Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 6, No. 3, p. 351-358, 2015
http://www.innspub.net

INNSPUB
RESEARCH PAPER

OPEN ACCESS

Applying the economic water use efficiency concept to determine the optimal cropping pattern in Rayen City

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Article published on March 28, 2015

Key words: Alfalfa, Barely, Corn, Wheat, Water Use Efficiency, Optimal Cropping Pattern.

Abstract

Despite of having a favorable condition for many agricultural crops, Iran faced severe water shortage due to improper cropping pattern in many parts of the country. In this study, the concept of water use efficiency (WUE) and economic water productivity (WPe) was applied to prioritizing four common cultivated crops in Rayen city; including wheat, corn, alfalfa and barely. Crop water use was calculated by multiplying the crop coefficient by the reference evapotranspiration during the growing season. Having yield at final harvest and the net income per unit produced crops, the WUE and WPe was calculated for all crops. Results showed that the lowest and the highest WUE was for wheat (0.94 kg m^{-3}) and alfalfa (1.56 kg m^{-3}), respectively. Also, corn with net income of about 75 million Riyal ha^{-1} and barely with net income of about 40 million Riyal ha^{-1} took the first and the last place, respectively, with respect to net income. Thus, corn WPe was higher than wheat and barley. So that corn cultivation would led to higher benefits in compare with the other crops in the study area. Based on the results, corn cultivation is encouraged due to high net income, WUE and WPe.

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Introduction

Many studies have reported the significant effect of irrigation management on water use efficiency has been investigated in different points of view (Zwart and Bastiansen, 2004). Sepahvand (2009) has reported that wheat cultivation has more advantageous compared with canola cultivation with respect to both water requirement and water use efficiency. The water use efficiency of wheat and canola was 0.64 and 0.6 kg/m^3, respectively. Peji *et al* (2011) have investigated the effect of different levels of irrigation depth on yield of onion. Their results showed that the highest water use efficiency (22.1 Kg m^{-3}) would be achieved under 55% reduction in irrigation depth while the lowest one (11.1 Kg m^{-3}) belonged to control treatment.

Determining the costs of water use is an effective tool for increasing the crop production per cube meter of water use. Determining the costs of water use aimed at increasing economic water productivity, distributing the net income and saving the available water for next generation (Sepahvand, 2009). To have a list of agricultural products and the related costs, the Statistic and Planning office of Agricultural Jihad Ministry prepared some questionaries' which are annually filled by farmers (Chizari and Mirzaei, 1998). In addition, analyzing the value of unit water use has a major importance for crop production. Estimating the costs of extracting water and its transferring to the agricultural fields is a way for calculating the value of unit water volume (Shams-Aldin *et al.*, 2010). The unit water value of wheat was estimated as 390 Riyals m^{-3} in Maragheh by HoseinZadeh and Salami (2004). Marvdashti and Farjoud (2007) have reported that considering an interest rate of 20 percent, the costs per one cube meter of water in Fars province is 63.3 Riyals m^{-3}.

The literature review showed that many studies have been done on determining the water use efficiency of different crops all over the world. However, economic water use efficiency is a more important index for agronomic crops than water use efficiency. In economic point of view, increased water use efficiency is not adequate enough and increasing net income should also be considered. The economic water use efficiency is defined as the net income per cube meter of water use (Sepahvand, 2009). In spite of the great importance of estimating economic water productivity especially for arid and semi-arid regions like Iran, a few studies have been conducted on this subject. Although agronomic products such as wheat, alfalfa, barley and corn are more encouraged for cultivation in Kerman Province than the other crops (Karbasi *et al.*, 2009), few studies have been conducted on determining the water use efficiency of these crops. Since drip irrigation is widely used in Rayen city of Kerman Province for the considered crops, a comprehensive study on the water requirement of the cultivated crops is essential to increase the economical water use efficiency under the new irrigation systems. In this study, the amount of water use, yield, WUE and economic water productivity of four mentioned crops was investigated under surface drip irrigation in Rayen City to propose the optimal cropping pattern.

Materials and methods

Site and climate condition

Rayen city is located 100 km far from the southern Kerman (4408.57 E and 5975.29 N) and is limited to Golbaft from northeast, to Bardsir from northwest, to Mahan from north, to Robour from southwest and to Jiroft from south. The elevation of the site is 2201 m above the sea level. The study area has mild climate with cold winters and cool and pleasant summers. Weather data were collected at Rayen weather station. The average, minimum, and maximum air temperatures are 30.9 ^oC, -10.8 ^oC, and 41 ^oC, respectively. The average humidity was 36.3 % with minimum (16 %) and maximum (89.3 %) values for December and June, respectively. Totally, 109 mm rain was recorded during the study period 60 % of which occurred during October to December.

Experimental design and crop management

The experimental area was 19 m×3 m which was divided into four plots; each one was under one of the four selected crops including wheat, barely, alfalfa and corn. Soil samples were taken from all plots due to different fertilizer demand for the selected crops. Soil samples were analyzed in Abbid Advisor Engineers Company. Table 1 and 2 shows some physical and chemical properties of soil in the experimental field.

Table 1. Soil physical properties.

Field of Study	Soil texture	Clay (%)	Silt (%)	Sand (%)
Alfalfa	Sandy loam	14.4	28	57.6
Corn	Sandy loam	15.1	32	52.9
Barley	Sandy loam	14	27	59
Wheat	Loam	17	31	52

Table 2. Some chemical characteristics of soil.

Farm	EC (dS/m)	pH	Mn^{+2}	Fe^{+2}	Na^{+}	Ca^{+2}	Mg^{+2}	$SO4^{-2}$	Cl^{-}	HCO^{3-}
			meq/L							
Alfalfa	1.1	7.5	0.007	0.064	2.1	6	2	3.8	2	4.6
Corn	1.1	7.47	0.008	0.084	2.7	6	2.3	3.68	1.9	4.7
Barley	1.15	7.35	0.009	0.065	1.9	5.6	1.7	3.4	1.7	4.2
Wheat	1.2	4.5	0.007	0.042	2.4	6.2	2.1	3.9	2.2	4.62

Alfalfa, corn, barley and wheat were cultivated on September 5, April 9, October 5 and October 5, 2012, respectively. Table 3 shows the crops information. To improve crop growth, 800 kg ha^{-1} animal fertilizer, 25 kg ha^{-1} ammonium phosphate, 150 kg ha^{-1} potassium and 100 kg ha^{-1} urea was applied to all plots based on the conventional practices during the growing seasons. Harvesting time was December 5, 2013 for alfalfa, September 29, 2013 for corn, June 27, 2013 for barely and July 11, 2013 for wheat (Table 3).

Table 3. The kind of cultivated varieties and planting and harvesting time.

Crop type	Cultivated Varieties	Planting Time	Harvesting Time
Alfalfa	M. Scutellata	9.05.2012	12.05.2013
Corn	Croce 704	4.09.2012	9.29.2013
Barley	Dayton	10.05.2012	6.27.2013
Wheat	Sardari	10.05.2012	7.11.2013

Irrigation requirements

Crop water requirement during the study period was estimated based on the Eq. 1 as follows:

$$ET_{crop} = K_c\left(ET_o\right) \quad (1)$$

Where ET_{rop} is the actual crop water requirement, Kc is the crop coefficient and ET_O is the reference evapotranspiration. ET_O was estimated based on the FAO-Penman-Monteith equation (Allen *et al.*, 1198). Crop coefficients during different crop growth stage was determined based on Riahi *et al.* (2010). Crop water requirement was supplied from a deep well which was 50 m far from the experimental field. Irrigation was performed via drip irrigation system for all plots. Some chemical properties of the water are summarized in Table 4.

Table 4. Some chemical characteristics of water.

EC (dS/m)	pH	K^{+}	Na^{+}	Ca^{+2}	Mg^{+2}	SO_4^{-2}	Cl^{-}	HCO_3^{-}
		meq/L						
0.7	7.5	0.01	1.82	3	2	2.1	2.12	3.6

Water cost for different crops

Marvdashti and Farjoodi (2007) defined total water cost as the sum of pumped water cost and the cost of transferring the cubic meter of water to the field. Water extraction costs include (a) cost of investments (the sum of the sum of well digging, require equipment, purchase and installation cost of the pump and its related tools) and (b) operation costs (including the costs of maintenance and management, fuel, repairs and etc.). Costs of water transferring include the costs of piping, costs of construction of water channels and the required construction from the location of the pump to the field Water transferring costs was estimated based on the questionnaires developed by Power Ministry. Since the well in the study area was drilled in 1990 therefore Eq. 2 was used to transform the costs based on the uniform annual costs (Peji *et al*, 2011):

$$EUAC = P\left(\frac{A}{P}, \%i, n\right) - SV\left(\frac{A}{F}, \%i, n\right) \quad (2)$$

Where, EUAC is equivalent uniform annual cost (Ryals), P is the investment value (Ryals), (A/P, %i, n) is the transforming factor of unified annual cost, I is the interest rate, sv is the scrap value, n is the project life and (A/F, %i, n) is the transforming factor of future value to unified installments. The project life for for pump engine and its equipment's 20 years, respectively.

Water use efficiency (WUE), net income per unit volume of water use and economic water productivity were calculated using Eqs. 3, 4 and 5, respectively.

$$WUE = \frac{Y}{WU} \quad (3)$$

$$NBPD = (Y \times P_c) - C \quad (4)$$

$$WP_e = \frac{NBPD}{WU} \quad (5)$$

Where, WUE is water use efficiency (kg m^{-3}), Y is yield (kg ha^{-1}), WU is total crop water used (m^3), Pc is the product price (Ryals kg^{-1}), C is the total production cost (Ryals), NPBD is the net income per unit volume of water use (Ryals) and WP_e is the economic water productivity (Ryal m^{-3}).

Results and discussion

Total water costs

Table 5 shows the total annual cost of pump and water transferring in 2013 (i.e. the base year). Three interest rates of 10, 15 and 20 percent was adapted to calculate the uniform annual and transforming the costs to the base year of 2013. The interest rate of 20 percent was adopted to calculate the net income and economic water productivity since the yearly interest rate of Iranian banks is 20 percent. The annually uniform costs of water extraction and transferring were 395846530, 547571171 and 828925007 Riyals for the interest rates of 10, 15 and 20 percent, respectively.

Table 5. The annually uniform costs of water extraction and transferring.

Interest rate (%)	20	15	10
Total annual cost (Riyal)	828925007	547571171	395846530

Results of the questionnaires of the Power Ministry showed that the total exploited water during the study period was 1241372 cube meter. The costs per cube meter of extracted water was calculated for three interest rate of 10, 15 and 20 percent (Table 6). The costs per cube meter of extracted water was 667.7 Riyal for the interest rate of 20 percent which is the common interest rate in the Iranian Banks. Asadi and Yazdanpanah (2011) have calculated the costs of cube meter of extracted water for four experimental fields of Arzoueieh City. They have reported that the costs per cube meter of extracted water depended on the water quality and operation management and was 152.4, 190.3, 199.7 and 398.1 Riyal per cube meter of extracted water, respectively, for the interest rate of 15 percent.

Table 6. Costs per cube meter of extracted water for different rates of interest.

Interest rate (%)	20 percent	15 percent	10 percent
Costs (Riyal)	667.7	441.1	318.6

Wheat economic water productivity

Total wheat water use was 5100 m^3 ha^{-1} during the growing season for which 4800 kg ha^{-1} yield was harvested (Table 7). The amount of water use was multiplied by the costs per cube meter of water use (i.e. 667.7 Riyal per cube meter of water use for the interest rate of 20 percent) to calculate the total water costs for wheat production which was 3405270 Riyals ha^{-1} (Table 8). Having the gross income by multiplying the yield price by the yield, the net income was calculated by subtracting the costs from the gross income and was 46994730 Riyals ha^{-1} for wheat. Finally, the economical water productivity (WPe) was calculated by dividing the net income by the amount of water use which led to WPe=9215 Riyals per cube meter of water use for wheat production.

Table 7. Yield, water use and WUE of wheat.

Yield (Kg ha^{-1})	Water use (m^3 ha^{-1})	WUE (Kg m^3)
4800	5100	0.94

Table 8. economical water productivity (Wpe) and the related components for wheat.

Pc (Riyals /kg)	C (Riyals)	NPBD (Riyals)	WPe: (Riyals m^3)
10500	3405270	46994730	9215

Pc is the Price of the product is determined by its quality and the sale time for each farm, C is the total production cost, WPe is the economic water productivity and NPBD is the net income per unit volume of water use

Wheat is one of the most important strategic crops in the study area where a numerous study was investigated on the amount of water use and WUE of wheat as an example, Sepahvand (2009) have compared the water use, WUE and economic water productivity of wheat and canola in the west part of Iran. They have reported that the water use, WUE and economic water productivity of wheat was 5000 m^3 ha^{-1}, 0.8 kg m^{-3} and 2228 Riyals m^{-3}, respectively.

Barely economic water productivity

Table 9 shows that the amount of water use and yield of barely were 4200 m^3 ha^{-1} and 5600 kg ha^{-1}, respectively. By dividing the yield by the water use, the barely WUE was 1.33 kg m-^{3}. For the interest rate of 20 percent, the total water costs for barely production was 2804340 Riyals ha^{-1} while the net income was 40876560 Riyals per ha^{-1} (Table 10). Dividing the net income by the amount of water use, the economical water productivity for barely was WPe=9732 Riyals per cube meter of water use (Table 10).

Table 9. Yield, water use and WUE of barely.

Yield (Kg/ha)	Water use (m^3/ha)	WUE (Kg/m^3)
5600	4200	1.33

Table 10. economical water productivity (Wpe) and the related components for barely.

Pc * (Rial/kg)	C (Rial)	NPBD (Rial)	WPe: (Rial/m^3)
7800	2803440	40876560	9733

Pc is the Price of the product is determined by its quality and the sale time for each farm, C is the total production cost, WPe is the economic water productivity and NPBD is the net income per unit volume of water use.

Having a cultivation area of over 56 million ha and annual production of 120 million ton, barely ranked as the fourth important grains all over the world after wheat, rice and corn (Riahi *et al.*, 2010). According to FAOSTAT (FAO, 2010), Iran ranked as the 14th countries for producing barely with a cultivated area of 1.98 million ha and annual production of 3.5 million ton. Having lower water use and higher WUE, barely is a more favorable crop than other grains which could tolerate drought for a longer period than the others (Fisher, 2007). However, the water requirement of barely has been rarely investigated all over the world.

Corn economic water productivity

Table 10 shows that the amount of water use and yield of corn were 7500 m^3 ha^{-1} and 9200 kg ha^{-1}, respectively. By dividing the yield by the water use, the barely WUE was 1.23 kg m-^{3}. For the interest rate of 20 percent, the total water cost for barely production was 5007750 Riyals ha^{-1} while the net income was 75032250 Riyals per ha^{-1} (Table 10). Dividing the net income by the amount of water use, the economical water productivity for barely was WPe=10004 Riyals per cube meter of water use (Table 12).

Table 11. Yield, water use and WUE of corn.

Yield (Kg/ha)	Water use (m^3/ha)	WUE (Kg/m^3)
9200	7500	1.23

Table 12. economical water productivity (Wpe) and the related components for corn.

Pc * (Rial/kg)	C (Rial)	NPBD (Rial)	WPe: (Rial/m^3)
8700	5007750	75032250	10004

Pc is the Price of the product is determined by its quality and the sale time for each farm, C is the total production cost, WPe is the economic water productivity and NPBD is the net income per unit volume of water use

Corn is one of the most important agricultural crops which plays an important role in supplying foods for the growing population and the animal products (Saberi *et al.* 2006). Corn is cultivated widely all over the world due to its high compatibility with different climate conditions (Amiri *et al.* 2009). However, corn is highly sensitive to drought (Caker, 2004) which caused a problem for farmers in arid and semi-arid regions to supply corn water requirement during its growing season. Thus, farmers tended to use irrigation systems with high efficiency due to global water shortage and a significant increase in the water costs. Karimi & Garmkchi (2008) investigated the performance of drip irrigation system in a maize field and its consequent effects on the corn WUE Gazvin city. They reported that the water used by corn during growth season varied among 6386 to 8494 m^3 which caused WUE to be among 0.88 to1.52 kg/m^3.

Alfalfa economic water productivity

Table 13 shows that the amount of water use and yield of alfalfa were 6900 m^3 ha^{-1} and 10800 kg ha^{-1}, respectively. By dividing the yield by the water use, the barely WUE was 1.56 kg m^{-3}. For the interest rate of 20 percent, the total water costs for barely production was 4607130 Riyals ha^{-1} while the net income was 32355870 Riyals per ha^{-1} (Table 10). Dividing the net income by the amount of water use, the economical water productivity for barely was WPe=9037 Riyals per cube meter of water use (Table 14).

Table 13. Yield, water use and WUE of Alfalfa.

Yield (Kg/ha)	Water use (m^3/ha)	WUE (Kg/m^3)
10800	6900	1.56

Table 14. economical water productivity (Wpe) and the related components for Alfalfa.

Pc * (Rial/kg)	C (Rial)	NPBD (Rial)	WPe: (Rial/m^3)
6200	4607130	62252870	9037

Pc is the Price of the product is determined by its quality and the sale time for each farm, C is the total production cost, WPe is the economic water productivity and NPBD is the net income per unit volume of water use

Haidari & Haghayeghi (2001) calculated the WUE of different agricultural products based on the obtained data in two national projects for different parts of Iran. For alfalfa, the given results under furrow irrigation was compared with those under conventional irrigation. Results showed that of the amount of water used under furrow irrigation was about 12000 m^3/ha with an average yield of 10 ton in the west Azarbeyjan. Also, these researchers demonstrated the significant effect of irrigation management method had WUE. They mentioned that unsuitable water management is the main reason for low WUE in many parts of Iran.

Prioritize the selected crops for cultivation

Regarding the water shortage and high water costs in the study area, the priority for cultivation is to the crops which has both maximum income and high economic water productivity (Islami *et al.* 2008). Thus, the four selected crops were prioritized for cultivation in the study area based on their WPe. Fig. 2 shows that the highest WPe belonged to corn (10004 Riyals m^{-3}) followed by barely (9732 Riyals m^{-3}). Also, alfalfa had the lowest WPe (9037 Riyals m^{-3}) in the study area. Overall, the optimal cropping pattern would be corn, barely, wheat and alfalfa, respectively.

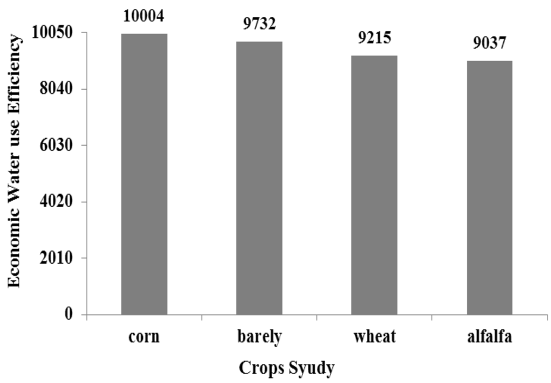

Fig. 2. Prioritizing the selected crops for cultivation based on the Wpe.

Conclusion

In this research, the concept of water use efficiency (WUE) and economic water productivity (WPe) was applied to prioritizing four selected crops in Rayen city; including corn, wheat, alfalfa and barely. Result showed that the lowest and the highest WUE was for wheat (0.94 kg m^{-3}) and alfalfa (1.56 kg m^{-3}). Also, corn with net income of about 75 million Riyal ha^{-1} and barely with net income of about 40 million Riyal ha^{-1} took the first and the last place, respectively, with respect to net income. Thus, corn WPe was higher than wheat and barley. So that corn cultivation would led to higher benefits in compare with the other crops in the study area. Based on the results, corn cultivation is encouraged due to high net income, WUE and WPe.

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