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Monitoring sugar beet rooting depth irrigated with recycled waste water and different irrigation methods for water savings in an arid climate

A.M. Hassanli[1,2*], Sh. Ahmadirad[1], S. Beecham[2]

[1]Department of Natural Resources and Environment, College of Agriculture, Shiraz University, Shiraz, I. R. Iran
[2]School of Natural and Built Environments, University of South Australia, Adelaide, SA, Astralia

*Corresponding Author: ali.hassanli@unisa.edu.au

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ABSTRACT- A detailed understanding of crop rooting systems will facilitate water use reduction, optimized nutrient uptake and irrigation scheduling more efficiently. A field experiment was conducted during 2005-2006 to investigate sugar beet rooting depth growth, irrigated with three irrigation methods (subsurface drip, surface drip and furrow) and two water qualities (recycled wastewater: EC= 1.52 dS m^{-1} and fresh water: EC=0.51 dS m^{-1}) in order to improve irrigation water management. A local rooting depth model was developed and three empirical models describing the root growth were evaluated. A significant reduction in sugar beet root depth was observed in the plots irrigated with furrows compared to those irrigated with the pressure irrigation methods. However, no significant difference ($p<0.05$) in root depth was observed for the crops irrigated with recycled wastewater and fresh water. A good correlation (R^2 = 0.99) between root depth and time was observed. The results also showed that using a locally developed rooting depth model to predict the soil water depletion may lead to water savings of between 20% and 34% when compared to the empirical models developed in other regions. The highest root yield obtained was 80 t ha^{-1} by surface drip irrigation with recycled waste water and the lowest was 41.4 t ha^{-1} by furrow irrigation with fresh water.

INTRODUCTION

Plant roots extract essential resources such as water and nutrients from soil. A detailed understanding of rooting system of crops will help to reduce water consumption, optimize nutrient up take and reduce inverse environmental impacts (Smith et al., 2000). In addition, an appropriate irrigation scheduling requires information about the development of rooting depth with time (Borg and Grimes, 1986). Rooting depth is the depth of the soil reservoir where a plant can obtain water and nutrients. The amount of water used by a crop depends on the soil water holding capacity and on the rooting depth (Martin et al., 1990). Crop roots do not extract water uniformly from the entire root zone; thus, the effective rooting depth is that portion of the root zone from where a crop extracts the majority of required water. Evans et al. (1996) reported that deeper roots can extract more water to keep the plant alive, but they do not necessarily extract sufficient water to maintain an optimum growth. Draycott (2006) describes how the plant rooting system develops from the day of germination until maturity to absorb water and nutrients.

In general, crops do not extract water from the lower depths as quickly and efficiently as from the upper layers. However, in arid areas, a higher percentage of available water from the lower portion of the root zone is usually extracted because crops are under more water stressed conditions (Bot and Benites, 2005). Draycott (2006) reported that a sugar beet root system initially grows at a rate of approximately 10 mm/day and can increase to 15 mm/day and in the absence of physical barriers can reach up to 200 cm. But it mainly varies between 60 and180 cm (Bot and Benites, 2005). In most cases, however, the majority of root activity takes place within the upper 30-50 cm where root density is the greatest (Draycott, 2006). Rinaldi and Vonella (2004) reported that despite the fact that sugar beet roots can grow to 200 cm, they observed a depth of 60 cm in a compacted calcareous soil. Pierret et al. (2000) used X-radiography and image analysis to measure the root length density. Franzen et al. (2004) used soil core and pit excavation methods for monitoring the root depth of sugar beet. They explained that the deepest root depth varied between 163 and 188 cm. Martin et al. (1990) found a variation of 80 and 200 cm. Romo and Diaz (1985) dug observational trenches to compare the effect of drip and flood irrigation on root distribution. Smith et al. (2000) reported that minirhizotron methods are more labour-saving than core sampling or profile wall methods. Kücke et al. (1995) used four different techniques at three different sites to measure sugar beet root length and density. They concluded that the core-break method is not reliable if it is not calibrated. They also examined the core method (where roots are extracted and the length is measured directly) and the monolith method (where the roots are extracted from monoliths dug out from a profile wall). As it is clear, measuring root development is not a straightforward and easy task. Larson and Johnston (1955) conducted a set of experiments to determine the sugar beet root development as well as the effect of soil moisture on the yield. They reported that moisture had no effect on the shape and anatomy of root extension. To develop an effective irrigation schedule, the plant factors such as the effective rooting depth, crop water uptake rates and crop sensitivity to drought stress must be taken into account (Evans et al., 1996). In addition to direct measurement which is a tedious task, the root depth can be estimated by one of the models reported in Martin et al. (1990). However, since a multitude of variables affects the root growth, calibration is needed at each site. Several studies on root anatomy and water uptake for corn and other crops have been reported but similar work on sugar beet is lacking (Draycott, 2006). Although plant roots play a vital role in the supply of resources for growth, we have a relatively poor understanding of how they function in the natural soil environment (Smith et al., 2000). Much research has been undertaken to improve modelling of the above ground development of plants and the water movement in the soil. In contrast, there is still a lack of information on plant root growth modelling and water-nutrient uptake, particularly for sugar beet. The aims of this paper are to monitor the sugar beet rooting depth development, examine the effect of irrigation methods and water qualities on the root depth, and investigate the effect of root depth monitoring on irrigation watersavings.

MATERIALS AND METHODS

An experiment was designed and conducted within two consecutive years (2005 and 2006) in the Korbal plain in Southern Iran (latitude: 29◦ 47′; longitude: 52◦ 42′) to evaluate the sugar beet rooting depth development with time and its effect on irrigation water management. The experimental site was located in an arid climate with the long sunny days. The annual mean rainfall was 340 mm and the annual mean evaporation from Pan was 2580 mm. In such climates, the crops rely heavily on irrigation. Three different irrigation methods were employed using both recycled municipal wastewater and fresh water (the quality analysis is given in Hassanli et al. (2010)). The experiment was a split plot design with two main plots (recycled and fresh water) and three sub plots (subsurface drip, surface drip and furrow irrigation, with 8140, 8520 and 11400 m^3ha^{-1} irrigation water respectively). This experimental design resulted in a total of six treatments. Each treatment consisted of four replicates, resulting in a total of 24 plots. Mean comparison was undertaken using the Duncan test at a 5% significance level. This split plot experimental method has been used successfully in other crop studies (Hassanli et al., 2009). Each of the 24 plots was 7 m long and 6 m wide and consisted of 10 crop rows. Sugar beet (*Beta vulgaris* L. Dortee) was sown and irrigated in the third week of April in each year at a row spacing of 60 cm and a plant spacing of 15-20 cm. The crop was harvested manually in the last week of October of each year (two weeks prior to harvest, irrigation was stopped). The chemical composition of both irrigation waters and the physico-chemical properties of the soil are given in Hassanli et al. (2009). The dominant soil texture was clay loam (47% clay, 42% silt and 11% sand). The subsurface drip laterals for each crop row were buried at a depth of 15 cm with dripping points located 30 cm apart. The 16 mm surface drip laterals were laid on the soil surface with dripping points located 30 cm apart. Irrigation water was applied once every 4 days. The volume of applied water was based on the soil water deficit measured in the root zone by gravimetric method. At each irrigation event, the depleted soil moisture was applied and the volume of irrigation water was measured. The crop root depth was monitored manually every week during the growing season using the trench profile wall method (Romo and Diaz, 1985; Kucke et al., 1995). In this method, a small back-hoe was used to dig a soil pit (trench) approximately 100 cm wide and 100 cm deep along the crop rows in one of the four replicates for each of the six treatments. This resulted in six trenches being dug prior to planting. The soil pits were prepared using a spade and trowel to expose the sugar beet roots at the observation times. The mean of the longest roots along the trench was measured in each trench by a ruler, as shown in Fig. 1.

Fig. 1. In-situ rooting depth measurement

Based on the first year's monitoring data, a polynomial equation (R^2 = 0.99) was fitted to the collected data. This equation was tested with the second year's monitoring data. A good correlation (R^2 = 0.99) between the two years' data was observed. The average of rooting depth for both years was used to formulate a locally developed model (LDM) as shown below:

$$Y=-0.005X^2+1.462X-18.21 \quad (1)$$

where Y is the sugar beet root depth (cm) in the experimental condition and X is the number of days since plantation time.

To examine the performance of the LDM presented in Eq. 1, it was compared with three other crop models, namely, Borg and Grimes (1986), sigmoid model, Martin et al. (1990), Linear Growth Model and CROPWAT, assuming 30 and 100 cm for the germination and mature stages.

Borg and Grimes' model (1986) describes root depth by a sigmoid development of the roots from the planting date until maturity. The model, shown in Eq. 2 is commonly used because of its practicality under the field conditions:

RDt=Rmax {0.5+0.5sin [3.03(t /tmax) - 1.47]} (2)

where R D t is the current root depth (cm), Rmax is the maximum effective rooting depth (cm), t is the number of days since germination and tmax is the number of days from germination until the maximum effective rooting depth.

The Linear Growth Model presented by Martin et al. (1990) estimates the vertical root depth development by Eq. 3.

RD=Rmin + (Rmax – Rmin) (t/tmax) (3)

where Rmin is the root depth (cm) at the germination time. The root depth estimated by the above models was based on the measured Rmax at tmax.

The volume of irrigation water based on the root depth, bulk density, soil moisture at the irrigation time and at the field capacity and also the irrigation efficiency, the physico-chemical properties of the soil, and the chemical properties of the recycled and fresh waters are described in Hassanli et al. (2010).

RESULTS AND DISCUSSION

Rooting depth will affect the amount of water available to the plants and the amount of water required to be stored in the root zone at each irrigation event during the growing season. However, the crop roots cannot extract soil moisture uniformly from the entire root zone. It is important to understand the effect of environmental and physiological variables on the rooting depth pattern at a particular site in order to improve the irrigation management practices. The statistical analysis showed that although the quality of both applied waters was different, there was no significant difference in the rooting depth in the plots irrigated with recycled and fresh waters (Fig. 2).

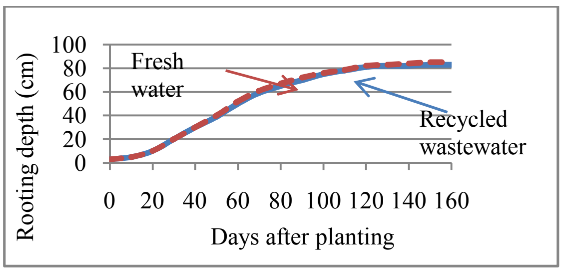

Fig. 2. Effect of water quality on sugar beet rooting depth

The salinity of the recycled water was nearly three times as much as that of the fresh water and the concentration of Na^+, SAR, HCO_3^- and Cl^- was much higher than that of the fresh water. The details are given using four empirical methods are presented in Fig. 3. The concentration of the two main nutrients in the recycled wastewater was also higher than that of the fresh water (Table 1). However, none of these differences showed a significant difference on sugar beet root depth. It appears that since sugar beet (*Beta vulgar*) is a salt tolerant crop (1)whose threshold is 7.0 d S/m (Rhoades et al., 1992), the salinity level in both applied waters was not enough to affect the sugar beet growth and consequently its root depth. How ever ,a considerable difference in Na^+ could affect sugar beet growth by causing soil dispersion and reducing the infiltration rate. In this 2-year experiment, the average root growth difference irrigated with recycled and fresh waters was not significant.

Table 1. Nutrient concentration, EC and pH in the recycled and fresh waters

	Recycled water (mgL^{-1})	Fresh water (mgL^{-1})
Total Nitrogen (TN)	18.5	14.3
Total Phosphorus (TP)	1.25	0.47
Salinity (EC, dSm^{-1})	1.52	0.51
pH	7.62	7.77

A significant reduction (at the 5% significance level) in rooting depth at 100 and 140 days after planting was observed in plots irrigated by furrow irrigation compared with those irrigated by both pressure irrigation methods (Table 2). The deepest final root depth of 83.9 cm was measured in the plots irrigated using the subsurface drip method. The possible reasons for limited rooting depth could be due to the compacted soil below 80 cm or/and water table variations in the study region. This depth did not differ significantly compared to the plots irrigated using the surface drip method. The measured root depths in all experimental treatments showed that there was a very good correlation (R^2 = 0.99) with time in the polynomial LDM equation (Eq. 1), as shown in Fig. 3. There was also a good agreement with the Borg and Grimes' model (Eq. 2). However, the experimental results did not support a linear increase in rooting depth from germination to maximum depth as given in Martin et al. (1990) Linear Growth Model (Eq. 3).

The findings of this study showed that assuming a linear increase in rooting depth in time ,as stated by some empirical models, is questionable for rooting depth estimation. In practice, environmental conditions such as restricting layers, presence of ground water table, climate and nutrient availability could all affect the rate of rooting depth growth Fertilizers (N and P) were added to the soil, based on the soil test results taken prior to the application of recycled and fresh waters, to ensure that the difference was due to the nutrient contents of the irrigation waters. In this study, using the measured depths led to significant water savings compared to the three empirical models developed in other regions for crop rooting depth estimation. The rooting depths measured in-situ during the crop growth stages and the estimated rooting depths

Table 2. Effect of irrigation methods on the rooting depth (cm) at different stages of growth in 2005 and 2006

	30-day-rooting depth		70-day-rooting depth		100-day-rooting depth		140-day-rooting depth	
	2005	2006	2005	2006	2005	2006	2005	2006
Furrow	16.7a	16.6a	60.6a	59.9a	73.6b	75.1b	80.7b	79.6b
Subsurface drip	17.3a	15.1a	61.0a	58.1a	79.5a	79.9a	84.7b	83.1a
Surface drip	18.4a	16.6a	63.7a	60.2a	77.5a	78.6a	83.6b	83.1a

rooting depths estimated by the LDM were much closer to the observed rooting depth compared to the estimation by the other three methods. The root depth obtained from the Borg and Grimes' model (1986) was closer to the measured rooting depth than the CROPWAT model, assuming 30 and 100 cm for the germination and mature stages, respectively. It was also closer to the measured depths than the values predicted using the Linear Growth Model proposed by Martin et al. (1990). These differences led to a significant difference in predicted irrigation water when irrigation is scheduled on the basis of compensation of the soil water depletion in the root zone at each irrigation event.

Table 3 shows that using the rooting depth obtained from the LDM (Eq. 1) to estimate the irrigation water is required to compensate the depleted soil water at each irrigation event and led to significant water savings during the growing season. For example, 60 days after planting, savings of 25.5%, 36.8% and 34.6% were achieved compared to the irrigation water estimated to refill the soil to the field capacity within the root zone using the Borg and Grimes model, the Linear Growth Model of Martin et al. (1990) and CROPWAT, respectively.

This is because the Borg and Grimes (1986) and Linear Growth models both assume a final depth of 100 cm after 90 days of growth. However, this assumption does not agree with the observed data in this study where the measured sugar beet root depth was 82.3 cm and 84.5 cm after 120 days and 140 days, respectively (Fig. 3).

This shows that applying general models to estimate the root depth in conditions different from those of the assumed model is problematic since they rarely account for environmental and physical variations at the site. This could be due to the fact that these models were developed for different climatic and geographical conditions. The amount of required irrigation water based on the rooting depth for different irrigation methods are shown in Table 4.

This table also shows that using the LDM for rooting depth estimation leads to significant water savings. However, the possible salt build-up within the root zone needs to be taken into account, particularly when using recycled Waste water containing inherently higher salt content. Otherwise either excess irrigation with fresh water or excess rainfall would be required to leach this accumulated salt.

Table 3. Estimated required water to compensate water depletion (mm) during the growing season using direct root measurement and including LDM model

Days after planting	Measured root depth	LDM	Borg & Grimes	Cropwat	Linear Growth Model
30	8.3	10.4	11.6	24.8	21.6
60	24.2	25.1	33.7	39.7	38.4
90	36.3	35.3	48.1	49.6	49.6
120	40.4	40.8	49.6	49.6	49.6
140	41.4	41.9	49.6	49.6	49.6

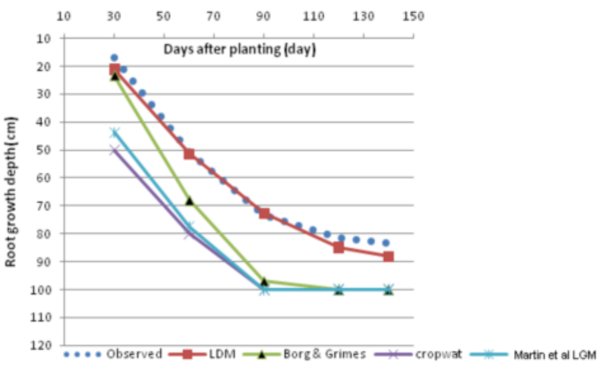

Fig. 3. Observed and estimated root depths of sugar beet against days after plantation

Table 4. Estimated applied irrigation water to refill depleted water (mm) using four models for rooting depth estimation in three irrigation methods

Method of rooting depth estimation	furrow	subsurface drip	surface drip
LDM	1140	814	859
Borg & Grimes	924	973	1027
Cropwat	1299	1094	1155
LinearGrowth Model	1258	1060	1119

The findings of this study have shown that the development of a local empirical model for rooting depth estimation, combined with soil water monitoring, may lead to more efficient produced greater water saving than using the empirical irrigation practices. In this study, the use of a locally developed model to estimate the sugar beet root depth for irrigation scheduling during the whole growing season models led to a better result comparing to that have been developed in other regions. This achievement is considerable in the study region that inherently suffers from w ater scarcity and is criticized during the severe droughts.

CONCLUSIONS

A Two-year study was conducted using root depth monitoring approach in an arid area. The results obtained from a locally developed empirical model (LDM) for monitoring and rooting depth estimation with time was more accurate than those using the three other preexisting empirical models. This could be due to the influence of environmental and physical conditions at the study site and the irrigation management practices employed. An analysis of the experimental data showed that using the LDM for rooting depth estimation, coupled with soil water monitoring for irrigation scheduling, led to significant water savings. In this study, irrigation with recycled municipal wastewater did not significantly affect the sugar beet rooting depth compared to irrigation with fresh water. This finding could be important since it indicates that sugar beet roots may not be adversely affected by implementation of recycled water reuse schemes. In contrast, the root depth influenced by the irrigation methods at some growth stages was observed. Using site-based rooting depths monitoring for estimating the irrigation water required to compensate the depleted soil water at each irrigation event may lead to considerable water savings although the other considerations may also need to be taken into account. For example, leaching practices to keep salinity below the threshold levels may be required to avoid excess salinity build-up within the root zone.

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REFERENCES

Abrol, I.P., Yadav, J.J.P., & Massoud, F.I. (1988). Salt-affected soils and their management. FAO Soil Bull. No. 39. 131p

Borg, H., & Grimes, D.W. (1986). Depth development of roots with time: an empirical description. *Trans. of the ASAE*, 29(1), 194-197.

Bot, A., & Benites, J. (2005). Drought-resistant soils-optimization of soil moisture forsustainable plant production. FAO Land and Water Bull. No. 11. 82p

Clark, K.D. (1998). CROPWAT for Windows: User guide. University of Southampton. Version 4.2. 43p.

Draycott, A.P. (2006). Sugar beet, Blackwell Publishing Ltd. 474p.

Evans, R., Cassel, D.K., & Sneed, R.E. (1996). Soil, water and crop characteristics important to irrigation scheduling. North Carolina Cooperative Extension Servic. http://www.bae.ncsu.edu/programs/extension/evans/ag452-1.html.Viewed 20 August 2008.

Franzen, D.W., Anfirud, M., & Carson, P. (2004). Sugar beet rooting depth. Sugar beet Research and Extension Reports, No.35, 105 p.

Hassanli, A.M., Ebrahimizadeh, M.A., & Beecham, S. (2009). The effects of irrigation methods with effluent and irrigation scheduling on water use efficiency and corn yields in an arid region, *Agricultural Water Management*, 96, 93-99.

Hassanli, A.M., Ahmadirad, SH., & Beecham, S. (2010). Evaluation of the influenceof irrigation methods and water quality on sugar beet yields and water use efficiency. *Agricultural Water Management*, 97, 357-362.

Kücke, M., Schmid, H., & Spiess, A. (1995). A comparison of four methods for measuring roots of field crops in three contrasting soils. *Journal of Plant and Soil*, 172(1), 63-71.

Larson, W.E., & Johnston, W.B. (1955). The effect of soil moisture level on the yield, consumptive use of water and root development by sugar beets. *Soil Scince Society American Journal*, 19, 275-279.

Martin, D.C., Stegman, E.C., & Feres, E. (1990). Irrigation scheduling principles. In: Hoffman, G.J., Howell, T.A. & Solomon, K.H. (1992). Management of farm irrigation systems. ASAE monograph, St. Joseph, 155-199.

Pierret, A., Moran, C., McLachlan, C.B., & Kirby, J.M. (2000). Measurement of root length density in intact samples using X-radiography and image analysis. *Image Analis Sterology*, 19, 145-149.

Rhoades, J.D., Kandiah, A., & Mashali, A.M. (1992). The use of saline waters for crop production. FAO Irrigation and Drainage Paper No. 48. 133p.

Rinaldi, M., & Vonella, A.V. (2004). The response of autumn and spring sown sugar beet (*Beta vulgaris* L) to irrigation in Southern Italy: Water and radiation use efficiency. *Field Crop Research*, 95(2), 103-114.

Romo, R., & Diaz, D.H. (1985). Root system and nutritional status of peaches under drip and flood irrigation in warm climates. *Acta Horticultural*, 173, 167-175.

Smit, A.L., Bengough, A.G., Engels, C., Noordwijk, MV., Pellerin, S., & VanDeGeij, S.C. (2000). Root Methods: A Handbook, Springer,587p.

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پایش توسعه عمقی ریشه چغندر قند در شرایط آبیاری با پساب فاضلاب باروشهای مختلف آبیاری بر صرفه جویی آب در یک اقلیم خشک

علی مراد حسن لی [۱،۲]*، شهرام احمدی راد[۱]، سیمون بیچام[۲]

[۱] بخش منابع طبیعی و محیط زیست دانشکده کشاورزی دانشگاه شیراز، ج. ا. ایران

[۲] مرکز مدیریت آب ، دانشکده محیط‌های طبیعی و دست‌ساخت دانشگاه استرالیای جنوبی، آدلاید استرالیا

*نویسنده مسئول

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واژه های کلیدی:
مدل های عمقی ریشه
پایش عمقی ریشه
پساب فاضلاب
چغندر قند

چکیده- آگاهی از جزییات سامانه توسعه ریشه گیاهان به کاهش مصرف آب، بهینه‌سازی مصرف عناصر غذایی و برنامه‌ریزی آبیاری کمک می‌کند. به منظور بررسی اثر پایش توسعه عمقی ریشه چغندر قند در سه روش آبیاری (جویچه‌ای، قطره‌ای سطحی و قطره‌ای زیر سطحی) با دو کیفیت آب (پساب فاضلاب شهری تصفیه شده با شوری ۱/۵۲ و آب معمولی با شوری ۰/۵۱ دسی زیمنس بر متر) بر بهبود مدیریت آب، یک آزمایش دو ساله در سال‌های ۶-۱۳۸۵ در مرودشت فارس انجام گردید. یک مدل محلی برای تخمین توسعه عمقی ریشه گیاه چغندر قند برای منطقه مورد مطالعه تدوین و با سه مدل تجربی دیگر که توانایی تخمین توسعه عمقی ریشه گیاه را دارند مورد ارزیابی قرار گرفت. نتایج تجزیه و تحلیل آماری نشان داد کاهش معنی داری ($P<5\%$) در توسعه عمقی ریشه‌ها در پلات هایی که با سیستم جویچه‌ای آبیاری می‌شدند در مقایسه با پلات‌هایی که با سیستم‌های قطره‌ای آبیاری می‌شدند وجود دارد. اما تفاوت معنی‌داری ($P<5\%$) در توسعه عمقی ریشه گیاه در پلات‌هایی که با پساب و آب معمولی آبیاری می‌شدند مشاهده نشد. نتایج اندازه‌گیری‌های میدانی طول عمقی ریشه ها نشان داد همبستگی قوی ($R^2=99$) بین رشد عمقی ریشه و زمان وجود دارد. همچنین نتایج بررسی‌ها نشان داد بهره‌گری از مدل تدوین شده محلی، برای براورد ظرفیت ذخیره آب در محدوه ریشه برای برنامه‌ریزی آبیاری در برخی مراحل رشد ممکن است منجر به صرفه‌جویی آبیاری بین ۲۰ تا ۳۴٪ در مقایسه با بهره‌گری از مدل‌های تجربی که برای مناطق با شرایط متفاوت تدوین شده‌اند گردد.در این تحقیق بیشترین عملکرد معادل ۸۰ تن در هکتار در پلات‌های آبیاری قطره‌ای سطحی با پساب و کمترین عملکرد معادل ۴۱/۴ تن در هکتار در پلات‌های آبیاری جویچه‌ای با آب شیرین حاصل شد.