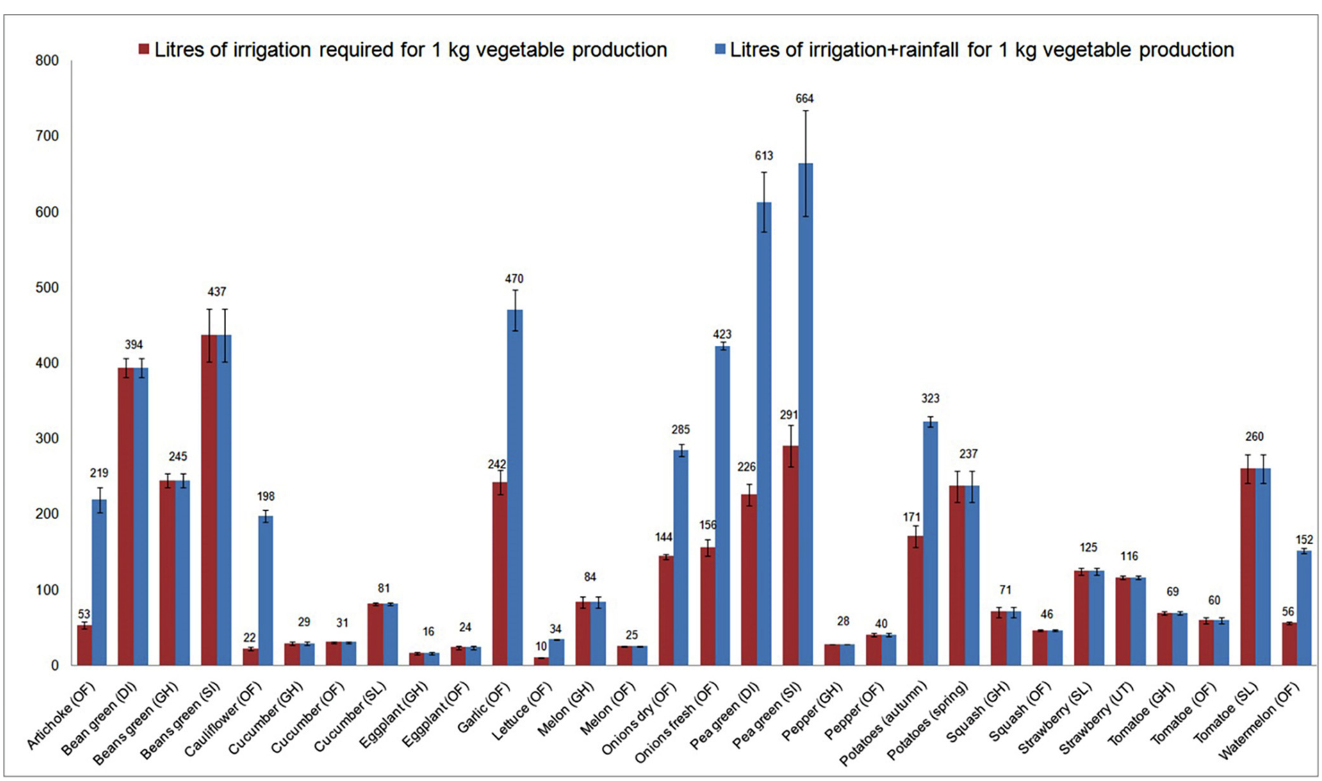

Fig. 2. Litres of irrigation and irrigation+rainfall required for the production of 1 kg of vegetable in Northern Cyprus.

irrigation required for these crops are determined to be 437, 397 and 291 L, respectively. The total water (irrigation+rainfall) requirements for these crops are also higher, but the highest water requirement is for green pea under sprinkler irrigation with 664 L, followed by green pea production under drip irrigation with 613 L. Bean is a summer crop in Northern Cyprus, and no rainfall is required for the production. Therefore, no differences are found for the required amount of irrigation and total water. The results also showed that the irrigation practice has a clear influence on the irrigation requirements of the crops. Sprinkler irrigation (SI) is found to increase the water requirements of crops compared to drip irrigation. Among the studied vegetables, lettuce (OF: open field), eggplant (GH: greenhouse production) and cauliflower (OF) are found to require the least amount of irrigation for the production of 1 kg of vegetables, 10, 16 and 22 L, respectively. Eggplant (GH), eggplant (OF) and melon (OF) are found to require the lowest quantities of total water (irrigation+rainfall) for the production of 1 kg of vegetables. Soilless culture (SL) is found to have highest efficacy in terms of the total need for irrigation in the production of 1 kg of vegetables, but the efficacy of SL is lower for tomato. Most vegetables are found to require less irrigation than the fruits to produce 1 kg of food.

The irrigation use efficiency (IUE), water use efficiency (WUE), irrigation economic productivity (IEP), irrigation economic efficiency (IEE) and water economic productivity (WEP) of selected important fruits crops in Northern Cyprus are displayed in Table 1. According to our results, carob has the highest IUE with 43.2 kg mt^{-1}, followed by fig and loquat with 41.4 and 21.4 kg mt^{-1}, respectively. At the same time, both varieties of grapes are found to have the lowest IUE. Most of the crops are found to have IUE values between 4 and 6 kg mt^{-1}. These results show that carob, fig, loquat, peach, almond and pear are very effective in using irrigation water. Among all fruits, pears and peaches have the highest WUE with 5.1 and 4.9 kg mt^{-1}, respectively. Fig, which has the second highest IUE, has the second highest WUE as well, suggesting that fig is very effective in using water for the production of fruits. A comparison of the crops in terms of their irrigation economic productivity showed that walnut, which has a moderate IUE, has the highest IEP with 111.2 \$ mt^{-1}. This crop is followed by almond and fig, which are among the most efficient crops in terms of IUE and WUE. The lowest IEP is calculated for grapefruit and Valencia orange with 0.6 and 0.8 \$ mt^{-1}, respectively. These results are very important for the country, where Valencia orange comprises approximately 52% of the irrigated fruit production. The irrigation economic efficiency (IEE) of the crops showed significant changes from the IEP, which is the multiplication of IEP by the share of irrigation in the total costs. The most effective crop is walnut again, with 41.1 \$ mt^{-1}, followed by loquat and fig, with 5.5 and 3.2 \$ mt^{-1}, respectively. The lowest IEE is calculated for grapefruit and Valencia orange, similar to IEP, with 0.3 and 0.4 \$ mt^{-1}, respectively. Not only the IEP and IEE but also the WEP of these crops are found to be lowest. Walnut, olive (cv. 'Koroneiki') and fig are found to have the highest WEP.

Results on the IUE of selected important vegetable crops in Northern Cyprus are shown in Table 2. According to the results, lettuce has the highest IUE with 100.6 kg mt^{-1}, followed by eggplant (GH) and cauliflower (OF) with 62.9 and 45.0 kg mt^{-1}, respectively. The lowest IUE is obtained for green bean (SI: sprinkler irrigation), 2.3 kg mt^{-1}, followed by green bean (DI: drip irrigation), 2.5 kg mt^{-1}. The overall IUE of vegetables is higher than that of fruits. The highest WUE is found for eggplant (GH) with 62.9 kg mt^{-1}, followed by eggplant (OF) and melon (OF) with 42.7 and 39.9 kg mt^{-1}, respectively. Lettuce, which has the highest IUE, is found to have a lower WUE due to the need for rainfall for production.

Similar to the IUE and WUE results, lettuce (OF) is found to have the highest IEP with 34.9 \$ mt^{-1}, followed by cauliflower (OF) and melon (OF) with 27.2 and 24.8 \$ mt^{-1}. The lowest IEP is measured from fresh onions (OF) with 1.3 \$ mt^{-1}, followed by dry onions (OF) and tomato (SL) with 1.8 and 2.5 \$ mt^{-1}. Surprisingly, spring crop potato production is also found to have very low IEP with 2.6 \$ mt^{-1}. Potato (as a spring crop) production accounts for approximately 35% of the irrigated vegetable production in the country (Ministry of Agriculture, 2017). Crops with the highest and lowest IEP are found to have the highest and lowest IEE with some changes among their orders. The highest IEE is determined for eggplant (GH) and the lowest for green pea (SI) with 4.3 and 0.1, respectively. Melon (OF) is determined to be the most effective crop in terms of WEP with 24.8 \$ mt^{-1}, whereas green pea (SI) is found to have a value of only 1.2 \$ mt^{-1}.

Table 1
Irrigation use efficiency (IUE), water use efficiency (WUE), irrigation economic productivity (IEP), irrigation economic efficiency (IEE) and water economic productivity (WEP) of selected important fruit crops in Northern Cyprus.

Products	IUE (kg/mt)	WUE (kg/mt)	IEP (\$/mt)	IEE (\$/mt)	WEP (\$/mt)
Almond	13.8 (c)	1.4 (g)	**33.6 (b)**	2.0 (cde)	***3.4 (c)***
Apricot	4.8 (e)	1.5 (g)	1.6 (e)	0.4 (de)	0.5 (e)
Banana	4.4 (e)	***3.3 (cd)***	1.5 (e)	0.8 (de)	1.2 (e)
Carob	**<u>43.2 (a)</u>**	2.6 (ef)	***12.0 (c)***	0.6 (de)	0.7 (e)
Fig	**<u>41.4 (a)</u>**	**4.1 (b)**	**31.9 (b)**	***3.2 (c)***	***3.1 (cd)***
Grape (Sultana)	3.0 (e)	1.4 (g)	1.8 (e)	0.4 (de)	0.8 (e)
Grape (Verigo-Local)	2.7 (e)	1.4 (g)	2.5 (e)	0.6 (de)	1.3 (e)
Grapefruit	4.7 (e)	2.7 (ef)	0.6 (e)	0.3 (e)	0.3 (e)
Lemon	4.1 (e)	2.6 (ef)	1.4 (e)	0.6 (de)	0.9 (e)
Loquat	**21.4 (b)**	2.5 (f)	11.1 (e)	**5.5 (b)**	1.3 (e)
Mandarin (Ortanique)	6.0 (de)	**3.8 (bc)**	1.3 (e)	0.6 (de)	0.8 (e)
Olive (Gemlik)	4.0 (e)	1.6 (g)	7.4 (cd)	1.4 (cde)	3.0 (cd)
Olive (Koroneiki)	4.4 (e)	2.8 (ef)	8.2 (cd)	1.7 (cde)	**5.1 (b)**
Olive (Local)	4.9 (e)	1.7 (g)	9.1 (cd)	1.4 (cde)	3.1 (cd)
Peach	***14.1 (c)***	**<u>4.9 (a)</u>**	8.7 (cd)	2.6 (cd)	3.0 (cd)
Pear	***14.9 (c)***	**<u>5.1 (a)</u>**	8.0 (cd)	1.5 (cde)	2.7 (cd)
Plum	***12.9 (c)***	***3.3 (cd)***	9.6 (cd)	2.2 (cde)	2.4 (d)
Pomegranate	5.2 (e)	3.1 (de)	1.6 (e)	0.8 (de)	1.0 (e)
Valencia orange	5.2 (e)	***3.3 (cd)***	0.8 (e)	0.4 (de)	0.5 (e)
Walnut	10.4 (cd)	2.0 (fg)	**<u>111.2 (a)</u>**	**<u>41.1 (a)</u>**	**<u>21.4 (a)</u>**

Values followed by the same letter or letters in the same column are not significantly different at the 5% level (Tukey's test). Highest values are indicated with **<u>bold and underlined</u>**, second highest values with **bold** and third highest values with ***bold and italic.***

Table 2
Irrigation use efficiency (IUE), water use efficiency (WUE), irrigation economic productivity (IEP), irrigation economic efficiency (IEE) and water economic productivity (WEP) of selected important vegetable crops in Northern Cyprus.

Products	IUE (kg/mt)	WUE (kg/mt)	IEP ($/mt)	IEE ($/mt)	WEP ($/mt)
Artichoke (OF)	18.9 (hi)	4.6 (jkl)	7.9 (gh)	***2.6 (cd)***	1.9 (ijk)
Green bean (DI)	2.5 (rs)	2.5 (kl)	3.2 (nop)	0.5 (jkl)	3.2 (h)
Green bean (GH)	4.1 (oprs)	4.1 (jkl)	5.4 (klm)	0.7 (jkl)	5.4 (g)
Green bean (SI)	2.3 (s)	2.3 (kl)	2.9 (nop)	0.5 (jkl)	2.9 (hi)
Cauliflower (OF)	***45.0 (c)***	5.1 (ijk)	**27.2 (b)**	**3.3 (b)**	3.1 (hi)
Cucumber (GH)	34.5 (f)	***34.5 (c)***	15.7 (e)	1.4 (efg)	***15.7 (c)***
Cucumber (OF)	32.6 (f)	***32.6 (cd)***	14.4 (e)	1.5 (e)	***14.4 (c)***
Cucumber (SL)	12.3 (kl)	12.3 (g)	6.2 (hijk)	1.4 (efg)	6.2 (fg)
Eggplant (GH)	**62.9 (b)**	**<u>62.9 (a)</u>**	***23.3 (cd)***	**<u>4.3 (a)</u>**	**<u>23.3 (ab)</u>**
Eggplant (OF)	42.7 (cd)	**42.7 (b)**	13.8 (e)	2.4 (d)	***13.8 (c)***
Garlic (OF)	4.1 (oprs)	2.1 (kl)	4.0 (mno)	0.8 (jkl)	2.1 (ij)
Lettuce (OF)	**<u>100.6 (a)</u>**	29.5 (d)	**<u>34.9 (a)</u>**	**3.2 (b)**	10.2 (d)
Melon (GH)	12.0 (klm)	12.0 (g)	7.6 (ghi)	0.7 (jkl)	7.6 (ef)
Melon (OF)	39.9 (de)	**39.9 (b)**	***24.8 (c)***	2.4 (d)	**<u>24.8 (a)</u>**
Onions dry (OF)	6.9 (nop)	3.5 (jkl)	1.8 (op)	0.4 (lm)	0.9 (kj)
Onions fresh (OF)	6.4 (nop)	2.4 (kl)	1.3 (p)	0.2 (lm)	0.5 (k)
Green pea (DI)	4.4 (oprs)	1.6 (l)	3.5 (nop)	0.2 (lm)	1.3 (ijk)
Green pea (SI)	3.5 (prs)	1.5 (l)	2.7 (op)	0.1 (m)	1.2 (ijk)
Pepper (GH)	35.9 (ef)	***35.9 (c)***	22.3 (d)	**3.2 (bc)**	**22.3 (b)**
Pepper (OF)	24.8 (g)	24.8 (e)	14.9 (e)	2.4 (d)	***14.9 (c)***
Potatoes (autumn crop)	5.9 (oprs)	3.1 (kl)	3.6 (mno)	0.8 (jkl)	1.9 (ijk)
Potatoes (spring crop)	4.2 (oprs)	4.2 (jkl)	2.6 (op)	0.7 (jkl)	2.6 (ij)
Squash (GH)	14.2 (jk)	14.2 (fg)	6.6 (hij)	0.6 (jkl)	6.6 (fg)
Squash (OF)	21.6 (gh)	21.6 (e)	9.6 (fg)	1.2 (fgh)	9.6 (d)
Strawberry (SL)	8.0 (mno)	8.0 (hi)	5.1 (klm)	1.5 (ef)	5.1 (g)
Strawberry (UT)	8.6 (lmn)	8.6 (h)	5.5 (kl)	1.2 (fgh)	5.5 (g)
Tomato (GH)	14.4 (jk)	14.4 (fg)	9.3 (fg)	0.9 (jkl)	9.3 (de)
Tomato (OF)	16.9 (ij)	16.9 (f)	10.4 (f)	1.2 (fgh)	10.4 (d)
Tomato (SL)	3.9 (prs)	3.9 (jkl)	2.5 (op)	0.5 (jkl)	2.5 (ij)
Watermelon (OF)	17.9 (hi)	6.6 (hij)	7.6 (ghi)	1.1 (hij)	2.8 (ij)

Values followed by the same letter or letters in the same column are not significantly different at the 5% level (Tukey's test). Highest values are indicated with **<u>bold and underlined</u>**, second highest values with **bold** and third highest values with ***bold and italic.*** **OF:** Open field **DI:** Drip irrigation **GH:** Greenhouse **SI:** Sprinkler irrigation **SL:** Soilless **UT:** Under tunnel.

IDE is as important as IUE, IEP and IEE. Among the dietary characteristics of the crops, protein and carbohydrates are the most important attributes that feed human beings. Higher-protein diets are reported to promote muscle mass. Carbohydrate, fat and protein are the sources of energy required for mechanical work in the human body, i.e., muscle functions, and to maintain the body's structure and functions. The aim of producing fruits and vegetables is to meet the energy requirements of human beings with less negative effects on human health. Therefore, irrigation dietary efficiency of crops, especially for protein, is very important. When considering the IDE-Protein of the crops, almond has the highest value with 2.91 g L^{-1}, followed by carob and walnut with 2.0 and 1.58 g L^{-1} (Table 3). All of these crops have the highest IDE-Energy in different orders. Other crops have less than 0.31 g L^{-1}

Table 3
Irrigation dietary efficiency (IDE) for energy, protein, carbohydrate, fibre and sugar of selected important fruit crops in Northern Cyprus.

Products	IDE-Energy (kcal/L)	IDE-Protein (g/L)	IDE-Carbohydrate (g/L)	IDE-Fibre (g/L)	IDE-Sugar (g/L)
Almond	**79.7 (b)**	**<u>2.91 (a)</u>**	***2.97 (c)***	**1.72 (b)**	0.60 (cd)
Apricot	2.3 (ef)	0.07 (e)	***0.54 (c)***	***0.10 (c)***	0.44 (d)
Banana	3.9 (ef)	0.05 (e)	***1.00 (c)***	***0.11 (c)***	0.54 (cd)
Carob	**<u>96.0 (a)</u>**	**2.00 (b)**	**<u>38.42 (a)</u>**	**<u>17.21 (a)</u>**	**<u>21.22 (a)</u>**
Fig	30.6 (d)	0.31 (d)	**7.94 (b)**	**1.20 (bc)**	**6.73 (b)**
Grape (Sultana)	2.1 (ef)	0.02 (e)	***0.54 (c)***	***0.03 (c)***	0.47 (cd)
Grape (Verigo-Local)	1.5 (ef)	0.02 (e)	***0.38 (c)***	***0.11 (c)***	0.34 (d)
Grapefruit	1.5 (ef)	0.03 (e)	***0.38 (c)***	***0.05 (c)***	0.33 (d)
Lemon	1.2 (f)	0.04 (e)	***0.38 (c)***	***0.11 (c)***	0.10 (d)
Loquat	10.1 (e)	0.09 (e)	***2.60 (c)***	**0.36 (bc)**	***2.42 (c)***
Mandarin (Ortanique)	3.2 (ef)	0.05 (e)	***0.80 (c)***	***0.11 (c)***	0.63 (cd)
Olive (Gemlik)	5.8 (ef)	0.04 (e)	***0.15 (c)***	***0.13 (c)***	0.02 (d)
Olive (Koroneiki)	6.5 (ef)	0.05 (e)	***0.17 (c)***	***0.15 (c)***	0.02 (d)
Olive (Local)	7.2 (ef)	0.05 (e)	***0.19 (c)***	***0.16 (c)***	0.03 (d)
Peach	5.5 (ef)	0.13 (de)	***1.34 (c)***	**0.21 (bc)**	1.18 (cd)
Pear	8.5 (ef)	0.05 (e)	***2.28 (c)***	***0.46 (c)***	1.46 (cd)
Plum	5.9 (ef)	0.09 (e)	***1.47 (c)***	***0.18 (c)***	1.27 (cd)
Pomegranate	4.3 (ef)	0.09 (e)	***0.97 (c)***	***0.21 (c)***	0.71 (cd)
Valencia orange	2.5 (ef)	0.05 (e)	***0.62 (c)***	***0.13 (c)***	0.62 (cd)
Walnut	***67.8 (c)***	***1.58 (c)***	***1.42 (c)***	**0.70 (bc)**	0.27 (d)

Values followed by the same letter or letters in the same column are not significantly different at the 5% level (Tukey's test). Highest values are indicated with **<u>bold and underlined</u>**, second highest values with **bold** and third highest values with ***bold and italic.***

IDE-Protein. Similar to the IUE results, grape varieties are found to have the lowest IDE-Protein with 0.02 g L^{-1}. Carob has the highest IDE-Carbohydrate, IDE-Fibre and IDE-Sugar with 38.42, 17.21 and 21.22 g L^{-1}, respectively.

Similar to the fruit crops, vegetable crops with high IUE and IEP are found to have higher IDE-Energy and IDE-Protein. The highest IDE-Energy is measured for eggplant (GH) with 15.7 g L^{-1}, while tomato (SL) has the lowest level with 0.7 g L^{-1} (Table 4). The highest IDE-Protein is measured for lettuce (OF) with 0.91 g L^{-1} and the highest IDE-Carbohydrate for eggplant (GH) with 3.70 g L^{-1}. The highest IDE-Fibre is measured for eggplant (GH), and the highest IDE-Sugar is calculated for melon (OF). As a general evaluation, spring potato crop, tomato (SL), green bean (DI and SI) and green pea (DI and SI) are found to have the lowest IDE coefficients for energy, protein, carbohydrate and fibre.

4. Discussion

The water footprint measures the amount of water used to produce each of the goods and services used by human beings. The "green" water footprint represents the water from precipitation, "blue" water represents the water from irrigation, and the "grey" water footprint represents the fresh water required to assimilate pollutants to meet specific water quality standards (Mekonnen and Hoekstra, 2011). According to the results of the present work, carob, fig and loquat are the three most efficient fruit crops in terms of IUE with 43.2 kg mt^{-1}, 41.4 kg mt^{-1} and 21.4 kg mt^{-1}, respectively and lettuce, eggplant and cauliflower are the most efficient vegetable crops with 100.6 kg mt^{-1}, 62.9 kg mt^{-1} and 45.0 kg mt^{-1}, respectively. These results are similar to the findings of Chouchane et al. (2015), who performed a similar study in Tunisia. They reported that tomatoes and potatoes were the main crops with high economic water productivity. These crops were among those with the least economic productivity in the present study, but the IEP values shows similarities, where they noted 10.75 IUE for tomato in Tunisia and a value of 14.4 was observed for greenhouse tomato crops in Northern Cyprus. However, some results are different, as these authors reported the highest economic productivity for oranges, while oranges had an average score in Northern Cyprus. The climates of both Northern Cyprus and Tunusia (WHO, 2016) are similar, but the economic levels and production practices of the crops are different. Both the IUE and IEP in Northern Cyprus crops are found to be higher than the coefficients in Tunisia. There is a large variation in natural resource endowments, and IUE may change at the biological, environmental, and management levels (Kassam et al., 2006). The water use efficiency of different species varies, in large part due to the carbohydrate pathways of crops (Ludlow and Muchow, 1990). C4 plants mainly have double the WUE of C3 plants (Yoo et al., 2009). However, all fruit and vegetable species in the present study with high WUE are C3 plants, while the best known commercial C4 plants (i.e., maize, sugarcane, sorghum and millets) do not hold an important place in Northern Cyprus agriculture.

The results of the present study show that carob, fig and loquat are the most effective fruit crops in terms of IUE and that walnut, fig and almond are the most effective fruit crops in terms of IEP. These five crops also have the highest IDE. Among the vegetable crops, lettuce, eggplant and cauliflower are found to have the highest IUE, IEP and IDE. The most efficient vegetable crops are among the most produced crops in Northern Cyprus, but these five fruit crops (carob, fig, loquat, walnut and almond) have a very small share of the total production in Northern Cyprus. Our results show that reshaping the distribution of crops based on their water consumption would reduce the use of water resources while continu-

Table 4
Irrigation dietary efficiency (IDE) for energy, protein, carbohydrate, fibre and sugar of selected important vegetable crops in Northern Cyprus.

Products	IDE-Energy (kcal/L)	IDE-Protein (g/L)	IDE-Carbohydrate (g/L)	IDE-Fibre (g/L)	IDE-Sugar (g/L)
Artichoke (OF)	8.9 (d)	***0.62 (c)***	1.98 (f)	***1.02 (c)***	0.19 (no)
Green bean (DI)	2.2 (no)	0.20 (hi)	0.45 (no)	0.19 (jkl)	0.23 (no)
Green bean (GH)	3.6 (ijk)	0.32 (e)	0.72 (lm)	0.31 (gh)	0.38 (jkl)
Green bean (SI)	2.0 (no)	0.18 (hi)	0.41 (o)	0.17 (jkl)	0.21 (no)
Cauliflower (OF)	***11.2 (c)***	**<u>0.86 (a)</u>**	2.23 (e)	0.90 (d)	0.86 (f)
Cucumber (GH)	5.2 (fg)	0.22 (gh)	1.25 (h)	0.17 (jkl)	0.58 (gh)
Cucumber (OF)	4.9 (gh)	0.21 (gh)	1.18 (h)	0.16 (jkl)	0.54 (gh)
Cucumber (SL)	1.9 (no)	0.08 (jkl)	0.45 (no)	0.06 (no)	0.21 (no)
Eggplant (GH)	**<u>15.7 (a)</u>**	***0.62 (c)***	**<u>3.70 (a)</u>**	**<u>1.89 (a)</u>**	**2.22 (c)**
Eggplant (OF)	***10.7 (c)***	0.42 (d)	2.51 (d)	**1.28 (b)**	1.51 (d)
Garlic (OF)	6.2 (e)	0.26 (fg)	1.37 (h)	0.09 (no)	0.04 (p)
Lettuce (OF)	**14.1 (b)**	**<u>0.91 (a)</u>**	***2.99 (c)***	**1.21 (b)**	***1.98 (d)***
Melon (GH)	4.1 (hi)	0.10 (jkl)	0.98 (jk)	0.11 (m)	0.95 (f)
Melon (OF)	**13.6 (b)**	0.34 (e)	**3.26 (b)**	0.36 (fg)	**<u>3.14 (a)</u>**
Onions dry (OF)	2.8 (lmn)	0.08 (mn)	0.65 (mn)	0.12 (m)	0.29 (lm)
Onions fresh (OF)	2.1 (no)	0.12 (jkl)	0.47 (no)	0.17 (jkl)	0.15 (op)
Green pea (DI)	2.5 (lmn)	0.02 (o)	0.68 (mn)	0.14 (jkl)	0.43 (ijk)
Green pea (SI)	2.0 (no)	0.01 (o)	0.53 (mno)	0.11 (m)	0.34 (lm)
Pepper (GH)	7.2 (e)	0.31 (e)	1.67 (g)	0.61 (e)	0.86 (f)
Pepper (OF)	5.0 (gh)	0.21 (gh)	1.15 (h)	0.42 (f)	0.60 (g)
Potatoes (autumn crop)	4.5 (hi)	0.12 (jkl)	1.03 (ijk)	0.13 (m)	0.05 (p)
Potatoes (spring crop)	3.3 (klm)	0.09 (mn)	0.74 (lm)	0.09 (no)	0.03 (p)
Squash (GH)	2.3 (no)	0.17 (hi)	0.48 (no)	0.16 (jkl)	0.31 (lm)
Squash (OF)	3.5 (jkl)	0.26 (fg)	0.72 (lm)	0.24 (hi)	0.47 (ij)
Strawberry (SL)	6.4 (e)	**0.64 (bc)**	0.93 (k)	0.06 (no)	0.87 (f)
Strawberry (UT)	6.9 (e)	**0.69 (b)**	1.00 (jk)	0.06 (no)	0.93 (f)
Tomato (GH)	2.6 (lmn)	0.13 (jkl)	0.56 (mno)	0.17 (jkl)	0.38 (jkl)
Tomato (OF)	3.0 (lmn)	0.15 (jkl)	0.66 (mn)	0.20 (jkl)	0.44 (ijk)
Tomato (SL)	0.7 (p)	0.03 (no)	0.15 (p)	0.05 (o)	0.10 (op)
Watermelon (OF)	5.4 (fg)	0.11 (jkl)	1.35 (h)	0.07 (no)	1.11 (e)

Values followed by the same letter or letters in the same column are not significantly different at the 5% level (Tukey's test). Highest values are indicated with **<u>bold and underlined</u>**, second highest values with **bold** and third highest values with ***bold and italic.*** **OF:** Open field **DI:** Drip irrigation **GH:** Greenhouse **SI:** Sprinkler irrigation **SL:** Soilless **UT:** Under tunnel.

ing to feed the population. Efficient use of water is a complex subject that involves many disciplines, i.e., plant physiology, marketing and food science (Hsiao et al., 2007). Choosing only the crops with high IUE is not sustainable; selected crops should have high IEP and IDE. Sustainability includes economic, environmental and social development for meeting the needs of the present without compromising the ability of future generations to meet their own needs (Giovannoni and Fabietti, 2014).

Reshaping the crop distribution, not only in Northern Cyprus but also throughout the world, is crucial for sustainability but is not the only option. As a general rule, the IUE of crops can be enhanced by choosing the appropriate crop or by implementation strategies to increase crop yield or reduce water use. These practices include selecting suitable crops for the climatic conditions and optimizing the planting distance (Pascale et al., 2011). Crop breeding (Mateos and Araus, 2016), high-density cropping (Pellegrini et al., 2016), soilless culture (Nikolaou et al., 2017), automatic irrigation systems (Prabhushankar et al., 2015) and partial root drying (Casa and Rouphael, 2014) are some of the opportunities for conserving water while maintaining or improving productivity, thus improving IUE. There is very little research on the effects of these methods in Northern Cyprus. The results of the present study also show that drip irrigation is more efficient than sprinkler irrigation. Another possibility is to cover the soil and/or plants to reduce water loss through evapotranspiration from soil and plants. Our results support this phenomenon by revealing higher IUE and WUE in greenhouse crops than in open field crops for the same species. However, soilless culture was found to be less effective than the greenhouse production and open field production. Contrary to our results, many studies (Nikolaou et al., 2017; Eiasu et al., 2012; Wang and Xing, 2017) reported that soilless culture is very effective in terms of water use efficiency. The main reason for this low impact is that soilless culture in Northern Cyprus is not a closed system. Thus, the wastewater is not being reused. Similarly, Burrage (2014) reported that soilless culture can be an effective tool to increase water use efficiency if closed irrigation systems are used. Therefore, these results show that using a relatively effective system is not a stand-alone remedy; the system must be used correctly to increase efficiency. Agronomic practices are as important as the climatic factors in ensuring irrigation water productivity. Advanced water-saving technology and efficient use of agronomic inputs are also important for water use efficiency (Li et al., 2006). Furthermore, the present results suggest that the farmers need agricultural consultation to improve water use efficiency.

A lack of available water for agricultural production is already a major problem in many parts of the world (Elliott et al., 2014), as in Northern Cyprus. Increasing temperatures and changes in precipitation patterns with increasing population size (an increase in the need for food) are all increasing this problem. Feeding the world while ensuring sustainability is (Challinor et al., 2014), or must be, the main concern of decision makers throughout the world. In the conditions of Northern Cyprus, it is exceedingly important to reshape the crop distribution by giving much attention to the crops with high IUE, IEP and IDE. However, it is also important to pay attention to the crop breeding, high-density cropping, soilless culture, automatic irrigation and partial root drying technologies to increase crop yield or to reduce crop water use, with the achievement of both at the same time the most desired outcome. To successfully reshape the crop distribution, it is incredibly important to conduct educational campaigns to improve consumers' awareness on the problems raised by climate change and water scarcity. Farmers have to produce what the consumers are demanding. Therefore, it is imperative for the consumers to demand crops with less water use or high water use efficiency. Sun et al. (2015) reported that changing diet patterns would promote water saving and help to alleviate stress on water resources while guaranteeing the nutritional value of the residents.

At the same time, attention must be given to farmers' water use for agricultural production. Decision makers must prepare long-term plans and support farmers to change their crop and production types. New laws must be put into place to prevent farmers from producing "what they want". Water is the main production factor all over the world, and managing water use may help decision makers to control agricultural production. Water must be shared among farmers who are complying with the rules (including crop type and production style). Decision makers have to keep in mind that vegetables bear fruit in one season, but fruits need approximately 3–5 years, which causes losses in the farmers' incomes. In this case, government support plays a critical role in convincing and supporting farmers. On the other hand, mixed cropping during the transition period may prevent or reduce the loss in farmers' income (Malézieux et al., 2009).

5. Conclusion

Present study showed that not only the irrigation use efficiency (IUE), but also the irrigation economic productivity (IEP), irrigation economic efficiency (IEE) and irrigation dietary efficiency (IDE) are differing among crops and it is so crucial to consider all in sustainable agricultural planning. Ensuring sustainability in agricultural production is becoming the main goal throughout the world. Success in such actions needs cross-sectoral interactions. An integrated, evidence-based approach is required, which must be coordinated by researchers, policymakers, farmers and private, public and civil society to be successful. Integrating these sectors into the application can result in increased irrigation/water use efficiency and decreased food insecurity over the long term throughout the world.

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