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Water capture efficiency, use efficiency and productivity in sole cropping and intercropping of rapeseed, bean and corn

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Abstract

In order to evaluate water capture, use efficiency and productivity in sole and intercropping systems of rapeseed (Brassica napus L.), bean (Phaseolus vulgaris L.) and corn (Zea mays L.), an experiment was conducted in two growing seasons of 2007-2008 and 2008-2009 in research field of faculty of agriculture, Ferdowsi University of Mashhad, Iran. The experiment was conducted as a randomized complete block design with three replications and six treatments. Treatments included monoculture of rapeseed (sown 23 September), bean and corn (sown in 30 April) as sole cropping and also simultaneous double cropping of bean and corn (sown in 30 April), two stage relay intercropping of rapeseed (sown in 23 September) and corn (sown in 30 April) and finally three stage relay intercropping of rapeseed (sown in 23 September), bean (sown in 9 April) and corn (sown in 30 April). Intercropping combinations showed positive and significant (P≤0.01) effect on water capture efficiency compared with sole cropping treatments. Double cropping had the maximum value of this index as 0.56 mm/mm. There was superiority for double cropping in water use efficiency and productivity for species in treatments, also among treatments significantly (P≤0.01) because of its higher seed yield. The values of land equivalent ratio for intercropping combinations were more than one (LER>1). This confirmed that they used land more efficient compared to sole cropping treatments from viewpoint of resources use and yield production. Rapeseed sole cropping and double cropping showed the highest values of economic productivity of irrigation water (EP) as 3.95 and 2.53 Tooman per ha production income/Tooman per ha water expense, respectively. Totally, it seems that double cropping in most cases was superior to other treatments.

Keywords: economic productivity of irrigation water (EP), fall sowing, land equivalent ratio (LER), seed yield.

1. Introduction

Water supply and its maintaining in the soil are influenced by environment, plant and management various factors (Soltani & Faraji, 2008). Management factors like applying of appropriate sowing date, proper density and using intercropping systems and plant breeding influence water use efficiency via affecting on yield, evapotranspiration (ET) or

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both of them (Tsubo et al., 2001). Totally, water use efficiency is influenced by different factors including climate, water, carbon dioxide, air temperature, air moisture, soil characteristics, photosynthetic pathway, plant species, variety, length of growth period, plant stomata behavior, leaf size, leaf structure and leaf arrangement, (Schott et al., 1994; Stanhill, 1986). Although, water supply is necessary for achieving sufficient yield, but characteristics like water capture efficiency, water use efficiency and water productivity (the multiplying of water capture efficiency and water use efficiency) are specially important (Ritchie & Basso, 2007). Caviglia et al. (2004) considered water capture efficiency as the ratio of seasonal eavapotranspiration (ET) to the value of available water during season or year. They estimated the value of water capture efficiency for soybean 0.65-0.47 based on seasonal calculations and 0.28-0.51 based on year calculation and for wheat 0.41-0.65 and 0.26-0.36 based on seasonal calculations and year calculation, respectively (Caviglia et al., 2004). Passioura (2006) believed that most of plant physiologists and biochemists assume that water use efficiency is related to gas exchange of a leaf, but from viewpoint of crop physiologists and meteorologists, this concept is extended to the gas exchange level of a canopy. Some scientists (Soltani & Faraji, 2008) defined physiological water use efficiency (WUE_p) or transpiration efficiency (TE) as the value of produced dry matter by plant per the value of used water during transpiration process. Transpiration efficiency shows the amount of dry matter produced by plant per each unit of used water in transpiration (Equation 1).

Equation (1): WUE_p= TE= A/T=K/VPD

In this equation, A is the amount of produced dry matter or biological yield (BY), T is plant transpiration, K is plant coefficient and VPD is decrease of atmosphere steam pressure. Caviglia et al. (2004) calculated water use efficiency based on shoot dry matter produced per each unit of evapotranspiration. They estimated the value of water use efficiency for soybean 1.64-4.08 g/m^2/mm based on dry matter and 0.73-0.92 g/m^2/mm based on seed yield. According to their estimations, these values for wheat were 4.27-4.38 g/m^2/mm based on dry matter and 1.18-1.34 g/m^2/mm based on seed yield (Caviglia et al., 2004).

Caviglia et al. (2004) evaluated the water productivity for soybean in seasonal scale 1.07-1.90 g/m^2/mm based on dry matter and 0.43-0.47 g/m^2/mm based on seed yield. In their study, these values in year scale for soybean in sole cropping were 0.83-1.16 and 0.26-0.37 g/m^2/mm based on dry matter and seed yield, in turn. They reported these values for wheat in seasonal scale 1.79-2.80 g/m^2/mm based on dry matter and 0.48-0.88 g/m^2/mm based on seed yield. In their study, these values were determined for wheat in year scale 1.15-1.57 g/m^2/mm and 0.31-0.49 g/m^2/mm (Caviglia et al., 2004).According to the report of Hulugalle and Lal (1986) there was more seed yield of corn and pigeon pea in intercropping compared to sole cropping in suitable rainfall conditions in western Nigeria. They assumed that enhancing of water use efficiency in intercropping was the reason of this result. Ghosh et al. (2006) reported that water use efficiency in intercropping of soybean-sorghum was more than that in soybean at sole cropping. The reason was improvement in root growth in intercropping compared to sole cropping.

Concerning to water shortage in dry land areas and ecological and agronomical importance of intercropping systems related to optimize utilization of water, this experiment conducted for evaluating water capture efficiency, water use efficiency, and water productivity in sole cropping and intercropping of three crops including rapeseed, bean, and corn.

2. Material and methods

This experiment was conducted in two growing seasons of 2007-2008 and 2008-2009 in research farm of faculty of agriculture, Ferdowsi University of Mashhad which is located in latitude of 36° and 16' north and longitude of 59° and 38' east with an altitude of 985m above the sea level in a loamy soil. The experiment carried out in a randomized complete block design with three replications and six treatments. Treatments included three sole cropping systems and three intercropping combinations. Sole cropping systems included sole cropping of rapeseed[1] (sown 23 September), bean[2] and corn[3] (sown in 30 April). Intercropping combinations included simultaneous double cropping of bean and corn (sown in 30 April), two stage relay intercropping of rapeseed (sown in 23 September) and bean plus corn (sown in 30 April) and finally three stage relay intercropping of rapeseed (sown in 23 September), bean (sown in 9 April) and corn (sown in 30 April). Modena cultivar of rapeseed and Derakhshan cultivar of bean and late matured 704 cultivar of corn used.

Farm operations carried out according to the conventional practices in the area. Crops sowed in plots of 3m×4m with 1m distance between each plot. Plants were cultivated in rows of 50cm apart with plant density of 20, 14 and 7 plant/m^2 for rapeseed, bean, and corn, respectively. There were six rows in each plot. In intercropping plots, species were sown in alternating single rows. Triple super phosphate and potassium sulfate fertilizers were applied pre plant with a rate of 100 and 150 kg/ha, respectively. Also, urea fertilizer at a rate of 150 kg/ha as manual in two splits in rapeseed treatments (post plant and at Mar. 13) and corn sole cropping (post planting and at six leaves stage), was applied. Irrigation was applied as required. The harvesting date of rapeseed in monoculture was 29 May 2008 & 6 June 2009, and in two stage relay intercropping and three stage relay intercropping was 2 June 2008 & 10 June 2009. The harvesting date of bean in sole cropping was 29 August 2008 & 5 September 2009, and in intercropping treatments was 5 September 2008 & 20 September 2009. Corn was harvested in 20 August 2008 & 28 August 2009 in sole cropping, and was harvested in 28 August 2008 & 8 September 2009 in intercropping treatments.

At the end of growth season, seed yield of each species at each plot measured. The value of evapotranpiration (ET) obtained by multiplying of evapotranpiration of source plant in Mashhad region and plant coefficient in different growth stages by OPTIWAT software (Alizadeh & Kamali, 2008). The amount of total used water (TWU) was recorded by applying of a bulk counter (0.0001 m^3) for each treatment throughout irrigation stages.

Water capture efficiency, use efficiency, and productivity based on seed yield were calculated by the following equations:

Equation (2): Water capture efficiency (C_{WAT})= total value of evapotranspiration (ET) /total used water (TWU) (Caviglia et al., 2004).

Equation (3): Water use efficiency based on seed yield (WUE_{SY})= seed yield/total evapotranspiration (Ghosh et al., 2006).

[1] *Brassica napus*
[2] *Phaseolus vulgaris*
[3] *Zea mays*

Equation (4): Water productivity based on seed yield (WP_{SY})= C_{WAT} × WUE_{SY} (Passioura, 2006).
In order to calculate of water capture efficiency for each combination, total base plant coefficients for species in each combination (KC) (with attending to phonological stage of considered species during season) was multiplied in evapotranspiration value. Then, total evapotranspiration of species in considered combinations during growth season was calculated and this value was divided to total incident water (including irrigation and rainfall) for considered combination during season.
In order to calculate of water use efficiency based on seed yield, seed yield of the species in each combination was divided to total evapotranspiration by considering species in that combination during growth period (Equation 3).
In order to calculate of water productivity based on seed yield for each combination, water use efficiency based on seed yield of each combination multiplied in water capture efficiency of that combination (Equation 4). Calculating of water capture efficiency, use efficiency, and productivity for each species in each combination was done as determining of these parameters for each combination but in calculating of each parameter, only considered species in each combination was entered.
Land Equivalent Ratio (LER) based on capture efficiency, use efficiency and productivity was calculated by the following equation: Equation (5): $\mathrm{LER} = \sum_{n=1}^{m} \mathrm{Yi/Yii}$
In this equation, Yi is water capture efficiency, use efficiency, and productivity based on seed yield of a species in intercropping, and Yii is water capture efficiency, use efficiency, and productivity based on seed yield of same species in sole cropping.
In order to compare of economical value in combinations from the viewpoint of using of irrigated water, index of water Economical Productivity (EP) based on seed yield for each treatment was calculated by the following equation:
Equation (6): EP= (P1Y1+P2Y2+…)/P3V
In this equation, EP is water economical productivity (ratio of Tooman for yield income/ha/Tooman water cost/ha), P1 is the price of first crop (Tooman/ha), Y1 is seed yield of first crop in intercropping (kg/ha), P2 is the price of second crop (Tooman/ha) in intercropping, Y2 is seed yield of second crop (kg/ha) in intercropping, P3 is water cost (Tooman/ha) and V is the volum of used water in intercropping (m^3/ha).
Statistical analysis was done by Excel and Optiwat, Mstat-C and PowerPoint softwares. Duncan's multiple range tests was used for means comparison.

3. Results and discussion

3.1. Precipitation, irrigation and evapotranspiration in treatments

Rainfall received in the treatments containing rapeseed (rapeseed sole cropping and relay intercropping combinations) were more than the other treatments because of the fall sowing (Table 1). In these treatments, the growth duration began from September and so the precipitation period was longer than that in other treatments.
The amount of irrigation and evapotranspiration for sole rapeseed was less than that in other treatments (Table 1). This was due to the occurrence of growth period in cold and wet seasons in which needed less water and evapotranspiration (Soltani & Faraji, 2008).

Table 1: The content of precipitation, irrigation and evapotranspiration in growth period of treatments (Mean of two years 2007-8 & 2008-9)

	Water content (mm)		
Treatments	**Precipitation**	**Irrigation**	**Evapotranspiration**
Sole rapeseed	208	534	211
Sole bean	19	1350	329
Sole corn	19	1253	399
Double cropping	19	1435	769
Two stage relay intercropping	210	1737	992
Three stage relay intercropping	210	1791	1005

The most value of irrigation and evapotranspiration recorded in relay intercropping combinations (Table 1). The growth period of such treatments started in September when rapeseed planted and lasted until summer when bean and corn harvested. The content of irrigation and evapotranspiration in sole cropping of bean and corn and double cropping was relatively high (Table 1), because of happening of their growth period in warm seasons (late spring and summer). The amount of evapotranspiration in intercropping combinations was more than that in sole cropping treatments (Table 1), because it was sum of the value of evapotranspiration of two or three crops.

3.2. Water capture efficiency

Based on results, intercropping combinations showed more water capture efficiency compared with sole cropping treatments, significantly (P≤0.01) (Fig.1). Among intercropping combinations, double cropping showed the maximum of water capture efficiency (0.56 mm/mm) that was significantly (P≤0.01) more than that in other intercropping treatments (Fig. 1). Among sole cropping treatments, corn showed the maximum value of this index (0.33 mm/mm) that was significantly more than that in other sole cropping treatments (Fig. 1).

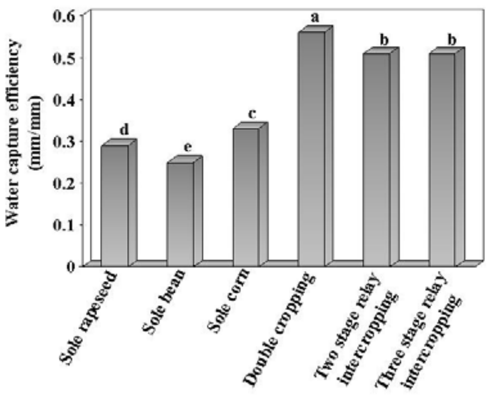

Fig. 1: *Water capture efficiency in treatments; (Mean of two years 2007-8 & 2008-9)*

It seems that the reason of enhancing of water capture efficiency in intercropping combinations compared to sole cropping treatments (Fig.1) was increase in evapotranspiration in intercropping combinations (Table 1) due to more crop species.

Some scientists believe that ecosystems containing more diversity use resources (such as water) more efficiently (Hulugalle & Lal, 1986; Walker & Ogindo, 2003). Sekiya and Yano (2004) during the study on intercropping of corn and pigeon pea (*Cajanus cajan*) observed bringing up water from deep soil by deep roots of pigeon pea and giving it to corn. Tsubo et al. (2001) stated that intercropping of cereals-legumes in low water regions were more successful for food production compared to sole cropping of such crops. Walker and Ogindo (2003) reported that in intercropping systems, canopy is more condensed with more shading, so evaporation is lower and then water use is more efficient. Because of variation in root structure and physiology of plants in mixed cultures, complementary effects on resource uptake occurs (Vandermeer, et al., 1998).
As previously explained (Table 1), total input water in relay intercropping combinations was more than that in double cropping. Therefore, this can be the reason for reduction of water capture efficiency in relay intercropping combinations compared to double cropping (Fig. 1). Also, because of being lower evapotranspiration in rapeseed sole cropping compared to corn sole cropping (Table 1), water capture efficiency in corn sole cropping compared to rapeseed sole cropping was more, significantly (Fig.1).

4. Water use efficiency
4.1. Water use efficiency of species in treatments

Water use efficiency for species in all sole cropping treatments, also in double cropping was significantly ($P \leq 0.01$) more than that in other combinations of crops (except for bean in two stage relay intercropping) (Table 2). The rate of this index for rapeseed in sole cropping compared to that in two and three stage relay intercropping combinations was 1.52 and 1.57 times, respectively. This value for bean in sole cropping compared to that in three-stage relay intercropping combination was 2.64 times, and for corn in sole cropping compared to

Table 2: Water use efficiency in species ($g/m^2/mm$) for sole and intercropping treatments (Mean of two years 2007-8 & 2008-9)

Treatments	Rapeseed	Bean	Corn
Sole cropping	0.96 a	0.37 a	1.25 a
Double cropping	-	0.33 a	1.15 a
Two stage relay intercropping	0.63 b	0.20 ab	0.47 b
Three stage relay intercropping	0.61 b	0.14 b	0.47 b

Means in each column with at least one common letter are not significantly different at $\alpha = 0.01$

that in two and three- stage relay intercropping combinations was 2.66 times (Table 2).
Increasing of water use efficiency for corn in sole cropping compared to that in intercropping combinations (Table 2) was due to lower evapotranspiration for corn in sole cropping because of shorter growth period of this crop and more biological yield, too (Table 3). Soltani and Galeshi (2002) believe that agronomic management improvement causes reduction in evaporation and increase in transpiration, and so these result in water use efficiency enhancing.

The superiority of water use efficiency for corn in double cropping compared to that in relay intercropping combinations (Table 2), probably was due to its more seed yield (Table 3). Superiority of water use efficiency for rapeseed in sole cropping compared to that in relay intercropping combinations (Table 2), was due to its more seed yield in sole cropping (Table 3). Such circumstances can be the reason for superiority of water use efficiency for bean in sole cropping and double cropping compared to that in three-stage relay intercropping (Table 2), too.

Table 3: Yield and yield components of species in treatments (Mean of two years 2007-8 & 2008-9)

Species in treatments	Pod or cob no./plant	Seed no./pod or cob	100 seed weight (g)	Seed yield (kg/ha)	Biological yield (kg/ha)	Harvest Index (%)
Rapeseed in 1sole cropping	238.7 b	15.83 b	0.38 a	2011 a	9307 a	0.23 a
Rapeseed in two stages relay intercropping	740.3 a	21.50 a	0.29 b	1404 b	8475 a	0.19 b
Rapeseed in three stages relay intercropping	739.9 a	20.50 a	0.28 c	1333 b	8753 a	0.19 b
Bean in sole cropping	15.83 a	2.31 a	28.67 a	1192 a	3365 a	0.36 a
Bean in double cropping	15.67 a	2.04 ab	31.89 a	1140 a	3266 a	0.37 a
Bean in two stages relay intercropping	6.67 b	1.85 ab	36.44 a	704.4 b	2111 b	0.33 a
Bean in three stages relay intercropping	6.39 b	1.42 b	31.56 a	484.7 b	1694 b	0.30 a
Corn in sole cropping	1.97 a	347.1 b	23.91 a	5000 a	17834 a	0.29 a
Corn in double cropping	2.27 a	318.1 b	22.45 a	4833 a	16350 a	0.30 a
Corn in two stages relay intercropping	2.10 a	210.6 a	18.77 ab	1950 b	6942 b	0.28 a
Corn in three stages relay intercropping	2.20 a	217.2 a	15.65 b	1965 b	7489 b	0.27 a

Means in each column for each section with at least one common letter are not significantly different at $\alpha = 0.01$

In this experiment, corn germination in relay intercropping combinations occurred under rapeseed shade. Therefore, there was delayed and weak germination and subsequently decrease in plant appearance and density which caused reduction in yield of corn in relay intercropping combinations, at last (Table 3). Therefore, water use efficiency of corn in relay intercropping combinations decreased significantly compared to that in sole and double cropping (Table 2). Higher water use efficiency of corn in all treatments compared to bean (Table 2) can be due to its different photosynthetic pathway (Stanhill, 1986). Photosynthetic pathway as one of the most stable and most effective metabolic processes on water use efficiency is considered. Plants having C4 photosynthetic pathway can preserve their photosynthetic ability in lower stomata conductance. This relates to their more efficient mechanism for carbon dioxide absorption and high ability for using radiation. It is the reason for twice water use efficiency in C4 photosynthetic pathway compared to it in C3 ones (Araus et al., 2002). Researchers showed the value of water use efficiency in crops having C3 photosynthetic pathway as 1-3 and in C4 ones as 2-5 g CO_2 per kg used water (Condon et al., 2004).

4.2. Water use efficiency in treatments

Among intercropping combinations from viewpoint of water use efficiency, double cropping showed the maximum as 0.78 g/m²/mm and showed significant difference compared to relay intercropping combinations (Fig. 2). Among sole cropping treatments from the viewpoint of water use efficiency, corn as 1.25 g/m²/mm showed the maximum with significant difference ($P \leq 0.01$) compared to other sole cropping treatments (Fig. 2).

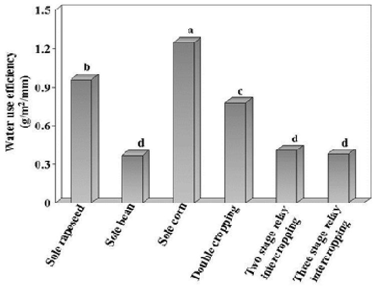

Fig. 2: *Water use efficiency in treatments (Mean of two years 2007-8 & 2008-9)*

It seems that the superiority of water use efficiency in rapeseed sole cropping compared to bean sole cropping (Fig. 2) is related to more yield and lower evapotranspiration in sole cropping of rapeseed (Table 1&3). The superiority of water use efficiency in sole cropping of corn compared to bean sole cropping (Fig. 2), also superiority of water use efficiency in intercropping combinations compared to bean sole cropping (Fig. 2) is related to more yield in corn (Table 3). The same reason can explain the superiority of water use efficiency in double cropping compared to relay intercropping combinations (Fig. 2) and superiority of water use efficiency in corn sole cropping compared to rapeseed sole cropping (Fig.2).

5. Water productivity

5.1. Water productivity of species in treatments

Rapeseed in sole cropping showed the maximum value of water productivity in which it was significantly ($P \leq 0.01$) more than that in relay intercropping combinations (Table 4). Also, the value of this index for corn in sole cropping and double cropping were significantly ($P \leq 0.01$) more than that in relay intercropping combinations (Table 4).

Table 4: Water productivity in species (g/m²/mm) for sole and intercropping treatments (Mean of two years 2007-8 & 2008-9)

Treatments	Rapeseed	Bean	Corn
Sole cropping	0.28 a	0.09 a	0.41 a
Double cropping	-	0.09 a	0.39 a
Two stage relay intercropping	0.18 b	0.05 a	0.16 b
Three stage relay intercropping	0.18 b	0.04 a	0.16 b

Means in each column with common letter are not significantly different at $\alpha = 0.01$

The superiority of water productivity for rapeseed in sole cropping compared to that in relay intercropping combinations was 1.55 times (Table 4). Corn showed superiority as 2.56 and 2.44 times in sole cropping and double cropping, respectively compared to that in relay intercropping combinations from viewpoint of water productivity (Table 4). Since water productivity is result of water capture and water use efficiency (Equation 4), it seems that the superiority of water productivity for rapeseed in sole cropping compared to that in relay intercropping combinations and superiority of water productivity for corn in sole cropping and double cropping compared to that in relay intercropping combinations (Table 4) is due to superiority of water use efficiency for rapeseed in sole cropping and for corn in sole and double cropping (Table 2).
Caviglia et al. (2004) believe that since productivity is result of absorbed resources by crops and resources use efficiency for dry matter production, so productivity will increase if resources capture and resources use improve.

5.2. Water productivity in treatments

Among cropping combinations from viewpoint of water productivity, double cropping was superior to relay intercropping combinations, significantly (P≤0.01) (Fig. 3). Among sole cropping treatments, corn sole cropping showed the maximum value of water productivity and showed significant differences (P≤0.01) compared to other sole cropping treatments (Fig. 3).

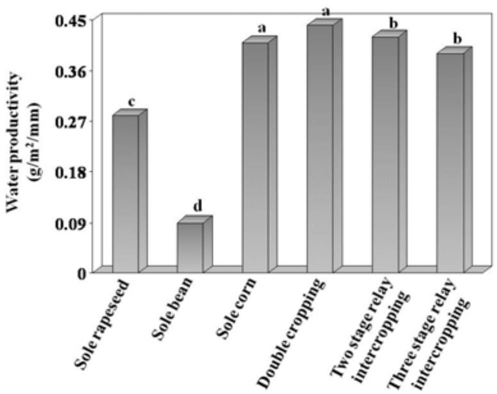

Fig. 3: *Water productivity in treatments (Mean of two years 2007-8 & 2008-9)*

Superiority of water productivity in sole cropping of rapeseed and corn compared to bean sole cropping (Fig. 3) was due to superiority of water capture efficiency and water use efficiency in sole cropping of these two crops (Fig. 1 & 2). There was the same reason for superiority of water productivity in intercropping combinations compared to bean sole cropping, superiority of water productivity in double cropping compared to relay intercropping combinations and superiority of water productivity in corn sole cropping compared to rapeseed sole cropping (Fig. 3). The advantage of water productivity in intercropping combinations compared to rapeseed sole cropping (Fig. 3) was only for superiority of water capture efficiency in intercropping combinations (Fig. 1).

6. Land equivalent ratio (LER)

The value of LER in all intercropping combinations was more than one (LER>1) (Table 5). Therefore, we can conclude that intercropping combinations used land more efficient compared to sole cropping treatments from viewpoint of resources use and yield production. Double cropping was superior to relay intercropping combinations in some cases (Table 5).

Table 5: Land Equivalent Ratio in intercropping treatments
(Mean of two years 2007-8 & 2008-9)

Characteristic	Intercropping combination		
	Double cropping	Two stage relay intercropping	Three stage relay intercropping
Water Capture Efficiency	2.08 b	3.15 a	3.07 a
Water Use Efficiency (BY)	1.7 a	1.98 a	1.79 a
Water Use Efficiency (SY)	1.86 a	1.64 ab	1.38 b
Water Productivity (BY)	1.9 a	2.06 a	1.81 a
Water Productivity (SY)	1.92 a	1.71 ab	1.41 b

Means in each row with at least one common letter are not significantly different at α= 0.05
BY: based on biological yield
SY: based on seed yield

Ghosh et al. (2006) believe that LER can be considered as a proper evaluation for utilize efficiency of environmental resources like radiation, nutrient and rainfall in intercropping. Many other scientists confirmed the superiority of intercropping by calculating of LER (Baumann et al., 2001; Khosravi, 2006).

7. Economic productivity of irrigation water (EP)

Based on results, rapeseed sole cropping among sole cropping treatments showed the maximum EP as 3.95 Tooman per ha production income/Tooman per ha water expense with significant difference (P≤0.01) compared to other treatments (Fig. 4). Among intercropping combinations, double cropping showed the maximum EP as 2.53 Tooman per ha production income/Tooman per ha water expense compared to relay intercropping

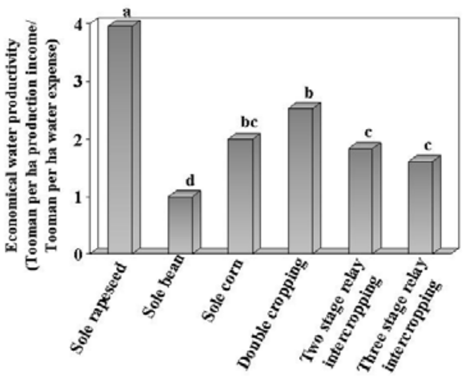

Fig. 4: *Economical water productivity in treatments (Mean of two years 2007-8 & 2008-9)*

combinations with significant difference ($P\leq0.01$) (Fig. 4).
The privilege of rapeseed sole cropping compared to other sole cropping treatments was due to its less irrigation water requirement (Table 1) because of the coincidence of growth stages in fall and winter. Bean sole cropping produced the least amount of seed yield compared to other sole cropping treatments (Table 3), so it had the least EP. Among intercropping combinations, double cropping showed the maximum of EP (Fig. 4). The reason was reduction of input irrigation water in double compared to relay intercropping combinations (Table 1) and higher seed yield in double cropping (Table 3).

Conclusion

Based on results, intercropping combinations showed positive and significant ($P\leq0.01$) effects on water capture efficiency compared with sole cropping treatments, in which double cropping had the maximum value of this index. Values of water use efficiency and productivity for species in treatments, also among treatments showed the superiority of double cropping because of its higher seed yield. Intercropping combinations showed land equivalent ratio as more than one (LER>1). This revealed that they used land more efficient compared to sole cropping treatments from viewpoint of resources use and yield production. Rapeseed sole cropping and double cropping showed the highest values of economic productivity of irrigation water (EP) as 3.95 and 2.53 Tooman per ha production income/Tooman per ha water expense, respectively. Totally, double cropping in most cases showed superiority compared to other treatments.

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