Journal of Agricultural Science and Technology B 8 (2018) 145-156
doi: 10.17265/2161-6264/2018.03.001

Magnetically Treated Irrigation Water Improves the Production and the Fruit Quality of Strawberry Plants (*Fragaria × ananassa* Duch.) in the Northwest of Morocco

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Abstract: Utilization of magnetically treated water has been investigated and applied in many countries such as Russia, Australia, Israel, China and Japan. Studies have shown that the magnetic field is used as a safe alternative to improve plant growth and development. Although the properties of magnetically treated water have received a great deal of interest in recent years, there are no studies conducted in Moroccan agricultural conditions. The present study aimed at gaining more insight on the effect of magnetically treated irrigation water (MTIW) in the northwest region of Morocco, on the yield of strawberry plants (*Fragaria* × *ananassa* Duch. cv. Camarosa) and its components. The experiments were conducted *in situ*, during two crop seasons (2011-2012 and 2013-2014). The results confirm that physical treatment of irrigation water by a static magnetic field improves the yield and quality of strawberry fruits. The percentages of increase in number of flowers, number of fruits, fruit yield and quality of export production per 100 plants were 27.4%, 30.9%, 34.8%, 24.3%, respectively, compared with normal irrigation water (average over both crop seasons). These results suggest that irrigation with MTIW improves the production as well as the quality of the strawberry fruit, thus water use efficiency was enhanced. Therefore, the MTIW can be considered as a promising technique for improvement but extensive research is still required.

Key words: Magnetic field, irrigation water, strawberry, production, quality.

1. Introduction

Strawberries are one of the most popular cash crops from a commercial and economic point of view. Morocco ranks as the world's fifth largest strawberry exporter, according to statistics provided by the Ministry of Agriculture and Fisheries. The country exported approximately 74,000 tons, representing 7% of the international market, during the 2013-2014 crop years. Strawberries are grown in an area of 3,526 ha, mostly in the fertile regions of Loukkos, Souss-Massa and Gharb, with a total production of 145,233 tons. Strawberry quality, thereby, plays an important role. Strawberry quality is defined by several parameters such as size, color and shape, firmness, flavour and aroma. However, the chemical and physical

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characteristics of strawberries vary greatly depending on environmental and cultivation factors [1], as well as agricultural practices [2]. Appropriate strategies are to be developed to increase crop productivity while conserving water supply. One of the new strategies is physical magnetic treatment technology. Magnetic treatment of water has opened new research avenues in agriculture. This technique is safe, simple, and environmentally friendly, has low operating costs and is proven to have no harmful effects. The literature reports have shown an improvement of irrigation water quality and water use efficiency, crop yields and quality, soil improvement, scale prevention/elimination in water using systems and water savings by using magnetic treatment [3-5]. More scientific reports focused on the stimulation of living organisms including plants, with various magnetic treatment [6, 7]. In fact, it was reported that the magnetic treatment changes water properties due to displacement and polarization of water atoms [8]. It was claimed that magnetic fields affect water absorption, preservation and ionization [9]. These changes result in a better assimilation of nutrients and fertilizers in plants during the vegetative growth period [10, 11]. It was found that the mobility of nutrient elements in root zone of citrus was improved greatly when using magnetic treatment [3, 12]. In this regard, few studies have been conducted on the exact mechanism of the action of magnetically treated water in exerting physical and electrochemical effects. However, there are hardly any studies conducted in Moroccan agricultural conditions. The objective of this study was to investigate the effects of magnetically treated irrigation water (MTIW) in the northwest region of Morocco, on strawberry plant's (*Fragaria* × *ananassa* Duch. cv. Camarosa) yield and its components.

2. Materials and Methods

2.1 Study Site

This study was conducted on a farm named Dirafrost located in the region of Laaouamra, 20 km south of Larache, Morocco (coordinates: 35°1'16" N and 6°9'47" W in minutes and seconds degrees (MSD), latitude of 35.0212059397254 and longitude of 6.16293206440213 (in decimal degrees)). The experimental region has a Mediterranean climate with an average annual rainfall of 700 mm and a mean maximum temperature of 32 °C (in summer) while the mean minimum temperature was 6 °C (in winter (Mazaria weather station, 2014)).

The soil was classified as a frank sandy with a clay content of 5%, silt loam content of 15% and a sand rate of 80%. The amount of organic matter was 1.55% and a basic pH of 7.2. The electrical conductivity is 314 µS/cm (Table 1).

2.2 Technical Crop Management

The experiments were conducted *in situ*, during two crop seasons (2012 and 2014).

The soil tillage was performed in September for the two crop seasons. It was done in steps: 1—cross passage of a disc harrow (cover-crop); 2—labour in 35 cm using a mouldboard plow; 3—passage of a chisel plow at the depth of 40 cm; 4—passage of a disc harrow in 25-35 cm; 5—spreading manure (by rate of 60 t/ha of cattle manure); 6—sprinkler irrigation to facilitate the decomposition of manure; 7—passage of a disc harrow; 8—bedding and mulching a black plastic and laying the drip line while the distance between drippers was 20 cm with a flow rate of 1.6 L/h; 9—soil disinfection by methane sodium; 10—punching planting holes in the covering.

Camarosa bare root variety was planted on November 4th and 10th of the years 2011 and 2013, respectively, at the rate of 70,000 plants per hectare. Each bed included two rows of strawberries plants, five plants per running meter, and one drip line. A 2 ha field experiment was conducted. Strawberries were grown under low plastic tunnels. The plants were fertilized weekly through the drip irrigation system. First and final harvests were undertaken between 1st

Table 1 Some chemical properties of the experimental site soil.

	pH	Electrical conductivity (μS/cm)	$CaCO_3$ (%)	Organic matter (%)	Available P (mg/kg)	Ca	K	Mg	Na
						(mEq/100 g)			
Soil (0-30 cm)	7.2	314	< 0.5	1.55	57.2	4.61	0.39	0.65	0.35

Table 2 Some chemical properties of irrigation water.

	pH	EC (μS/cm)	NO_3^-	SO_4^{2-}	HCO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	B	Fe	Mn	Cu	Zn
			mEq/L								ppm				
Irrigation water	7.6	675.29	1.08	0.91	2.34	1.41	4.73	0.4	1.2	< 0.05	< 0.05	< 0.05	< 0.005	< 0.05	< 0.05

February and 30th June for the two crop seasons.

2.3 Irrigation Water

Water used comes from a well. The chemical properties of irrigation water are shown in Table 2. The crop irrigation method used is drip irrigation.

In October, 3.2 L of irrigation water was given daily, thereafter, watering was continued daily for a duration of 20-30 min (30 m^3/h/ha). Considerably, higher rates are required during prolonged hot and dry periods.

2.4 Water Treatment

Irrigation water was treated magnetically by passing once, in the normal flow rate of the pipeline, through a magnetic treatment device which was designed especially for field conditions. The magnetically treatment device (Fig. 1) is a commercial device, making use of permanent magnets. The reason for using this device type is their convenience and economy. They deliver magnetic fields dependably without any power source, without maintenance and without ever weakening from external influences. The device has been installed horizontally in the front of the irrigation pipe in field treatments, irrigated with treated water. The aforementioned treated water has been called as MTIW.

2.5 Experiment Procedure

The experimental field is formed by two adjacent plots. In each plot, there are three valves used to raise the pressure of water (from the secondary pipeline) in the drip line, in order to homogenize the pressure of water in the drippers. Each pair of valves feeds 50 beds with two rows of strawberry plants. Three sub-units were fixed in each plot (450 m^2), they coincide with the inter valve distance. Each sub-unit had eight beds of 100 strawberry plants.

The magnetic treatment device was installed in the front of the secondary pipe line in the plot irrigated with MTIW, as shown in Fig. 2. Thus, water flowing downstream in the three valves is already treated by the static magnetic field. The flow of the magnetic treatment device is sufficient not to modify the pressure of water in the drippers compared with those of the control plot.

Statistically, the experimental system was performed as a completely randomized design with treatment (MTIW) at two levels and three replications (sub-units). Indeed, this design is not truly a completely randomized one, given practical constraints, the sub-units irrigated with MTIW and ordinary water are not distributed randomly. However, since there is no difference in fertility between the two plots, the design can be statistically analyzed as a completely randomized design.

2.6 Data Recorded

Quantitative traits, such as the number of flowers, fruit yield (kg/100 plants) and number of fruits (number/100 plants), were investigated for each treatment.

The quality of the fruits, reflecting the market value, was examined by measuring the percentage of export

Fig. 1 Magnetic treatment device.

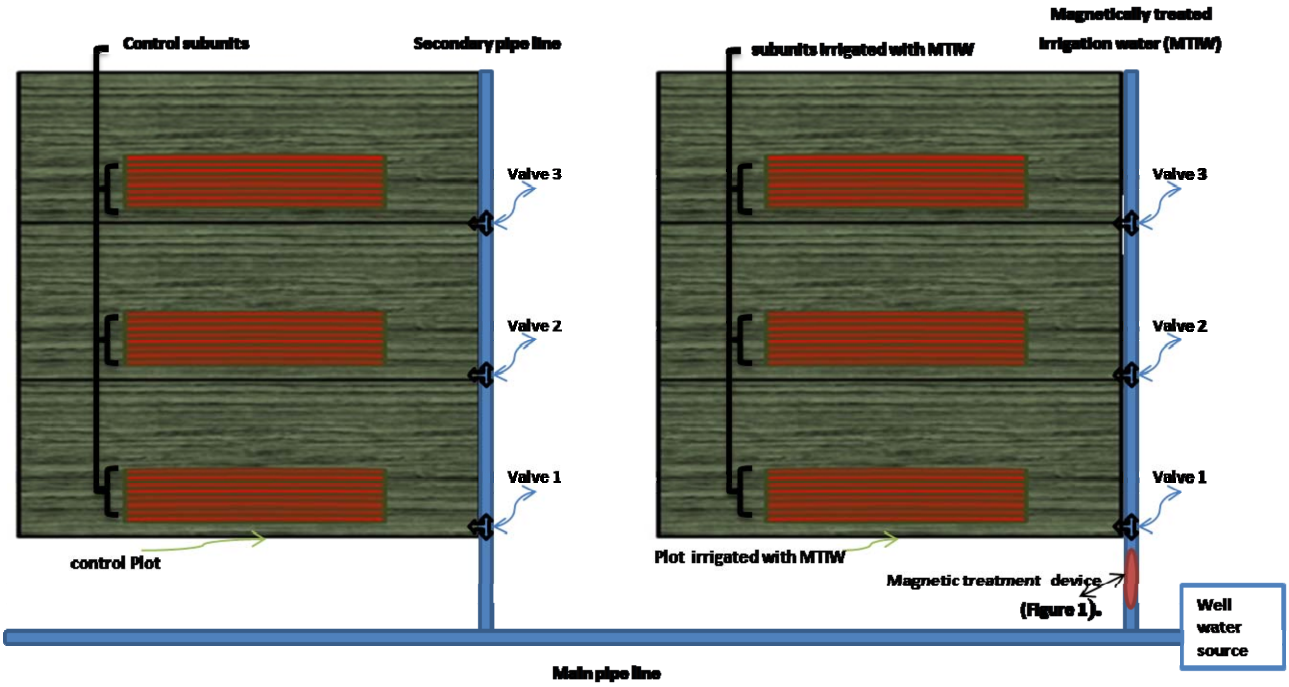

Fig. 2 Schematic drawing of the experimental system.

production and fruit size for three calibers (small-caliber: diameter less than 35 mm; medium-caliber: diameter between 35 mm and 45 mm and large-caliber: diameter larger than 45 mm). There is a special request from the foreign market for each of these calibers.

Growing degree days (GDD) was used, a measure of accumulated heat over the growing season, as a guiding metric when compared with different parameters for both 2012 and 2014 crop seasons because it is a standard measure. The dates to begin accumulating degree days are the planting dates for both crop seasons. The starting points and ending point are the GDDs of the first harvest and the last harvest for both crop seasons.

2.7 Statistical Analysis

All statistics were performed using SAS program, for Windows, version 9.0. The one-way analysis of variance (ANOVA 1) test was carried to verify statistical differences ($p \leq 0.05$) for all data and so test the main effects of the magnetic field and find the differences between the plants irrigated with MTIW and the control.

All parameters data were expressed corresponding of GDD values between start and end of harvest. GDDs were calculated according to the following equation GDD = $[(T_{max} + T_{min})/2] - T_{Base}$ (base temperature 3 °C) and were accumulated from planting day until harvest start and then between start and end of harvest.

3. Results

3.1 The Number of Flowers

The comparison of the number of flowers in the 2012 and 2014 crop seasons of strawberry plants, as affected by normal and MTIW, is presented in Fig. 3.

The results show that the irrigation of strawberry plants with MTIW resulted in significant increases in the number of flowers compared with the plants irrigated with normal irrigation water. The results are highly significant for the plants corresponding with the 2012 crop season. The increments were 25.6% and 29.2% on average of the mean values recorded on the harvests during the 2012 and 2014 crop seasons, respectively (Fig. 3). It is visible that the MTIW enhanced the number of flowers in the two cropping seasons for all the harvests. In fact, the highest number of flowers recorded, in 2012 and 2014 crop seasons for plants irrigated with MTIW, was 333 and 975, respectively, as compared with the control group (279 and 752, respectively).

3.2 The Number of Fruits

The mean number of fruits of strawberry plants irrigated with normal and MTIW observed during the two crop seasons 2012 and 2014 is shown in Fig. 4. The mean number of fruits of strawberry plants is strongly affected by the magnetic treatment. The percentages of increase in the number of fruits were 43.5% and 27.4% when irrigated with MTIW on average of the mean values obtained in the harvests during the 2012 and 2014 crop seasons, respectively. The magnetic treatment resulted in the highest number

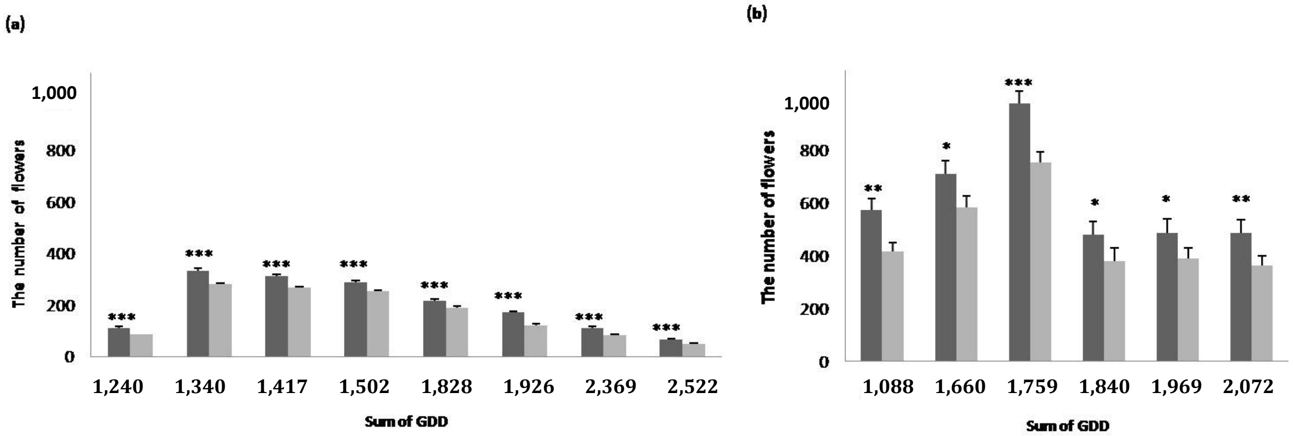

Fig. 3 The number of flowers of 100 strawberry plants irrigated with normal (▇) and MTIW (▇) for 2012 (a) and 2014 (b) cropping seasons.

The data presented function of the sum of GDD.

*, **, *** showed that the difference is significant at the 0.05, 0.01 and 0.001 levels, respectively.

The thin vertical bars represent standard error of the means.

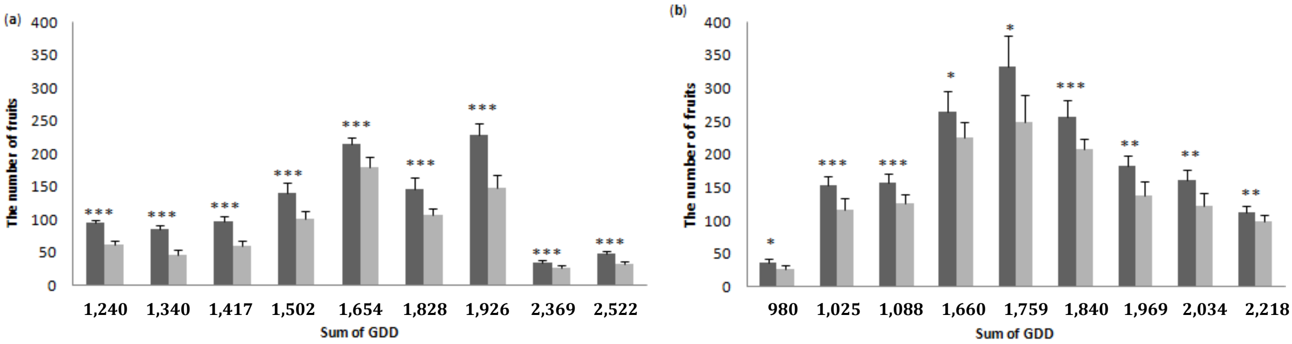

Fig. 4 The number of fruits of 100 strawberry plants irrigated with normal ( ) and MTIW ( ) for 2012 (a) and 2014 (b) cropping seasons.

The data presented function of the sum of GDD.

*, **, *** showed that the difference is significant at the 0.05, 0.01 and 0.001 levels, respectively.

The thin vertical bars represent standard error of the means.

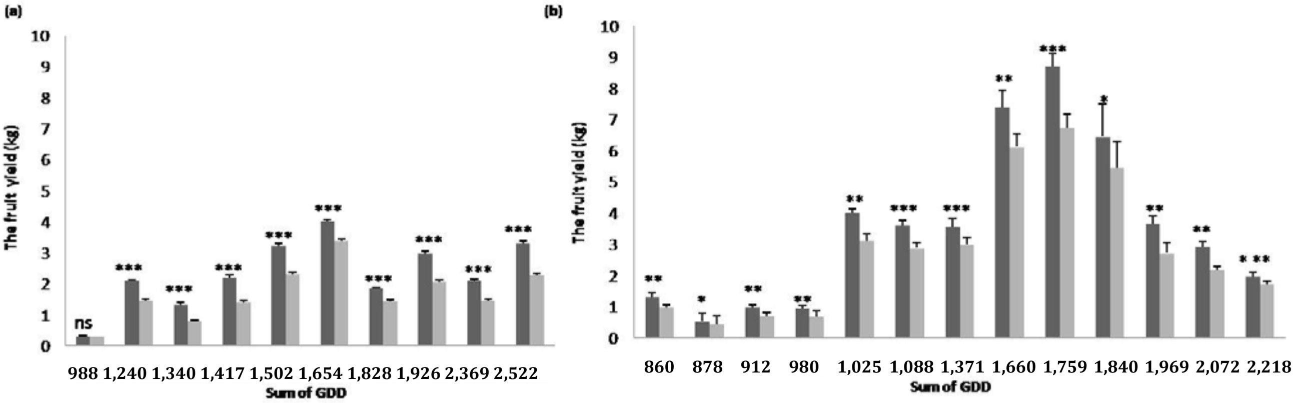

Fig. 5 The fruit yield (kg) of 100 strawberry plants irrigated with normal ( ) and MTIW ( ) for 2012 (a) and 2014 (b) cropping seasons.

The data presented function of the sum of GDD.

*, **, *** showed that the difference is significant at the 0.05, 0.01 and 0.001 levels, respectively; ns: not significant.

The thin vertical bars represent standard error of the means.

of fruits with 228 and 333 in 2012 and 2014 crop seasons, respectively, when compared to the control with 180 and 250 in 2012 and 2014 crop seasons, respectively.

3.3 The Fruit Yield

The mean fruit yield (as a value of kg/100 plants) of strawberry plants irrigated with normal water and MTIW measured during the two crop seasons (2012 and 2014) is shown in Fig. 5.

The results show that irrigating strawberry plants with MTIW increased the fruit yield significantly, indeed extremely, over the control in 2012 and 2014 crop seasons. On average, in the different mentioned harvests, the increase reached 42% in the 2012 crop season and 27.7% in 2014 crop season. The stimulatory effect of irrigation with MTIW is evident, as represented in Fig. 5. On the other hand, if the fruit yield of all harvests recorded was added and then converted this sum to a production by hectare, in 2012 and 2014 crop seasons, for the plot irrigated with MTIW, a production of 28.3 tons and 56.2 tons was obtained respectively, over 20.2 tons and 44.6 tons, respectively, for the controls. So, these results concluded that an increase of 8.1 tons and 11.6 tons per hectare was achieved in 2012 and 2014 crop seasons, respectively.

3.4 The Fruit Quality

The strawberry fruits, used for fresh-market sales, must be firm, well colored and rot free. Obviously, strawberries must be harvested early in the day while temperatures are cool. Given that the region has a Mediterranean climate, the fresh-market strawberry season ends in mid April. Afterwards, frozen strawberries destined for the agro-industry will be developed.

3.4.1 The Export Production

In this part, only the percent of fresh-market production/total yield that is export quality production was examined. The mean export production of strawberries that are affected by normal and MTIW is presented in Fig. 6. Data presented in Fig. 6 show that strawberry plants irrigated with MTIW resulted in a significant increase regarding the quantity of export production, over the controls in 2012 and 2014 crop seasons. On average, in the different mentioned harvests, the export production for the plants irrigated with MTIW, reached 65.7% of total production in the aforementioned period for 2012 crop season and 54.3% in 2014 crop season while for the control plants, the export production was 47.6% and 51.4% in 2012 and 2014 crop seasons, respectively. Thus the increases were 42.2% and 6.5% in 2012 and 2014 crop seasons, respectively.

3.4.2 The Fruit Calibers

Quality of strawberries (cv. Camarosa) depends on their appearance; indeed, the most important factor in attaining good quality is the fruit size.

The mean numbers of fruits exported for the medium and large calibers already mentioned, of plants irrigated with normal irrigation water and MTIW observed during the two crop seasons, are shown in Figs. 7 and 8.

As shown in Fig. 7, in strawberry plants irrigated with MTIW, the numbers of medium-caliber fruits were, on average of the aforementioned harvests, 40 and 54 for the two crop seasons, respectively, compared with 22 and 40 for plants irrigated with normal irrigation water, respectively. Furthermore, the number of larger-caliber fruits improved by 260.3% and 51.2% for the two crop seasons, respectively (Fig. 8).

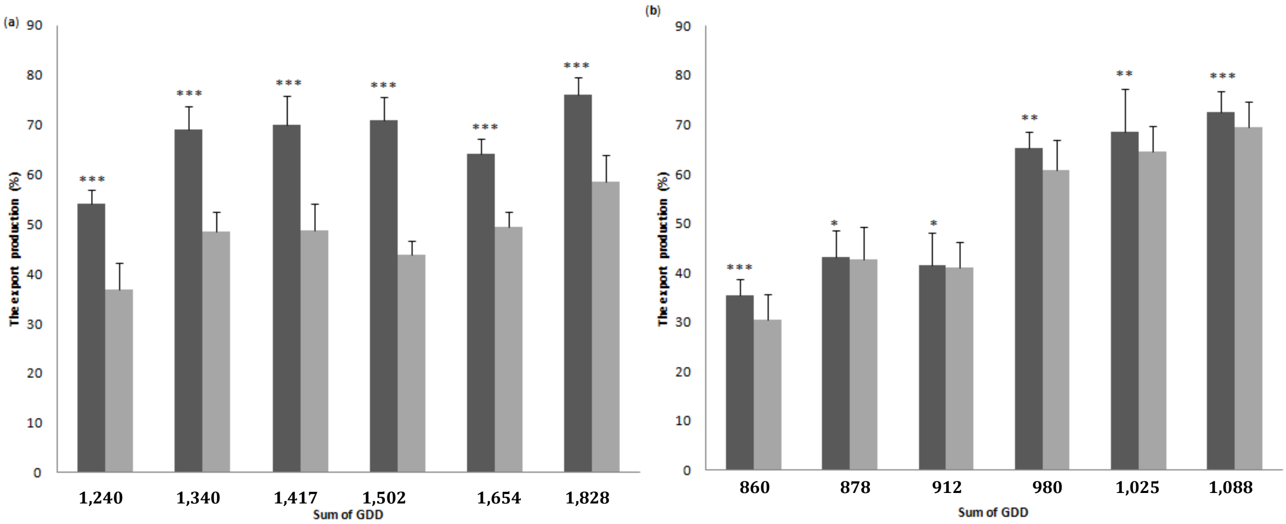

Fig. 6 The export production (the percent of fresh-market production/total yield) of 100 strawberry plants irrigated with normal ( ) and MTIW ( ) for 2012 (a) and 2014 (b) cropping seasons.

The data presented function of the sum of GDD.

*, **, *** showed that the difference is significant at the 0.05, 0.01 and 0.001 levels, respectively.

The thin vertical bars represent standard error of the means.

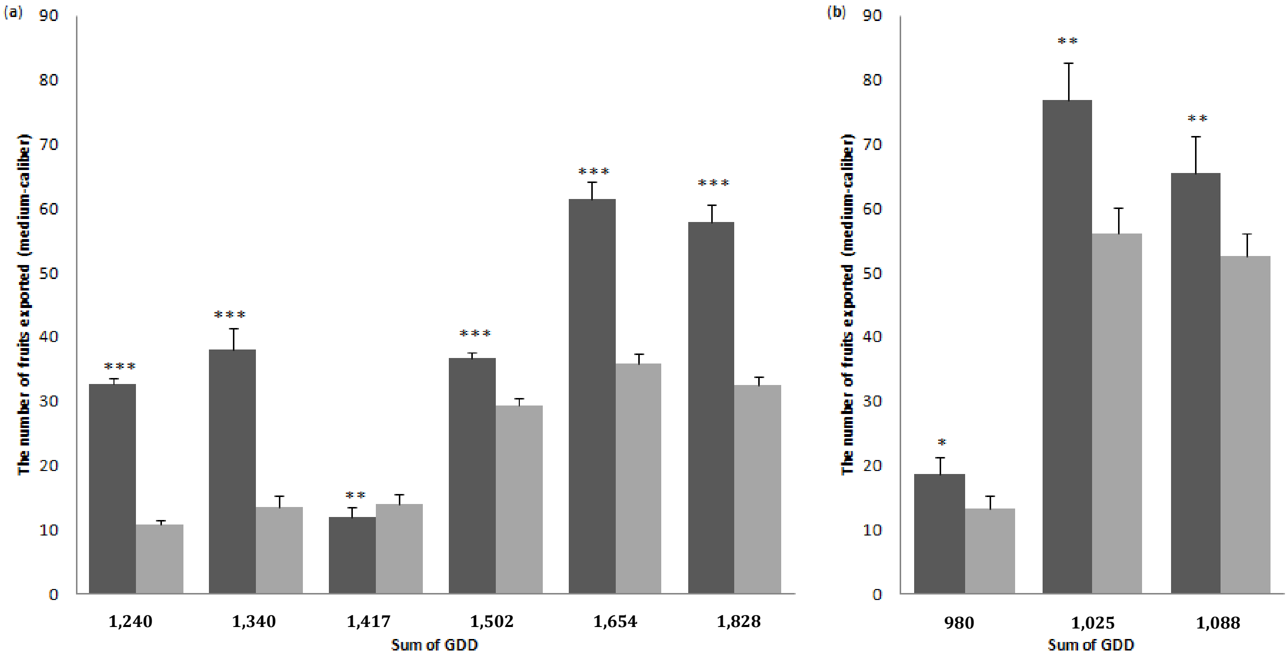

Fig. 7 The number of fruits exported (medium-caliber: diameter between 35 mm and 45 mm) of 100 strawberry plants irrigated with normal (■) and MTIW (■) for 2012 (a) and 2014 (b) cropping seasons.

The data presented function of the sum of GDD.

*, **, *** showed that the difference is significant at the 0.05, 0.01 and 0.001 levels, respectively.

The thin vertical bars represent standard error of the means.

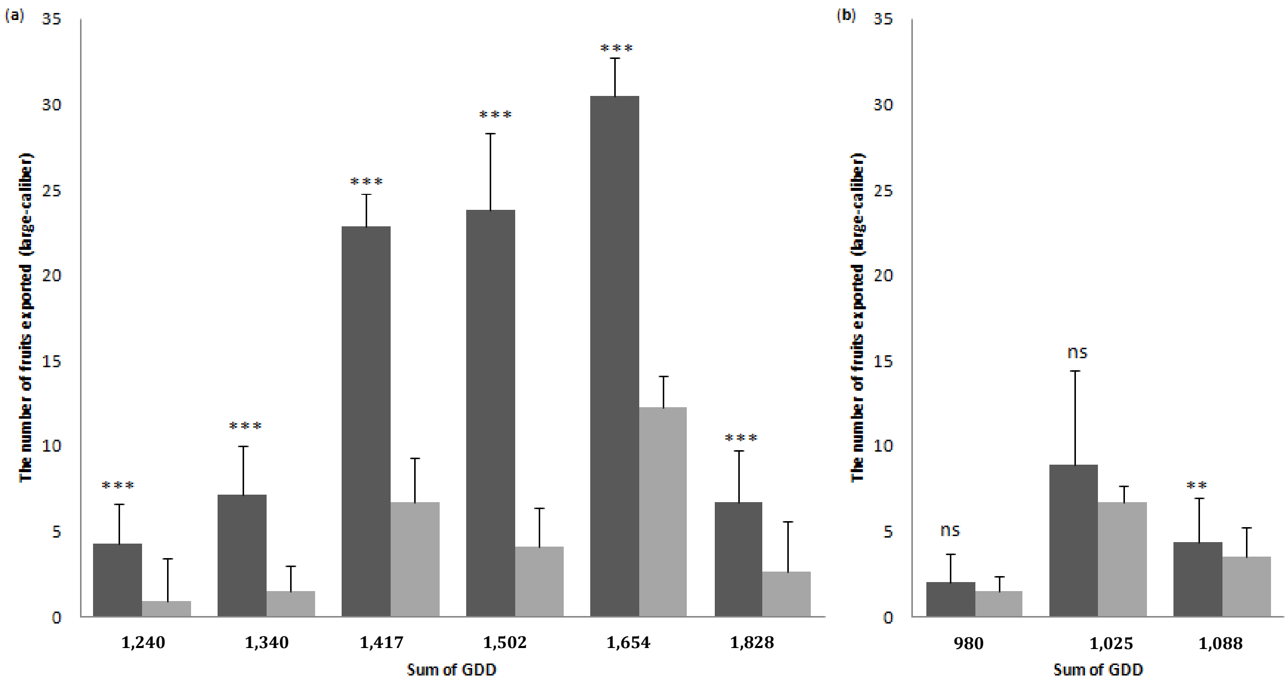

Fig. 8 The number of fruits exported (large-caliber: diameter larger than 45mm) of 100 strawberry plants irrigated with normal (■) and MTIW (■) for 2012 (a) and 2014 (b) cropping seasons.

The data presented function of the sum of GDD.

, * showed that the difference is significant at the 0.01 and 0.001 levels, respectively; ns: not significant.

The thin vertical bars represent standard error of the means.

4. Discussion

The results presented above confirm that physical treatment of irrigation water by a static magnetic field improved yield and quality of strawberry fruits. These results were in line with those of Eşitken and Turan [3], they have shown an enhancement of number of flowers and total yield of fruits for strawberry crop. The results obtained from this study, corroborated with previous studies on cabbage and potato where MTIW improved the quality of crops and gave a higher yield value and its components compared to the control [13, 14].

Similar enhancing effects of MTIW have been reported abroad on other crops like cereal, sunflower, flax, pea, buckwheat, wheat, groundnut, tomato, soybean, potato, canola and lettuce. In these studies the crop yield and quality were increased [15-29]. These beneficial effects of physical water treatment on yield and its components were due to the increase in plant growth [24, 29].

These results concur with those of Taimourya et al. [14], they reported an improvement of all plant growth parameters of potatoes when irrigated with MTIW over the control. A significant increase in fresh weight and plant height was also observed when chickpea and lentil plants were irrigated with magnetically treated water [30, 31]. Furthermore, the magnetic treatment of irrigation water led to easy breakthrough of water into the cell membrane of maize [32]. In fact, the changes caused by magnetic treatment of water include decreasing water surface tension and increased viscosity [33]; therefore, the reduced surface tension of the magnetically treated water may facilitate penetration of cell walls and thus increase water absorption in soil [34].

These results tally with those obtained by Reina et al. [23] and Taia et al. [9], they reported a significant increase in the rate of water absorption accompanied with an increase in total mass of lettuce. An increase of water use efficiency was also observed in cowpea, jojoba, celery, canola and snow pea when irrigated with MTIW [29, 35-37]. Moreover, an increase in nutrient uptake was reported as a result of using magnetic treatment [38, 39]. Furthermore, it was recorded that magnetically treated water increases nutrient mobility in soil and enhances extraction and uptake of P, K, N and Fe by plants [39, 40]. The stimulatory impact of magnetic treatment was also attributed to the increase of the availability of minerals in soil through boosting the solubility of salts and minerals [41]. The MTIW has a high solubility [42, 43]; therefore, nutrients are more soluble in water [39]. In fact, magnetic treatment of water restructures the water molecules into very small clusters, each made up of six symmetrically organized molecules [40]. The size of molecule groups gets reduced below the diameter of capillaries in the roots of plants thus it can easily enter the passageways in plant cell membranes [40]. Various studies have demonstrated higher absorption of nutrients in crops irrigated with magnetically treated water [3, 4, 42, 44].

5. Conclusions

The current study has shown that using MTIW could be employed as one of the most valuable physical growth stimulation approaches that can assist in improving yield and quality of strawberry crops. Magnetic technologies are ecologically friendly and non-polluting to the soil. In addition, the utilisation of magnetic treatment in agricultural production will enable intense and increased production both in terms of quantity and quality. It can also be used for conserving irrigation water and increasing the efficiency of added fertilizers. In conclusion, magnetic technology is a promising physical growth stimulation approach. However, further field and laboratory experiments are needed to overcome the field challenges and to gain knowledge about the working mechanism of the magnetically treated water.

Acknowledgments

The authors would like to thank Mr. Jounaid and Mr. Mokhtari, the director and CEO of Atlas-Innov Company, for providing help in magnetic treatment equipments. The authors acknowledge Dirafrost Company, Mr. Ratbi and El Ghyam for organising access to the study site. Also, sincere thanks go to ORMVAG for providing access to the archive of global historical weather data. Mr. Ezzari, technician from PPBV department, is kindly thanked for his valuable input during the study. Mr. Hlayba, laureate of IAV institute, is thanked for setting up and collecting data for the 2014 cropping season. The authors finally wish to thank Mrs. Daoudi and Pr. Ben Abdellah for their comments that greatly improved the manuscript.

Competing Interests

All authors read and approved the final manuscript. They have declared that no competing interests exist.

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