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A state-by-state analysis of agricultural water productivity in Iran

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Abstract

Introduction: Among irrigation management indicators, water productivity is considered the most important by some researchers. However, others strongly oppose this view, arguing that the concept of this indicator fundamentally differs from that of consumption. This study aims to investigate the water productivity of various crops and dietary patterns in Iran.

Materials and Methods: To effectively compare Iran's water productivity with global averages, measurement criteria were selected to facilitate this comparison. Specifically, if the ratio of Iran to the world falls between 0.9 and 1.1, Iran's water productivity aligns with global values. If it exceeds the global average by 20%, Iran's water productivity is considered very good. Conversely, if it is less than 70% of the global average, the water productivity is very low, indicating unfavorable conditions.

Results: Dietary patterns should gradually shift towards products that consume less water. If two agricultural products have similar nutritional values but one consumes less water, the less water-intensive product is preferred. This research investigates two issues: the status of water productivity in Iran's agricultural sector compared to global averages, and essential strategies for improving water productivity. The comparison of Iran's average water productivity with global averages reveals that Iran's location is favorable for barley and bean production but not for wheat and peas.

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Conclusion: General strategies to increase water productivity involve enhancing crop yield or reducing water consumption. It appears that Iran should implement two policies as soon as possible: firstly, increasing crop yield rather than expanding cultivated areas, and secondly, gradually adjusting dietary patterns in line with agricultural water productivity. If these changes are not made, the country's water issues may become critical in the near future.

Keywords: Irrigation management indicators, Dietary patterns, Agricultural water management, Water productivity.

1. Introduction

Understanding the various aspects of dietary patterns and their relationships with water efficiency and productivity is essential for effective resource management in production. Among the indicators for evaluating irrigation performance, irrigation efficiency and water productivity are of significant importance. Irrigation efficiency is defined as the ratio of the volume of water consumed during plant evapotranspiration (ET) to the total volume of water introduced into the field. The usefulness of high irrigation efficiency as a measure is a topic of debate among researchers. For instance, some argue that the modernization of irrigation methods has contributed to the reduction of groundwater recharge and the unsustainable development of agricultural and garden lands, and thus, it should not be considered a valuable measure in all circumstances (Burke et al., 1999; Perry, 2018; Perry et al., 2017).

To address this challenge, Molden (1997) proposed the concept of water productivity. From an irrigation efficiency perspective, even losses that might be useful elsewhere in the hydrological system were not considered valuable. In irrigation, when water is used, not all of it is lost; a part of it is returned to the system and can be used for other purposes. Molden (1997) defined water productivity as the physical mass (weight or volume) or economic value of production obtained per unit of inflow, whether gross or net. The inflow can be fresh water, recycled water, or any water available for irrigation. In other words, agricultural water productivity refers to the output obtained from each unit of water volume. From an agricultural perspective, the output is a product; from a financial perspective, it is income; and from an economic perspective, it is employment. From an agricultural viewpoint, water productivity is the ratio of the product produced to the water supplied to the plant, regardless of whether this water is used by the plant, used as runoff, or infiltrates to join the groundwater.

Keller et al. (1996; 1998) introduced the term “effective irrigation efficiency”. Some equate the terms effective irrigation efficiency and water productivity (Zwart & Bastiaanssen 2004; Blumling et al., 2007). According to the literature, water productivity is a concept that some researchers have attempted to apply in their research as a socially accepted concept. Irrigation efficiency and water productivity are two parameters with different units and cannot generally be compared. However, some believe that water productivity is a more meaningful index than irrigation efficiency because it also considers plant performance. Blumling et al. (2007) attempted to find a correlation between irrigation efficiency and water productivity. However, such works are still under investigation. If such correlations are found, crop composition can be optimized to yield the highest output while maintaining optimal irrigation efficiency. When water is the limiting resource, crop production should focus on maximizing yield per unit water input, not yield per unit area.

Keller (2005) found that crop yield versus ET curves at different locations were slightly correlated. For grain corn, he attributed the lack of correlation primarily to the difference in the deficit of saturation vapor pressure (Δe) between places and seasons and the role of the evaporation component in ET. By normalizing the deficit of Δe, he found a strong correlation between corn yield and normalized ET. Interestingly, water productivity was maximized by fully irrigating a smaller area, instead of under-irrigating a larger area with the same amount of water. He reported this hypothesis to be true for other grain products as well.

In Iran, the irrigation efficiency is approximately 56%, and considering the efficiency of water conveyance and distribution at about 80%, the total irrigation efficiency is estimated to be between 43-47% (Abassi et al., 2014; Kiani and Sedaqat Doust, 2014). Water productivity in Iran's agricultural sector is close to 1.2 kg/m^3 of water. The pressure on limited water resources is likely to intensify in Iran in the future. The world population is projected to reach 9.6 billion people by 2050. It is estimated that, given current trends in food consumption, ensuring adequate nutrition for the future population will require a doubling of food production by 2050. The availability of suitable water and arable land for supplying food products depends on production location conditions and production methods. Local dietary patterns are also heavily influenced by the availability of foods as well as local traditions and culture.

The allocation of land for food production impacts water, soil, air quality, and climate. Factors such as population growth, food preferences, new technologies, and crop yields have all played a significant role in shaping land use and diets. If the world adopts the average Indian diet, 55% less agricultural land will be needed to meet demand. Conversely, if the average diet of the US population is followed, 178% more land will be required (Alexander et al., 2016). Food waste and overeating also play essential roles. Therefore, actions to influence future diets and reduce food waste can significantly contribute to global food security and provide climate change mitigation options (Alexander et al., 2016). In many parts of the world, diets are changing to consume more energy from animal food sources. Animal products, especially meat, require more resources such as water and soil than plant foods. The importance of diets for future food security and sustainable use of natural resources is well recognized. Consumption of animal products also has many environmental effects. Ersin & Hoekstra (2014) found that changing consumption patterns can bring the water footprint to sustainable levels. Researchers have found that in this situation, sustainable production and consumption patterns can be found to meet the growing demand of the population in 2050. The trend towards Western diets is not sustainable or desirable for the global population due to environmental and health reasons. Considering that intensive agriculture alone might not be enough to respond to changes in food preferences and population growth, other methods are needed to prevent the increase of agricultural land. It seems that behavioral and economic mechanisms need to be better understood to determine how to achieve more equitable and healthy food consumption that is also environmentally sound. A change in diet should happen in people's behavior patterns.

The relative importance of saving water by changing dietary patterns depends on available water resources. Jalava et al. (2014) investigated four scenarios of reducing animal protein in the daily diet to determine the effect of dietary change on the amount of water consumption. In these scenarios, the consumption of animal protein was limited to 50, 25, 12.5, and 0% (a diet without animal protein consumption). Considering animal protein-free diets, the greatest relative water savings from diet change in water-scarce regions belonged to the Middle East (up to 559%), Africa (79%), Central and Eastern Asia (74%), and some Latin American countries (25%). They reported that the scenario of limiting protein to 25% and 0% can supply the green and blue water needed by 67 and 168 million people, respectively. Besides, reducing the share of animal products in the diet can reduce global green water consumption by 6, 11, 15, and 21% in the four applied scenarios, respectively, while for blue water; the reduction is 4, 6, 9, and 14%. In Latin America, Europe, Central and East Asia, and sub-Saharan Africa, dietary changes mainly reduce green water consumption, while in the Middle East, North America, Australia, and Oceania, both blue and green water are significantly reduced. At the same time, in South and Southeast Asia, dietary changes do not lead to reduced water consumption.

This study aims to examine the water productivity of various crops and cropping patterns in Iran. To facilitate a more effective comparison of Iran's water productivity with global averages, specific measurement criteria were selected. These criteria were designed to enable a comparison of Iran's situation with global average values.

2. Material and Methods

This research was carried out based on the existing database of FAO and UNESCO data in 2010. The main emphasis of this study is on water productivity in the agricultural sector. With the help of this database, it is possible to determine the crops that are compatible with each province from the viewpoint of water productivity and developing cultivation patterns .In this study, first, the water productivity for a large number of products is presented at the national level and then at the provincial level. Then, the status of the desired products from the viewpoint of water productivity at the national level compared to the world average is determined (Table 1) and competitive plants are determined. In order to better compare Iran's water productivity with global water productivity, a ratio was defined in such a way that it could compare the situation of Iran with the global average values. In other words, if the ratio of Iran to the world is between 0.9 and 1.1, Iran's water productivity is the same as the world's values. If it is 20% more than the global average, Iran's water productivity is very high, and similarly, if it is less than 70%, the water productivity is very low and the conditions are unfavorable.

Since many of the crops are grown in various provinces of the country, the most suitable areas to cultivate each crop have been identified and introduced . Iran is the fifth country in the world in terms of irrigated land and nearly 90% of agricultural products are obtained from irrigated lands. Therefore, there is a lot of pressure on its water resources. On the other hand, Iran is a semi-arid and arid country, and the temporal and spatial distribution of its rainfall is more or less inappropriate. Therefore, the contribution of rainfall to agricultural water productivity cannot be high .

Table 1. Criteria for measuring the state of agricultural water productivity compared to the global average

The status of Iran's average value compared to the world's average	Productivity ratio
Very low	Less than 0.7
Low	0.7 to 0.9
Medium	0.9 to 1.1
High	1.1 to 1.2
Very high	More than 1.2

3. Results and Discussion

The water productivity of Iran’s main agricultural products, compared to the world’s average values, was calculated based on Table 1. The results are presented in Table 2. Among the 60 products for which FAO presents productivity data in Iran, 19 products (32%) exhibit very high productivity, meaning that their water productivity is at least 20% higher than the world's average. A total of 7 products (12%) have high productivity, with their water productivity being between 10 and 20% higher than the global average productivity. Thus, 44% of the products have higher water productivity than the global average. In contrast, 12 products (20%) have low water productivity and 10 products (16%) have very low water productivity. It is evident that in order to conserve water, the cultivation area of plants with low and very low water productivity should be reduced. Instead, crops with high and very high water productivity should be promoted in crop patterns.

Table 2. Water productivity of main agricultural crops in Iran compared to the world's average

Crops	Production	Very high	High	Medium	Low	Very low
Staple Foods	Bakery wheat					x
	Paddy				x	
	Rice with the inner skin				x	
	Unpeeled rice				x	
	Barley	x				
	Edible corn		x			
	Potato			x		
Beans	Small red beans	x				
	White beans	x				
	Peas and cobs					x
	Lentils					x
Oil Seeds	Soybean				x	
	Sunflower seed					x
	Safflower seed					x
	Sesame				x	
	Cottonseed			x		
Vegetable Oil (without chemical treatment)	Crude corn oil		x			
	Refined corn oil		x			
	Soy oil				x	
	Peanut oil	x				
	Olive oil				x	
	Sunflower or safflower oil					x
	Sesame Oil				x	
	Cottonseed oil			x		
	Linseed oil					x

Crops	Production	Very high	High	Medium	Low	Very low
Fruits	Orange			x		
	Tangerine	x				
	Sweet lemon and sour lemon	x				
	Grapefruit		x			
	Citrus mix	x				
	Apple			x		
	Pear and peach				x	
	Apricot			x		
	Cherry		x			
	Peaches and nectarines	x				
	Plum					
	Black plum Bukhara plum and	x				
	Strawberry				x	
	Grape	x				
	Fig				x	
	Date			x		
Nuts (skinless)	Almonds			x		
	Walnut			x		
	Pistachio				x	
	Hazelnut					x
	Peanut	x				
Vegetables	Tomato				x	
	Cauliflower and broccoli	x				
	Brussels sprouts	x				
	Cucumbers and cucumbers			x		
	Eggplant	x				
	Green pepper	x				
	Onion	x				
	Garlic					x
	Green beans		x			
	Green Peas		x			
	Carrots and turnips	x				
	Celery	x				
	Mixed vegetables			x		

In all groups, there are plants with varying degrees of productivity. For instance, among cereals, barley exhibits very good water productivity, corn has good water productivity, rice has low water productivity, and wheat has very low water productivity. This variability allows farmers to easily change cultivation patterns to increase water productivity. Barley performs significantly better than wheat in terms of water productivity. Considering the country's need for each of these two products, it might be beneficial to create incentives for farmers to replace barley with wheat. This could save some water and, in return, allocate a larger share of imports to wheat.

Compared to Southeast Asia, which has an annual rainfall of more than 2000 mm and yields two to three crops per year, rice cannot maintain a good position from an economic viewpoint. Therefore, it is undoubtedly necessary to consider a second crop after harvesting rice. The water productivity of some types of beans (small red beans and white beans) is very good, while others (peas and lentils) have very low productivity. Substitution can result in some water savings.

Most stone fruit trees are in a good position from the viewpoint of water productivity. However, pears and pistachios are in an unfavorable situation. Regarding pistachios, due to insufficient water and salinity of water and soil, it is not possible to predict a suitable future. Vegetable oils are not in a promising situation, while most vegetables are in a very good position.

To check the competitive products of each province with others, first the provinces are shown with a code in Figure 1. Based on the statistics collected from FAO and UNESCO in 2010, Yazd province (code 28 in Figure 1) was the most suitable for cultivating 49 out of the 60 investigated crops. In Yazd (28), Ardabil (3), and Fars (27) provinces, many crops contribute to higher water productivity (Table 3).

Table 3 briefly presents the provinces with the highest and lowest water productivity for different products. In this table, the top three and the bottom three provinces are highlighted. The ratio of the average water productivity of the two groups has also been calculated. A higher ratio indicates a greater difference between the water productivity of a product in the best and worst cultivation provinces. For example, when this ratio is large (3.5) for wheat, it suggests that wheat is cultivated even in provinces where water productivity is suboptimal. The closer this ratio is to 1, the smaller the difference between the water productivity values of a crop in various provinces.

The table reveals that provinces known for cultivating certain products do not necessarily have good water productivity. For instance, potato cultivation in Hamadan (15) has very low water productivity. Similarly, rice cultivation in

Gilan (4) and Mazandaran (5) provinces is not in a good condition. This suggests that over-irrigation has been practiced in these provinces.

Figure 1. Provinces of Iran with their numerical codes

Table 3. Superior and inferior provinces from the point of view of productivity of different products

Crops	Production	Three provinces with the highest water productivity	Three provinces with the lowest water productivity	The ratio of the highest to the lowest
Staple Foods	Bakery wheat	1, 4, and 3	26, 25, and 31	3.49
	Unpeeled rice	3, 28, and 3	18, 25, and 22	2.00
	Barley	3, 28, and 3	22, 14, and 25	2.77
	Potato	3, 28, and 19	18, 26, and 15	1.76
Beans	Small red beans	3, 28, and 3	1, 22	1.81
	White beans	4, 2 and 26	1, 8 and 30	3.67
	Peas and cobs	3, 28 and 3	14, 15 and 25	2.35
	Lentils	3, 16 and 9	18, 1 and 25	1.68
Oil Seeds	Soybean	3, 28 and 3	18, 25 and 1	2.36
	Peanut	3, 28 and 3	1, 30 and 25	1.25
	Sunflower seed	28, 3 and 3	30, 25 and 14	1.74
	Safflower seed	3, 28 and 3	14, 25 and 22	1.58
	Sesame	3, 28 and 3	14, 25 and 22	1.82
	Cottonseed	28, 3 and 16	18, 25 and 14	1.95

Crops	Production	Three provinces with the highest water productivity	Three provinces with the lowest water productivity	The ratio of the highest to the lowest
Vegetable Oil (without chemical treatment)	Crude corn oil	28, 19 and 9	15, 22 and 24	1.99
	Soy oil	3, 28 and 3	18, 25 and 1	2
	Peanut oil	3, 28 and 19	1, 25 and 30	1.25
	Olive oil	3, 28 and 3	18, 14 and 25	2
	Sunflower or safflower oil	3, 28 and 3	25, 30 and 14	1.76
	Sesame Oil	3, 28 and 3	14, 25 and 22	1.78
	Cottonseed oil	28, 3 and 16	18, 25 and 14	1.96
	Linseed oil	3, 28 and 3	14, 25 and 22	1.80
Fruits	Orange	3, 28 and 3	14, 25 and 2	1.82
	Tangerine	3, 28 and 3	14, 25 and 2	1.82
	Sweet lemon and sour lemon	28, 3 and 16	18, 1 and 30	1.76
	Grapefruit	28, 3 and 16	18, 25 and 4	1.97
	Apple	3, 28 and 3	18, 30 and 25	2.01
	Pear and peach	3, 28 and 3	14, 25 and 18	2.36
	Cherry	3, 28 and 3	18, 25 and 4	2.06
	Peaches and nectarines	3, 3 and 28	14, 25 and 18	2.34
	Plum	3, 28 and 3	18, 25 and 14	2.08
	Black and Bukhara plum	3, 28 and 3	14, 18 and 25	2.15
	Strawberry	3, 28 and 3	14, 18 and 25	2.26
	Grape	3, 3 and 28	14, 22 and 25	2.01
	Fig	3, 28 and 3	14, 22 and 25	2.22
	Date	3, 28 and 3	14, 22 and 25	2.48
Nuts (skinless)	Almonds	3, 28 and 3	25, 30 and 14	2.46
	Walnut	3, 28 and 3	25, 14 and 18	2.32
	Pistachio	3, 28 and 3	24, 14 and 30	2.46
	Hazelnut	3, 28 and 3	25, 14 and 18	2.27
Vegetables	Tomato	3, 28 and 3	30, 25 and 14	2.01
	Cauliflower and broccoli	3, 28 and 3	22, 25 and 14	2.42
	Brussels sprouts	3, 28 and 3	22, 25 and 14	2.42
	Cucumbers and cucumbers	3, 28 and 3	30, 25 and 14	2.04
	Eggplant	3, 28 and 3	22, 25 and 18	2.41
	Green pepper	3, 28 and 3	30, 25 and 18	2.08
	Onion	3, 28 and 3	25, 14 and 18	2.26
	Garlic	3, 28 and 3	25, 18 and 14	2.26
	Green beans	3, 28 and 3	22, 25 and 14	2.04
	Green Peas	3, 28 and 3	22, 25 and 14	2.22
	Carrots and turnips	3, 28 and 3	22, 25 and 14	2.48
	Celery	3, 28 and 3	22, 25 and 14	2.48

Among the products considered in this study, the ranking of the provinces in terms of the highest or lowest water productivity is presented in Table 4. This table clearly indicates that the provinces of Yazd (28), Ardabil (3), and Fars (27) have crop patterns that contribute to higher water productivity. This could be attributed to reduced water consumption, enhanced product yield, or a combination of both. Undoubtedly, the agricultural practices and culture of the people in these regions also play a significant role.

Table 4. The frequency of provinces in very high or very low water productivity values

In the three top provinces		In the three bottom provinces	
Province code	**Number of items**	**Province code**	**Number of items**
28	49	25	47
3	47	14	37
3	44	18	23
19	4	22	20
16	2	30	12
4	2	1	8
1	1	16	3
26	1	15	3
9	1	26	2
		31	1
		10	1
		2	1
		8	1
		24	1

4. Conclusions

There are general strategies to increase water productivity, which can be achieved by enhancing crop yields or reducing water consumption. There are two methods to boost crop yield: agricultural methods and breeding techniques.

Agricultural methods encompass proper tillage, timely cultivation, sufficient irrigation, optimal use of inputs, and the utilization of appropriate implements. Breeding techniques involve managing biotic environmental factors, including pests and diseases, and managing abiotic environmental factors and stresses such as salinity, drought, and temperature.

Various strategies are available to reduce water consumption. These include rain-fed cultivation, supplemental irrigation, conservation agriculture, altering planting times, using mulches and soil covers, and employing gated pipes and other irrigation controlling tools.

It appears that two policies can be implemented to address the limitations of low water productivity in various areas of Iran: increasing crop yield instead of expanding the area under cultivation, and adjusting dietary patterns according to the agricultural water productivity of each region.

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