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POSSIBILITY FOR USE OF PHOTOVOLTAIC IRRIGNATION SYSTEMS IN REPUBLIC OF SERBIA

MOGUĆNOSTI UPOTREBE SOLARNE ENERGIJE ZA NAVODNJAVANJE U REPUBLICI SRBIJI

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ABSTRACT

This paper will present one possible solution of insufficient precipitation during plants vegetative phase using RES. Since the most active period for the majority of agricultural products occurs when available solar energy is at a peak, one could argue that the use of irrigation systems powered by solar energy is the best solution.

The paper will compare the classical and the corresponding PV system for irrigation, with their advantages, disadvantages and utilization possibilities. Republic of Serbia solar energy potential will be presented, with special reference on agricultural areas, since the potential on the perspective location will determine the possibility of achieving adequate water supply for irrigation. Differentiating based on the specificities in agricultural areas, the possibility of PV irrigation systems use for different cultivar groups will be discussed.

The presented technical solutions will include financial analysis for different types of irrigation systems and the suggestions for cost reduction for PV based irrigation systems.

Key words*: vegetable farming, fruit production, solar energy, PV irrigation*

REZIME

Ovaj rad se bazira na problemu rešavanja nedovoljnih količina padavina tokom vegetacionog perioda biljaka, korišćenjem OIE. Nedostatak vode se može rešiti navodnjavanjem. Pošto se većina poljoprivrednih kultura uzgaja u periodu godine kada ima najviše solarne energije, a tada je potreba biljaka za vodom najveća, moglo bi se reći da je korišćenje solarne energije za navodnjavanje najbolje rešenje. Pad cene fotonaponskih (FN) panela, nestabilna svetska politička scena, koja začas može prouzrokovati značajan porast cene nafte, kao i podsticajne mere države su omogućile da se navodnjavanje putem solarne energije u Republici Srbiji isplati.

U uvodnom delu rada je upoređen klasičan i FN sistem za navodnjavanje, njihove prednosti, mane i mogućnosti korišćenja. Prikazan je solarni potencijal na teritoriji R. Srbije, sa posebnim osvrtom na poljoprivredna područja. Naime, od solarnog potencijala neke lokacije direktno zavisi mogućnost ispunjenja zahteva za potrebnom količinom vode. U skladu sa specifičnostima poljoprivrednih područja, prikazane su mogućnosti navodnjavanja raznih poljoprivrednih kultura, upotrebom solarnih sistema za navodnjavanje. Opisan je postupak izbora najosnovnije opreme za fotonaponski zalivni sistem, koji je bazirana na osnovu praktične primene klasičnog sistema za navodnjavanje površine 2 ha, zasađene paprikom.

Pored prikaza tehničkih rešenja, analizirani su i ekonomski aspekti. Razmatra se isplativost raznih varijanti zalivnih sistema i daju se tehnički predlozi za smanjivanje cene koštanja FN sistema za navodnjavanje.

Ključne reči: *povrtarstvo, voćarstvo, solarna energija, fotonaponsko navodnjavanje*

INTRODUCTION

In the beginning of this centuries first decade the story about renewable energy sources (RES) timidly started to appear in Republic of Serbia, while the rest of the world shows considerable development in this area. Not before the beginning of the second decade had Serbia started to get involved in activities related to the RES, through legal acts (*SGRS*), regulations and other activities. Conditions for the acquisition of incentive measures and feed-in tariff are defined for the RES based objects connected to the existing power system, either thermal or electrical. Off-grid renewable based systems for electrical energy generation are not considered. On the other hand, these systems are very popular in the agriculture, particularly when solar energy is applied. In 2009 experts from the Center for Renewable Energy Sources and Power Quality indicated the possibility for the use of independent photovoltaic (PV) systems in agriculture (*Čorba et al.*, *2009*). Back then, due to the high price of PV modules and the lack of incentive rates, off-grid PV systems were unprofitable for the most application in the agriculture.

The decrease of the PV modules price, accompanied by the introduction of incentive measures for farmers (currently applicable only in Vojvodina) make off-grid PV systems acceptable in the agriculture. For example, there are fewer dairy farms in Vojvodina, where off-grid PV systems provide electricity for the needs of milk storing. Also, these systems are increasingly used for irrigation.

Off-grid PV systems for crops irrigation are especially interesting because they can be used without electricity storage, which makes them significantly less expensive. The profitability of the off-grid PV systems will depend on the cultivar group, more specifically the crop water requirements. The total investment amount will also be determined based on the land area, type of the irrigation system, the technology of irrigation, as well as the choice of the equipment.

This work will indicate the profitability of the investment for an independent PV systems used for irrigation in an intensive crop production, such as vegetable and fruit growing.

Nomenclature:

CCS (€)	– Cumulative cost saving
C_{PVIS} (€)	– Cost of PV irrigation system
C_{PUMP} (€)	– Cost of irrigation pump
C_M (€)	– Maintenance cost of conventional pump per year– kapacitet pumpe na dan
C_F (€)	– Fuel price for one year irrigation
E_{PVS} (kWh)	– PV modules energy production
E_p (kWh)	– pump energy consumption
G (kWh/m^2)	– global irradiation
IOI (h)	– ideal hour insolation
L (m)	– total length of drip tape omotic drying
P_{PV} (Wp)	– PV modules nominal power
Q (m^3/h)	– water total amount per day
Q_p (m^3/h)	– pump capacity per day
q (l/h)	– water amount by drip tape emitter
n	– PV module number

MATERIAL

Today, there are various types of irrigation systems, which can be adjusted to best suit the irrigated crop. Various nozzle types with small and large capacities are used, like micro sprinklers, rainfall irrigation, typhoons etc. There are also drip and flooding irrigations. Every watering system has its advantages and disadvantages. When it comes to classical irrigation systems, they usually have a common feature - diesel or gasoline pumps. In rare cases, if there is an electrical distribution network nearby, the electricity can be used to power the pumps. Alternative source of energy for irrigation can be the solar energy. In that situation, off-grid PV systems with or without batteries are used. In this case, usually submersible electrical pumps are used. In order to make the investment in PV based irrigation profitable all the aspects should be carefully considered first. The solar potential of the location should be studied. In accordance with the plant culture and the potential of PV systems, the most optimal system for irrigation can be chosen. The selection should also correspond to the watering concept, the needs of the plants and the financial capacity of the investor.

Solar irradiation

Serbia is among the European countries with high solar potential. The sum of solar irradiation on a horizontal surface, on the territory of Serbia, is in the range of 1280 kWh/m^2 and 1500 kWh/m^2 per year (*PVGIS*). The sums of irradiation on annual basis and horizontally placed surface are shown in Table 1. Vojvodina, Mačva, eastern and western Serbia have similar conditions in terms of global irradiation. Slightly higher values are measured in the far south of Serbia, where it can reach values up to 1500 kWh/m^2. For the optimal angles of PV modules these values are higher. These data were obtained by using interactive software of European Commission PVGIS.

Table 1. Global irradiation by regions in Serbia

Region of Serbia	Global irradiation G [kWh/m^2]
Vojvodina	1340 – 1380
Mačva and western Serbia	1280 – 1390
Southern and eastern Serbia	1320 – 1500

Depending on the time of the year, when the irrigation is necessary, the tilt angle of PV modules can be adjusted. As the plant growth period coincides with the period when the availability of solar energy is maximum, the need for irrigation occurs in the period from spring to autumn. In that period the tilt angle of the PV modules should be in the range of 15° - 20°. Table 2 shows the average daily sum of irradiation for the majority part of the country, as well as the southern parts of Serbia, for fixed 15° tilt angle of PV modules. The most optimal situation would be the possibility of changing the tilt angle of the PV modules during each month. The last column of Table 2 shows the optimal tilt angle for each month (taken from PVGIS interactive software), for the wider area of Novi Sad. For the rest of Serbia the tilt angle changes slightly, only for a few degrees.

Table 2. Global irradiation by regions in Serbia

Month	Most of Serbia [kWh/m^2]	Southern Serbia [kWh/m^2]	Optimal tilt angle [°]
January	1.41	1.68	59
February	2.27	2.35	54
March	4.12	4.1	44
April	5.18	5.02	31
May	5.87	5.79	18
June	6.32	6.57	11
July	6.61	6.92	15
August	6.14	6.50	27
September	4.54	4.78	41
October	3.40	3.62	54
November	2.04	2.32	62
December	1.17	1.41	60

Precipitation in the growing period

The water need for different corps depends on the species, climate, soil and the production type. In practice, the regime of irrigation is usually used according to the critical periods related to water. Critical phases related to water are the flowering, the growth of leaves and shoots, the forming of the fruits and the growth of the yield. In Serbia, the average annual water needs of plants are about 500 mm. Based on the agro-meteorological analysis of the Republic Hydro-meteorological Service of Serbia (*Radičević et al., 2014*), Table 3 shows the rainfall in the Serbia regions for five years. The precipitations are shown for the growing season, from early April until the end of September.

Table 3. Precipitation during the vegetation period

Precipitation during the vegetation period April – September [mm]				
Year	Vojvodina	Western Serbia	Eastern Serbia	Southern Serbia
2010	575	420	323	294
2011	240	248	183	194
2012	240	315	278	295
2013	325	303	247	245
2014	613	739	688	620
Average	**399**	**405**	**344**	**330**
Deficit	**101**	**95**	**156**	**170**

Compared to the average needs of plants, the rainfall deficit for these years is between 100 mm and 170 mm. If the average rainfall for the growing period of twenty years is observed (Table 4), then the average deficit of rainfall ranges from 150 mm to 170 mm.

Table 4. Precipitation in the range of 20 years

Precipitation during the vegetation period 1981 – 2010 [mm]			
Vojvodina	Western Serbia	Eastern Serbia	Southern Serbia
350	430	330	330

The region of eastern and southern Serbia has a bigger deficit of rainfall than the other parts of Serbia, in the growing period. In average, in Vojvodina and western Serbia there is a lack of 100 mm, and during more drier years it can be up to 200 mm. Eastern and southern Serbia lacks on an average 160 mm of rainfall, while in dry years it can reach 300 mm.

PV irrigation system components

The off-grid irrigation PV system without the electricity storing possibility (there is possibility of storing water) consists of four basic elements shown on the Figure 1:

1. Photovoltaic modules,
2. MPPT controller,
3. Electric pump and
4. The irrigation system.

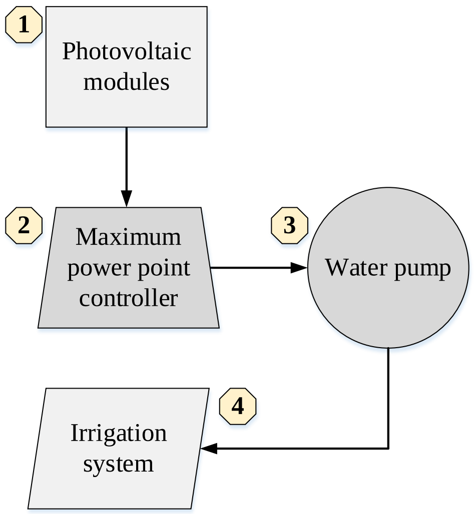

Fig. 1. Photovoltaic irrigation system block diagram

The required power of the PV modules depends on the solar radiation and on the characteristics of the chosen pump. The MPPT controller uses the maximum possible power of the PV modules and supplies the pump. The pump can either be on the surface or it can be submersible. Its power depends on the amount of water needed for irrigation and on the irrigation system configuration. The most favorable solar energy irrigation systems are small sprinklers and the drip types. These systems do not require high pressure. Watering may be done partially, which reduces the required amount of water for irrigation. This means that the pump's and the PV module's power is lower, and therefore the investment will be lower as well. The partial way of pumping water to the plants means a longer period of one irrigation cycle.

The PV irrigation system component choice

The components of PV irrigation systems have been defined for the system of drip irrigation. This combination is more energy efficient and it contributes to the environmental protection as it uses a renewable energy source with minimal waste of water. The type of the drip tape for irrigation is chosen based on the cultivated plants. The required daily amount of the water is a function of the length of the tape and the amount of water by tape emitters:

$$Q = L \cdot q \tag{1}$$

In order to satisfy the need for water, it is necessary that the pump for irrigation has a higher capacity than the daily needs of plants:

$$Q_p \geq Q \tag{2}$$

When the selected pump is in accordance with the expression (2) the electric power of the pump is defined. Using the next expression, the required power of the PV modules is determined as:

$$E_{PVS} \geq E_p \tag{3}$$

which means that the electricity generated by the PV modules on a daily basis should be higher or equal to the irrigation pumps consumption.

The total power of the PV modules is calculated in the following way:

$$P_{PV} = \frac{E_{PVS}}{IHI \cdot n} \tag{4}$$

The nominal power of the PV panel is set for standard test conditions (STC), where the radiation is 1000 W/m^2. According to these values and the daily global radiation (Table 2), the duration of insolation for STC can be defined. This time interval is called the ideal hour insolation (IHI), which is used to calculate the power of PV modules (4). During real work conditions of PV systems, the PV modules power has to be defined as a function of radiation and temperature. Therefore it is necessary to define the mean values of radiation and temperature in the interval of use for the irrigation system. After defining the total power of the PV modules, the adjustment of the PV modules and the MPPT controller, should be done, according to voltage and current.

PV irrigation systems for different plant types

The components of the PV irrigation system for peppers in Vojvodina are based on the experience of a farmer from Ruski Krstur, who produces peppers on a surface of 2 ha, with conventional irrigation system. The elements of additional three PV systems for one hectare land irrigation, particularly apples in Vojvodina, raspberries in the west and peppers in the south of Serbia are defined according to the average annual deficit of rainfall, the needs of appropriate culture for water and the available irradiation for certain regions. The total height of the water column for all systems, with all the losses included, is 25 m. The estimated time of irrigation for additional three cases is 5 hours a day.

The electric power of the pump and the necessary power for the PV modules for certain regions of Serbia are calculated using the parameters presented in Table 5.

Table 5. The parameters for the calculation of photovoltaic modules

Region of Serbia	Vojvodina	Western Serbia	Eastern, southern Serbia
Plant	apple	raspberry	pepper
Annual num. of irrigation	5	10	60
Daily water amount	60 m^3/ha	60 m^3/ha	25 m^3/ha
Pump capacity	12 m^3/h	12 m^3/h	5 m^3/h
Irradiation	550 W/m^2	550 W/m^2	600 W/m^2
PV module temperature	39 °C	39 °C	44 °C

The nominal PV module power, which was used for calculation is 250 Wp.

Irrigation of peppers in Ruski Krstur using PV systems

According to the parameters obtained from the pepper producers and environmental conditions presented in Table 5, the PV irrigation system is defined, in order to replace the classic form of irrigation with pumps which use diesel fuel. With water consumption of 60 m^3/h and 8 hour watering per day, during the production cycle the process of irrigation is done about 60 times. These watering parameters will be satisfied by an electrical submersible pump of 4 kW. To run this pump, it is necessary to install 24 PV modules with total installed capacity of 6kWp. The PV modules connection to the MPPT controller is shown in Figure 2.

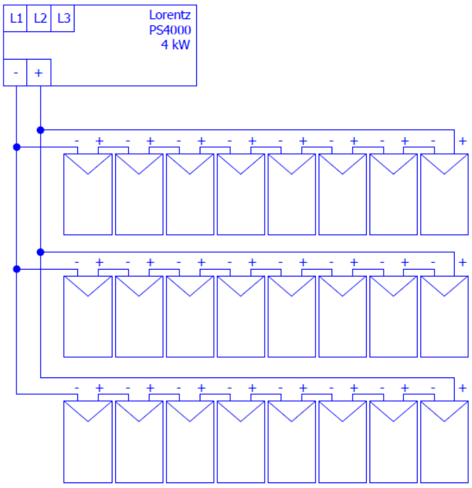

Fig. 2. 6 kWp photovoltaic irrigation system (Takač, 2016)

Irrigation of apples in Vojvodina using PV systems

Necessary compensation of 150 mm of the rainfall annually was assumed for the irrigation needs of the apples. The daily consumption of the electrical pump is 9.35 kWh, with an additional 10 % reserve. Using the parameters from Table 5, the required power of the PV modules can be calculated at 3.75 kWp for this irrigation system.

Irrigation of raspberries in western Serbia using PV systems

For the irrigation of raspberries in a year with average rainfall, it is necessary to compensate 200 mm of water. Since the watering is planned to be done 10 times a year, the required daily amount of the water is the same as for the apples. Therefore, the electricity consumption of the pump is the same 9.35 kWh. Using the parameters from Table 5, the required power of the PV panel can be calculated for this irrigation system, which is 3.75 kWp.

Irrigation of peppers in southern Serbia using PV systems

For watering of the peppers there is an average need for water which is about 300 mm. During 60 days of watering, with 5 m^3/h, a minimum of 6 kWh electrical energy is needed per day. Due to a slightly higher radiation and lower capacity of watering, the required power of PV modules is 2.25 kWp.

The price of PV irrigation systems for different plants

The price of the PV modules and the electrical pumps with MPPT controller presents the largest part of the whole PV based irrigation system. Without the elements necessary for water delivery to the plants (well, pipes, drip tapes, valves, filters), the price of PV irrigation systems is 1.3 €/Wp. The price is defined according to the average prices of PV modules and electric pumps which can be found in the market.

The cumulative cost saving

The cumulative cost saving (CCS) is the measure of profitability the PV irrigation systems.

After the first year CCS_1 is calculated based on the expression:

$$CCS_1 = C_{PVIS} - (C_{PUMP} + C_{M1} + C_{F1}) \quad (5)$$

Every next year CCS_i is calculated as:

$$CCS_i = CCS_{i-1} - \sum_i (C_{Mi} + C_{Fi}) \quad (6)$$

DISCUSSION

Based on the previously described components and parameters of PV systems for watering apples, raspberries and peppers, in various regions of Serbia, the techno-economic analysis of profitability has been made. The analysis was made for an area of 1 ha, for two cases: one with 100 % own funding of the investment, and the second by 50 % grant funding.

The cumulative cost savings for 20 years, which is projected to be the minimal installation period of PV irrigation systems, are shown in the following graphs. The values in the graphs represent the difference between the funds invested in the PV system and the classic irrigation system with fuel consumption. In the analysis a 5 % annual increase of fuel price and maintenance cost are included. The irrigation system becomes profitable when the CCS becomes negative. At the end of the analyzed interval, the higher the negative value of the CCS become, the higher are the savings, which means that the PV irrigation system is more cost-effective. All the values are expressed in Euro. Figure 3 shows the CSS irrigation area of 1 ha, financed by own funds. Irrigating apples and raspberries using the PV system is unprofitable, while the irrigation of peppers in the South of Serbia will pay off after five years.

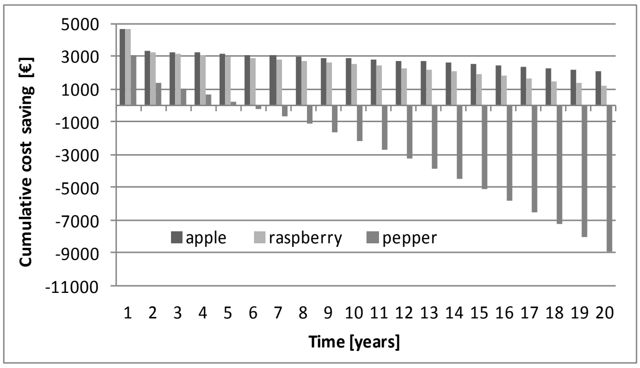

Fig. 3. Cumulative cost savings of 1ha, own investment

In the case when the government subsidies are used (Figure 4) for the PV irrigation system, watering 1 ha of apples will pay off after 12 years, for the raspberries after 7 years and in case of the pepper it takes only 1 year to pay off the investments.

Additional analyses were done with a reduced surface of 0.5 ha. In that way, conditions for reducing the investment in PV irrigation systems is created. If bigger surface needs to be irrigated, sequential irrigation has to be applied (by 0.5 ha parcels), leading to the process length and fuel consumption increase.

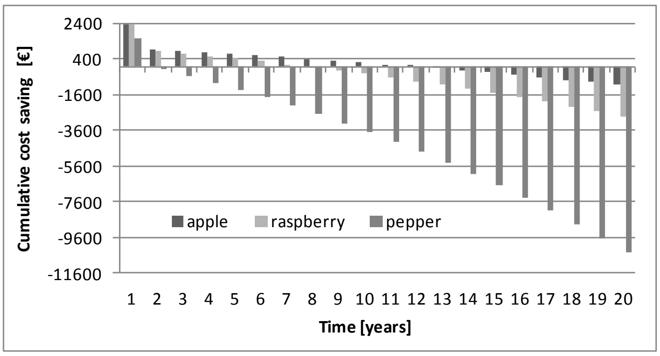

Fig. 4. Cumulative cost savings of 1ha, government subsidy

Figure 5, shows the CSS for the irrigation area of 0.5 ha, financed by own funds. Watering the apples using the PV system remains unprofitable in 20 years interval. For the raspberries the investment would pay off after 16 years, while for the pepper in the south of Serbia, that period would be 3 years.

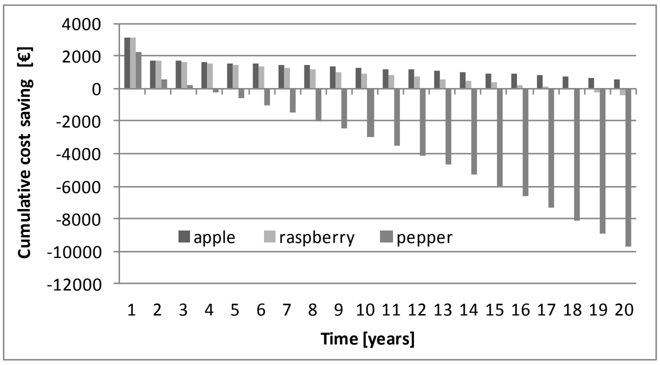

Fig. 5. Cumulative cost savings of 0,5ha, own investment

In the case of using government subsidies for irrigating an area of 0.5 ha (Figure 6) using the PV system for watering of apples would pay off after 3 years, with the raspberries after 2 years and with peppers after 1 year.

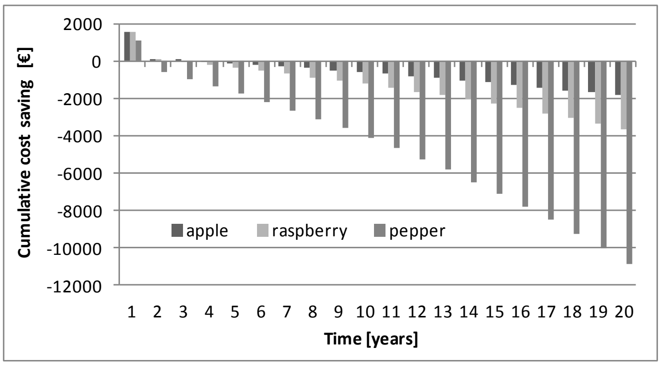

Fig. 6. Cumulative cost savings 0,5 ha, subvention

CONCLUSION

Republic of Serbia has significant solar potential (1400 kWh/m^2 in average), especially during plant vegetative state. In average, the lack of rainfall during the same period is 160mm. The correlation between the lack of rainfall and the solar irradiation level indicate a strong possibility for the use of photovoltaic based irrigation systems. Depending on the cultivar group, area, the frequency of irrigation and the geographical region the power level of the PV modules for the analyzed PV systems is ranging between 2 kWp and 6 kWp.

The PV watering system requires big initial investments. Therefore, it is necessary to carefully analyze the market that offers the necessary equipment, their quality and price. In addition, it is necessary to harmonize the wanted watering surface with the grown culture. The analyses show that the systems will pay off earlier if smaller surfaces are irrigated. For example, for irrigating 1ha of raspberries the payback period would be 7 years, whereas a system with smaller capacity (0.5 ha) would pay off after 2 years, with subsidies. Watering the apples with own funding is not profitable with 1 ha, and not even with 0.5 ha. However, if the orchard covers a larger area, it is necessary to use the irrigation more times during the year, so at one moment, this system will pay off, too. So, PV irrigation systems with higher power can also be profitable. What is necessary to do is to use them as often as possible.

PV irrigation systems, as well as conventional ones, may be portable. In that way, it can easily be used in different places. As in Germany, a household can sell electrical energy from RES to its neighbor, so the independent PV irrigation system can be rented too. In that way, the profitability of the system is increased.

Besides the economic aspect, the impact on the environment can be observed, too. Using solar energy instead of diesel fuel for irrigation reduces the emission of harmful gases. If the average CO_2 emission per kilometer is 150 g, or per liter consumed diesel fuel is 3 kg (*ICCT*), for the analyzed irrigation PV system the savings ranges from 0.4 t to 4.5 t annually. These values are gaining in importance if one takes into account the time of exploitation the systems and the area of the land which could be irrigated.

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