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WATER PRODUCTIVITY ANALYSIS OF SOME IRRIGATED CROPS IN IRAN

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SUMMARY- In the Mediterranean countries, the great challenge of the agricultural sector is to produce more crop from less water, which can be achieved by increasing crop water productivity (WP). It is, further, necessary to determine the values of WP for different agricultural crops and apply new technologies and management practices in order to enhance and optimize the value of this index. The present paper aims to determine the range of water productivity values for a number of crops in Iran. For that, 10 crops were selected for investigation that included wheat, barley, rice, sugar beets, Maize, $cotton_{seed}$, alfaalfa, potato, tomato, and sesame. Analysis was based on results obtained from 67 field studies carried out in 13 provinces across Iran from 1993 to 2006. The findings showed crop water productivity for each of the above crops ranged over 1.62, 2.37, 0.42, 0.53, 1.17, 0.61, 0.89, 2.74, 6.77, 0.11 kgm^{-3}, respectively. Investigations also revealed that deficit irrigation could be recommended as the most efficient management practice to enhance crop water use efficiency in the region. Extensive research is, therefore, recommended to determine appropriate deficit irrigation management scenarios and to identify the reactions by strategic crops to the different management scenarios adopted. The analysis of the results indicate that selection of an appropriate practice and accurate irrigation scheduling will play important roles in improving water use efficiency. Application of the linked GIS-remote sensing and water balance models, application of the findings of genetic and breeding research on strategic crops, and selection of suitable plant species and varieties are among the most important approaches and tools for achieving improved crop water productivity.

Key words: Barley, cotton, crop water productivity, maize, rice, sugar beets, wheat

RESUME- *Dans les pays méditerranéens, le grand défi du secteur agricole est de produire plus pour recadrer de moins d'eau, qui peut être atteint en augmentant la productivité de besoin en eau des plantes (WP). C'est, plus, nécessaire de déterminer les valeurs de WP pour les différentes cultures agricoles et appliquer des nouvelles technologies et les pratiques de gestion afin d'améliorer et optimiser la valeur de cet index. Le présent papier vise à déterminer la gamme de valeurs de productivité de besoin en eau pour plusieurs cultures en Iran. Pour cela, 10 cultures ont été choisies pour l'investigation inclut le blé, l'orge, le riz, les betteraves à sucre, le Maïs, la graine de coton, alfaalfa, la pomme de terre, la tomate, et le sésame. L'analyse a été basée sur des résultats obtenus de 67 études de champ qui ont été exécuté dans 13 provinces en Iran depuis 1993 à 2006. Les conclusions ont montré que la productivité des besoins en eau pour chacune des cultures déjà mentionnées est situé respectivement 1,62, 2,37, 0,42, 0,53, 1,17, 0,61, 0,89, 2,74, 6,77, 0,11* kgm^{-3}*. Les investigations qui ont révélé aussi l' irrigation déficitaire pourrait être recommandée comme la pratique de la gestion la plus efficace pour améliorer l'efficacité d'usage d'eau de plante dans la région. Une recherche extensive est donc recommandée pour déterminer les scénarios de gestion de l'irrigation déficitaire appropriée et identifier les réactions par les cultures stratégiques aux différents scénarios de gestion adoptés. L'analyse des résultats indique que la sélection d'une pratique appropriée et la planification d'irrigation précise jouera des rôles importants dans l'amélioration de l'efficacité d'usage d'eau. L'application de la sensation GIS-à distance liée aux modèles des bilans hydriques, l'application des conclusions de recherche génétique et élevant sur les récoltes stratégiques, et la sélection d'espèce de plante convenable et de variétés est parmi les approches les plus importantes et les outils pour atteindre l'amélioration de la productivité de besoin en eau de plante.*

Mots clés : *L'orge, le coton, la productivité de besoin en eau de plante, le maïs, le riz, les betteraves à sucre, le blé.*

INTRODUCTION

The great challenge of the agricultural sector is to produce more food from less water, which can be achieved by increasing water use efficiency. Hence, the ideas of drought resistance and drought tolerance are giving way in the agricultural world to the idea of water productivity (WP). This change is great advance because the latter can be quantified, with unit of amount of crop yield per volume of water supplied. Water productivity expresses the value or benefit derived from the use of water, and includes essential aspects of water management. Hence, is very relevant for such regions Its substantial and sustainable improvements can only be achieved through integrated farm resources management. Kijne et al. (2003) provide several strategies for enhancement of WP by integrating varietal improvement and better resources management at plant level, field level and agro-climatic level. Examples of options and practices that can be taken are: increasing the harvest index, improving drought and salinity tolerance, applying deficit irrigation water reuse.

Data on WP across scales are useful parameters to assess whether water outflows upstream are effectively reused downstream. Unfortunately, there are few reliable data on the WP at different scale levels within the same system. Bastiaanssen et al. (2002) used remote sensing and GIS technologies to analyzed crop WP at various irrigation system scales in the Indus basin Pakistan. They found high variability in crop WP at scale of small canal command areas. Tuong and Bouman (2003) also found that WP for rice at scale levels larger than the field varies widely but than at the field level. Tennakoon and Milory (2003) to use actual farm management data to assess the Australian cotton industry's performance. The observed average WP of $cotton_{lint}$ was 0.25 kgm^{-3}, which compare well internationally. Gilham et al.(1995) estimated the WP for cotton in a number of developing countries to range from 0.03 to 0.1 kgm^{-3} . Zwart and Bastiaanssen (2004) based on a review of 84 literature sources with results of experiments found that the ranges of WP of wheat, rice, cotton and maize exceed in all cases those reported by FAO earlier. Globally measured average WP values per unit water depletion are 1.09, 1.09, 0.65, 0.23 and 1.80 kgm^{-3} for wheat, rice, $cotton_{seed}$, $cotton_{lint}$ and maize, respectively. The International Food Policy Research Institute (IFPRI) recently performed a study focusing on water productivity based on assumptions slightly different to those of FAO (Cia and Rosegrant, 2003). This study concluded that the average water productivity of rice will increase in the period 1995-2025 from 0.39 to 0.53 kgm^{-3} in developing countries and from 0.47 to 0.57 kgm^{-3} in developed countries. According to IFPRI, the average water productivity of all other cereals during the same period will increase from 0.56 to 0.94 kgm^{-3} in developing countries and from 1 to 1.32 kgm^{-3} in developed countries.

A profound WP analysis by Singh et al. (2006) was carried out at five selected farmer fields, two for wheat-rice and three for wheat-cotton, in India. The ecohydrological model SWAP in combination with field experiments were used to determine the required hydrological and biophysical variables. For instance, the WP_{ET}, expressed in terms of crop grain (or seed) yield per unit amount of evapotranspiration, varied from 1.22 to 1.56 kgm^{-3} for wheat among different farmer fields. The corresponding value for cotton varied from 0.09 to 0.31 kgm^{-3}. Hatfield et al. (2001) reviewed the effects of soil management on WP by modification of the soil surface, such as tillage and mulching, and by improvement in soil nutrient statues by adding nitrogen and/ or phosphorus. Many researchers studied the influence of irrigation water management on WP (e.g. Oktem et al., 2003; Yazar et al., 2002; Kang et al., 2000; Zhang et al., 1998).

Increasing public debate regarding the allocation of water resources within Iran has introduced a new level of significance to the issue of water use efficiency (WUE). Various studies have researched water use and yield relationship of specific crops, on specific locations, with water management practices. The current investigation summarizes the results of 67 field experiments that have been conducted over the last 13 years and tries to find a range of plausible values for 10 crops :wheat, barely, rice, sugar beet, maize, cotton, alfaalfa, potato, tomato, and sesame.

MATERIALS AND METHODS

For the present survey, the results from 67 field studies performed across Iran were used to investigate water crop productivity for the 10 crops of wheat, barley, rice, sugar beets, maize, cotton, alfaalfa, potato, tomato, and sesame (Abbasi et al., 2000; Afshar & Mehr Abadi, 2003; Arab Zade &

Tavakkoli, 2005; Azari, 2006; Baghani & Ghodsi, 2004; Baghani & Shojaat, 2002; Bahramlo, 2006; Ebrahimi Pak, 2001; Farhadi, 1998; Foroughi, 2006; Ghadami P.A., 2006; Gilani & Absalan, 2004; Golkar, 1998; Haghayeghi Moghadam et al., 2005; Heidari et al., 2006; Janbaz, 1996; Karimzadeh, 2006; Khoramian, 2002; Maaman push & Mousavi, 2006; Madeh Khaksar & Dahanzadeh, 2006; Moussavi Fazl, 2003; Nahvi et al., 2006; Rabizadeh, 2002; Rahimian, 1997; Rezaee & Nahvi, 2003; Salami, 2004; Sheikh Hosseini, 1996; Sheini Dashtgol et al., 2006; Sotudehnia, 2002; Taheri Ghannad et al., 2006; Tavakkoli, 1996; Tavakoli, 2006; Tavana, 1998; Torabi & Jahad Akbar, 2005; Vaziri, 2000; Vaziri, 1998; Yazdani et al., 2003; Zeighami Gol, 1998). For each study crop, the results from a select number of studies such as drought tolerance, yield assessment, water consumption rates of different crop varieties, application of different irrigation methods, and climatic adaptation were used. The regional distribution was selected in such a manner that the results could be generalized to the whole national scale. For this purpose, 13 provinces where these crops were grown as primary were selected and the results obtained over the years 1993 to 2006 were collected and analyzed. *Table 1* presents the number of studies, geographical locations, and the temporal range for each of the crops evaluated in this survey. Thus, irrigation management and quantity scenarios, irrigation system, geographical and temporal situations, and species and variety of the study crops were taken, in our study, as variables affecting crop water productivity. Using crop yields and actual water use rates, the productivity was computed as a ratio of yield (kg) to actual water use (m^3) from which its variations and average values were determined for Iran.

Table 1. Details of the study results used for each crop

Crop	No. of study	Location	Experimental year(s)
Wheat	13	Province of Khorasan, Eastern Azerbayjan, Kermanshah, Tehran, Kerman, Golestan, and Khuzistan	1993-2004
Barley	4	Province of Tehran, and Kerman	1993-2003
Rice	9	Province of Khuzistan, Gilan, and Mazandaran.	1997-2002
Sugar beet	9	Province of Khorasan, Isfahan, Tehran, Khuzistan, and Kermanshah	1995-2002
Maize	8	Province of Isfahan, Khorasan, Ghazvin, Tehran, and Kerman	1998-2004
Cotton	4	Province of Golestan, and Khorasan	1998-2001
Alfaalfa	4	Province of Chahar-Mahal & Bakhtiari, Khuzistan, Kerman, and Hamedan	1995-2003
Potato	6	Province of Hamedan, Kerman, and Khuzistan	2000-2006
Tomato	7	Province of Khorasan, Semnan, and Khuzistan	1996-2006
Sesame	3	Province of Tehran	1997

RESULTS AND DISCUSSION

Wheat and barley

For wheat, the results from 13 research projects were used in which the parameters irrigation, wheat variety, and temporal and spatial conditions served as variables. The 5 varieties used included the spring wheat (M-75-1-120), Sabalan dry farmed wheat, wheat (M-70-4), and Qods fall wheat. Spatially, studies had been carried out in the 7 provinces of Khorasan, Eastern Azerbayjan, Kermanshah, Tehran, Kerman, Golestan, and Khuzistan. The study period was 1993-2004. According to the analysis of the results, the variation range of the productivity for the wheat is 0.15-4 kgm^{-3} (Fig. 1a). The findings indicate that deficit irrigation of wheat has a considerable effect on enhancing its water productivity despite its relatively reduced yield. This is witnessed by a productivity level of 4 kgm^{-3} obtained in the study No. 7 carried out in Tehran Province where the irrigation water supplied was as low as 10% of the crop water demand. This is also confirmed by findings from most effective management practices to increase crop water productivity for wheat. The studies No. 3, 4, and 9. In other words, deficit irrigation could be regarded as one of the study also shows that, in the absence of an appropriate management system, irrigation method has no effective role in enhancing crop water productivity. For instance, the productivity obtained for one treatment in study No. 10 using a center-pivot sprinkler irrigation system with maximum water use efficiency was only 0.85 kgm^{-3}.

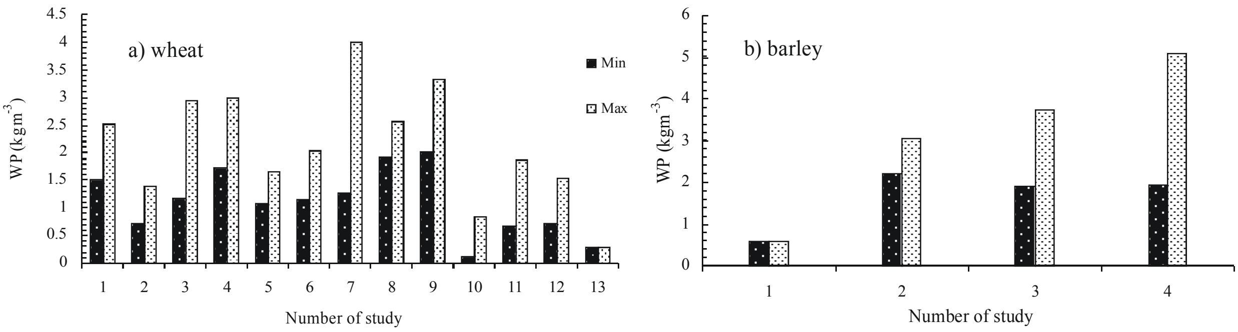

Fig. 1. WP values of wheat and barley in the selected studies

Results from 4 studies were used to evaluate the productivity index for barley. The studies had been conducted over the period 1993-2003 in Tehran and Kerman provinces, Iran. On the basis of our calculations, the productivity index of yield to water used for the crop ranged between 0.6 to 5.1 kgm^{-3} (Fig. 1b). In the case of barley, similar to that of wheat, deficit irrigation proved to play a significant role in enhancing the water productivity such that maximum productivity was obtained for the study and treatments in which irrigation water met only 20% of the crop water demand (5.1 kgm^{-3}).

Rice

The findings from 9 different studies were used to evaluate the productivity for rice. In all these studies, the parameters irrigation management, crop variety, time and space were different. The five varieties used included red, short grained Anbouri rice; red, medium-grained rice; LD183; Hashemi; Khazar (upland and lowland) rice; and Tarom. Temporally, they were grown in the years 1997 to 2002 in the three provinces of Khuzistan, Gilan, and Mazandaran. The analysis of the results revealed that the qualitative value of the productivity index for rice varied from 0.06 to 0.85 kgm^{-3} (Fig. 2). A study was conducted in Shavoor station in Khuzistan Province to investigate the effects of different surface irrigation regimes on the performance of the three varieties of LD138, medium, and short grained Anbouri. The study revealed that all the three varieties had the highest productivity index values in the treatment irrigated every other two days. In contrast, every other day and everyday irrigation schedules had the lowest productivity values. These results indicate that due to its high level of water saving, the every-other-two-days irrigation regime enhances the productivity index value despite its effect on reducing yield. In study No. 5 which was conducted in Mazadaran Province in order to select the best regulated deficit irrigation management practice for growing rice seedlings, different treatments with irrigation depths of 519 to 898 mm were used. The values for the water productivity obtained in these treatments were 0.58 and 0.33 kgm^{-3}. Study No. 7 aimed to compare the two furrow and sprinkler irrigation systems. Here it was found that the sprinkler irrigation system had a higher productivity value (0.85 kgm^{-3}) than the furrow irrigation method (0.75 kgm^{-3}). The above investigations additionally indicate the effect of different irrigation management scenarios aimed at deficit irrigation in increasing the productivity of rice. It need not be mentioned that the management must be accomplished accurately and based on research findings. The remarkable point in this regard is that given the high water demand of rice, crop species and variety have a greater effect on the productivity value than the irrigation method or regime.

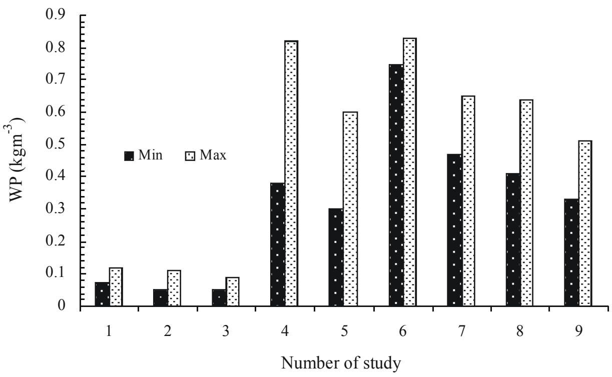

Fig. 2. WP values of rice in the selected studies

Sugar beets

The results from 9 studies were used for sugar beet. Irrigation management, space and time were the variables in these studies. The period was 1995-2002 and the studies had taken place in the 5 provinces of Khorasan, Isfahan, Tehran, Khuzistan, and Kermanshah. The results revealed that the productivity values for the root yield (RY) ranged over 1.65-10.7 kgm^{-3}; for sugar content (SY), 0.23-1.77 kgm^{-3}; and for white sugar content (W-SY), it varied over 0.16-1.7 kgm^{-3} (Fig. 3). In study No. 6 investigating the effect of furrow irrigation with single and twin-row plantings, it was revealed that the productivity value of treatments with twin rows was around twice as much as that in treatments with single rows. It must be mentioned that all the treatments in this study had the lowest value of crop water productivity among all the studies surveyed. The maximum water productivity for root yeild (10.7 kgm^{-3}) was obtained for one treatment in study No. 4 irrigated with sprinkler irrigation system. The productivity values for treatments irrigated by sprinkler and furrow systems were 4.14 and 6.11 kgm^{-3}, respectively.

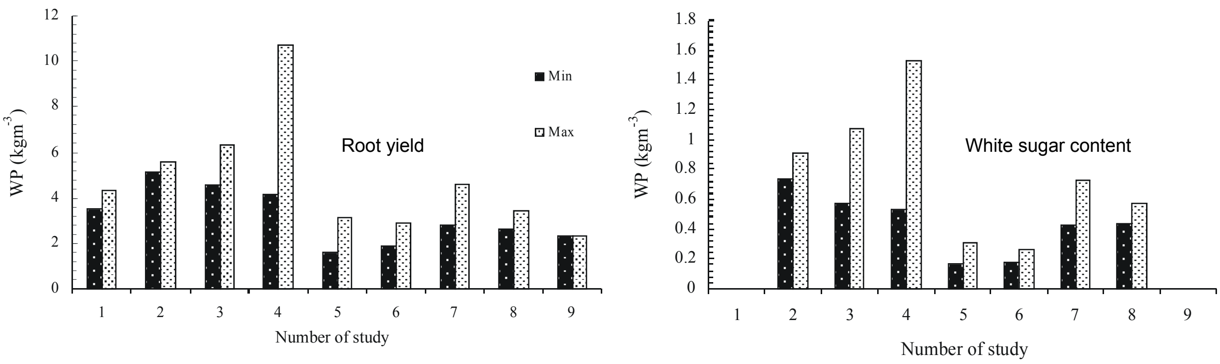

Fig. 3. WP values of sugar beet (RY, and W-SY) in the selected studies

Maize

The results from 9 studies were used for maize. Irrigation management, crop variety, space and time were the variables in these studies. The period was 1998-2004 and the studies had taken place in Isfahan, Khorasan, Ghazvin, Tehran, and Kerman provinces. According to our calculations, the maximum and minimum crop water productivity values obtained for the grain type of corn varied over 0.6-1.98 kgm^{-3} (Fig. 4). Maximum water productivity value belonged to study No. 3 in which irrigation scheduling was based on crop green cover as determined by infrared thermometer measurements. The variations in crop water productivity under the experimental conditions varied from 1.75 to 1.98

kgm^{-3}. These findings indicate that it is essential to employ appropriate models and methods of determining accurate times and quantities of irrigation for crop irrigation planning.

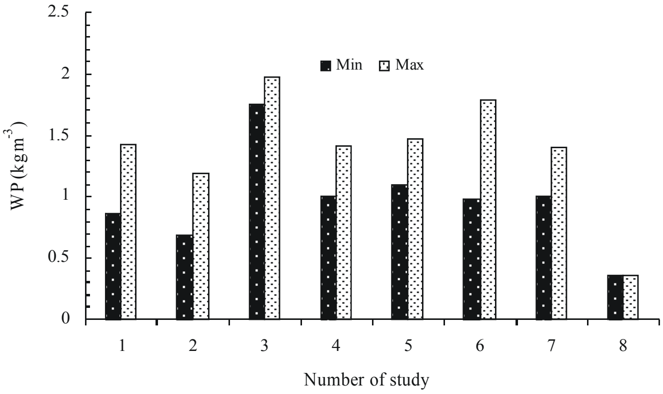

Fig. 4. WP values of maize in the selected studies

Cotton

The results from 4 studies were used for cotton. The period of the studies stretched over the years 1998-2001 and they were performed in Golestan and Khorasan provinces. According to our calculations, the variations of crop water productivity values obtained for cotton$_{seed}$ varied over 0.17-1.35 kgm^{-3} (Fig. 5), with its minimum obtained for the conventional furrow irrigation system in 1988 (Study No. 2). Study No. 1 in Golestan Province aimed to investigate the impact of deficit irrigation on crop. The results from these studies showed that although complete irrigation results in maximum crop yield, it has the lowest value of crop water productivity rate (0.76 kgm^{-3}) among all treatments and that the treatment irrigated by up to 50% of the crop water demand yielded the highest productivity level (1.35 kgm^{-3}).

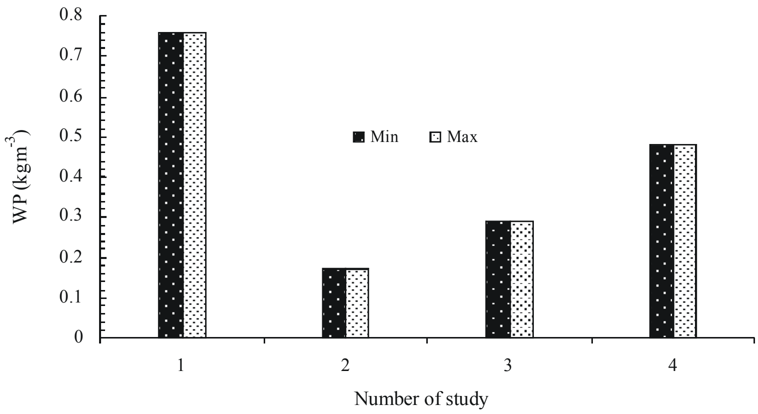

Fig. 5. WP values of cotton in the selected studies

Alfaalfa

The results from 4 studies were used for trefoil. The studies were conducted over the years 1995-2003 in Chahar-Mahal & Bakhtiari, Khuzistan, Kerman, and Hamedan provinces. The results showed a variation between 0.19 to 2.1 kgm^{-3} in crop water productivity for alfaalfa (Fig. 6). The maximum value of the index belonged to the treatment in which the water use was 400 mm.

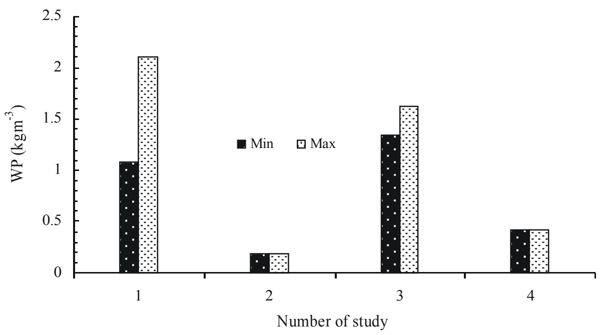

Fig. 6. WP values of alfaalfa in the selected studies

Potato

For this crop, the results from 6 studies were used in which location, time, crop variety, and irrigation management were the different parameters. The studies took place over the years 2000-2006 in Hamedan, Kerman, and Khuzistan provinces. According to our calculations, the crop water productivity value obtained for potato varied between 5.7 and 1 kgm^{-3} (Fig. 7).

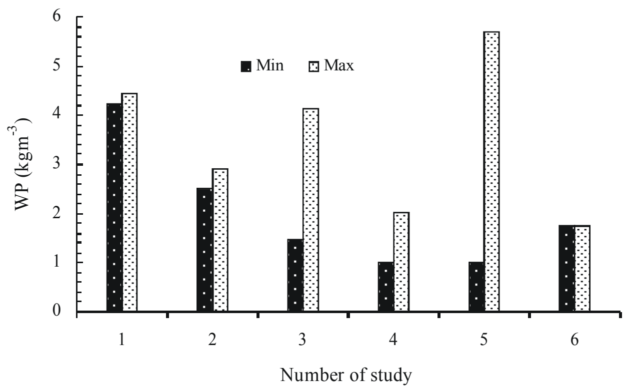

Fig. 7. WP values of potato in the selected studies

Tomato

For the tomato crop, the results from 7 studies were used in which time, location, crop variety, and irrigation management were the different parameters. The studies were conducted over the years 1996-2002 in three different provinces. Based on our calculations, the qualitative values of crop water productivity for tomato varied between 1.74 and 10.35 kgm^{-3} (Fig. 8), with its maximum belonging to the treatment irrigated with sprinkler irrigation. The results showed that crop water productivity was 2.2 times higher than that in the treatment using a furrow irrigation method. It was also shown that great care had to be taken in deficit irrigating tomato as, in certain cases, the practice would seem illogical due to the severe drops in crop yield. Examination of the results from the studies surveyed indicates that deficit irrigation may be exercised after the first harvest but that it should never be practiced during the flowering stage and before the fruition stage.

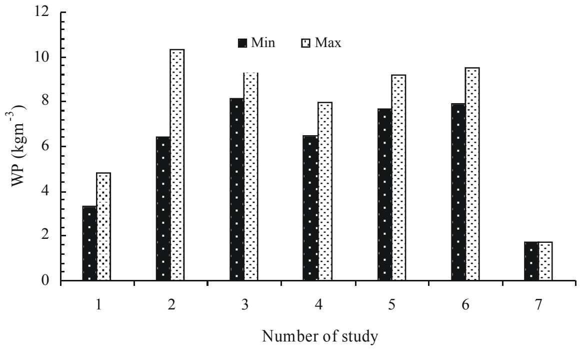

Fig. 8. WP values of tomato in the selected studies

Sesame

For sesame, the results from 3 studies were used. The studies had been conducted in Tehran Province in 1987 on three varieties of Naz-Chandshakheh, Karaj-1, and Varamin 2822. Based on our calculations, the qualitative values of crop water productivity for sesame grains varied between 0.07 and 0.22 kgm^{-3}, for its oil yield between 0.04 to 0.1 kgm^{-3} (Fig. 10). Investigations showed that the Naz-Chandshakheh variety scored the highest value of productivity index as compared to the other two varieties studied.

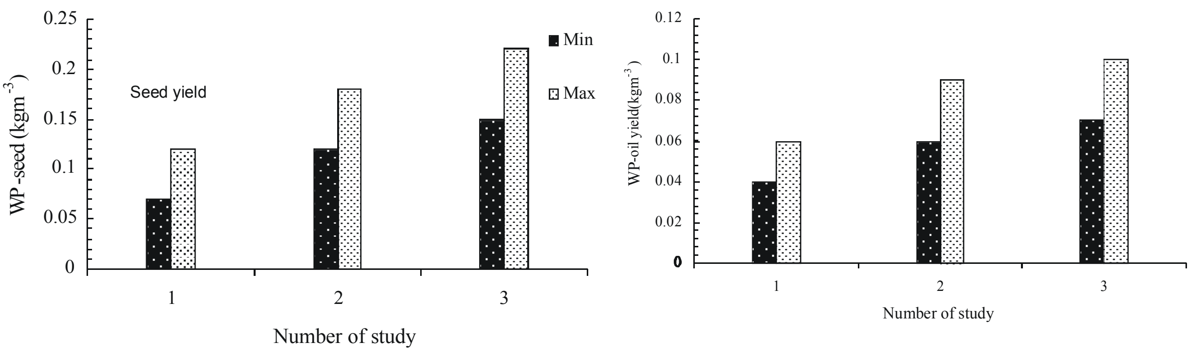

Fig. 9. WP values of sesame in the selected studies

CONCLUSIONS

In this paper, using the actual values of yield and water quantities consumed, the crop productivity (kg) was calculated for 10 crops in terms of the actual volume of water used (m^3) and the variations and average values of the water productivity were calculated in each case. *Table 2* presents the average values of water use productivity index for the crops studied in Iran. Comparison of these values with the values obtained on a global scale shows that the variations in the values of the Iranian index are almost the same those in the global values. Only, the WP value of rice is lower than the global value. The maximum values depict the potential for crop productivity that can be enhanced when practices and management systems are improved. The minimum values also indicate the conditions of water use efficiency in Iran under the traditional agricultural practices and in the absence of efficient management and irrigation systems. The results from the present survey reveal that improved irrigation management is the major and the effective measure in optimized water utilization and in enhanced crop water productivity. Figure 10 shows the WP values distribution of the studied crops based on number of experiment.

Table 2. Average values of cop water use productivity for various crops in Iran

Crop	Wheat	Barley	Rice	Sugar beet	Maize	Cotton	Alfa alfa	Potato	Tomato	Sesame
Water Productivity (kgm^{-3})	1.62	2.37	0.42	0.53 (W-SY) 4(R)	1.17	0.6	0.89	2.74	6.77	0.11(see) 0.06(oilyied)

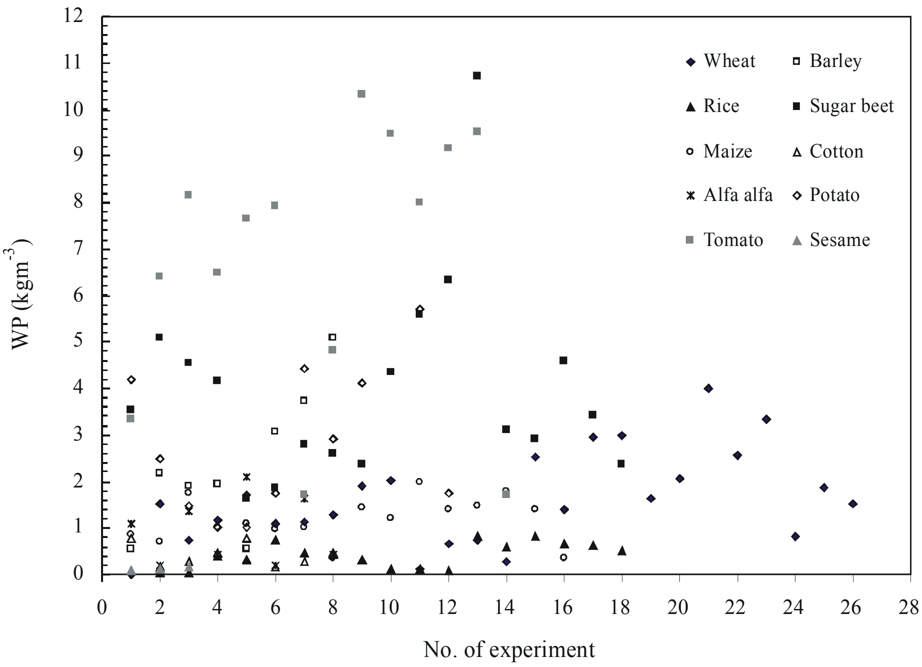

Fig. 10. WP values distribution of the studied crops based on number of experiment

The most important findings of the this survey are:

- In the Mediterranean countries which are mostly plagued by arid and semi-arid areas, deficit irrigation could be recommended as the most efficient management measure to improve water use efficiency and crop water productivity. Therefore, extensive research will have to be carried out in these countries to identify appropriate deficit irrigation management scenarios and to identify the reactions of strategic crops to these management scenarios.

- Selecting appropriate irrigation methods and effecting accurate irrigation scheduling will play significant roles in improved water use efficiency. In this relation, different pressurized irrigation systems could be recommended for use and simple management measures to control the discharge of surface water distribution systems should be effected.

- With regard to time and space limitations, on the one hand, and the rather high costs of implementing research on all crops, it will be essential to use water-soil-crop balance models in simulating plant growth process, to identify plant reactions, to determine the sensitivity of agricultural production to different parameters and factors, and finally to prepare the conditions for higher water use efficiency levels in these regions. In this regard, development of regional models, which are compatible with and adaptable to general local conditions, can be recommended.

- Selection of suitable plant species and variety and execution of genetic and breeding studies on the strategic crops in the region should also be included in the tools of achieving improved productivity.

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