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Publication Information

Pub ID	Pub Date
072251	2007 ASABE Annual Meeting Paper

An ASABE Meeting Presentation

Paper Number: 072251

Evaluation of Sensor Based Residential Irrigation Water Application

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Written for presentation at the
2007 ASABE Annual International Meeting
Sponsored by ASABE
Minneapolis Convention Center
Minneapolis, Minnesota
17 - 20 June 2007

Abstract. *An irrigation study to determine the effects of sensor based irrigation controllers on residential irrigation water use is described in this paper. This project is comprised of 59 homes in Pinellas County, Florida, with automatic in-ground residential irrigation systems. Experimental treatments evaluated include: T1) an automatic time based irrigation controller, set and operated by the cooperator, with the integration of a soil moisture sensor, T2) a rain sensor with a timer-based irrigation schedule, T3) an automatic time based controller only, and T4) similar to T2 with educational material detailing seasonal irrigation recommendations based on historical climate data. Preliminary results show that sensors are successful for irrigation water use savings at the single family home level. Data reported here is from June 2006, through March 2007. In homes with the installation of the soil moisture sensors (T1), water savings of 51% have been recorded compared to homes with an irrigation time clock only (T3). With the installation of a rain sensor (T2) the water used was 19% lower than T3. A further decrease in the amount of water use occurred after the distribution of the educational materials, with a difference of 58% between the two rain sensor treatments (T2 and T4).*

Keywords. Soil moisture sensor, rain sensor, automation, irrigation scheduling, residential irrigation, water use, turfgrass, turf quality, landscape.

Introduction

Nearly all new homes in Florida are constructed with in-ground automatic irrigation systems. Studies have shown that residential lawn and landscape irrigation can account for more than 59% of a home's total water use (Mayer et al., 1999). Furthermore, recent research in Florida has indicated that homeowners are over irrigating, by 2 to 3 times the required amounts (Haley et al., 2007). Irrigation water use conservation efforts are necessary due to the rise in the population of Florida. The South West Florida Water Management District (SWFWMD), which is one of the five Florida water management districts, accounts for a quarter of the State's overall population, with more than four million inhabitants. Between 1990 and 2000, the population within the District grew by approximately 19%, and is projected to increase another 1.8 million by 2025 (SWFWMD, 2005). The 2000 population for Pinellas County was 921,482 and is forecasted to be 1,078,600 by 2025, an increase of 17% (SWFWMD, 2005).

Within the SWFWMD, public water use accounts for 42% of the total freshwater consumption, which is the second largest water use sector after agriculture. Although there has been considerable population growth, the water use amount has remained fairly constant from 1993-2002. This is a result of an 11% decrease in per capita water use, from 533 to 476 L/d. However, when the per capita water use is normalized for drought or excessively wet seasons; the total public water use shows an upward trend. It is expected that as population growth continues, public water use will become the dominant water use sector. According to the SWFWMD, the projected water demand for the public supply is expected to increase to 845 million L/d (SWFWMD, 2005). More than 80% if this water withdrawn from groundwater sources, most of which comes from the Floridan aquifer, which has increasingly been regarded as a limited resource. Within the SWFWMD, the exclusive source of natural replenishment to the Floridan aquifer is from precipitation.

Within the SWFWMD, irrigation is permitted once per week. In accordance with Pinellas County Code 82-2, irrigation within Pinellas County is only authorized for one day a week and watering is prohibited between the hours of 8:00 am and 6:00 pm (PCU, 2006a). The current rate for potable water from Pinellas County Utilities is $4.04 as of October 1, 2006 for 3780 L, increasing from $3.60 (PCU, 2006b). According to the Florida Water Rates Evaluation of Single-Family Homes, completed in 2005, from a questionnaire regarding water matters, the main concern of homeowners was outdoor use (Whitcomb, 2005).

In a study on residential irrigation efficiency with the St. Johns River Water Management District (SJRWMD), on average, 64% of the water used by residences went to irrigation. In the summer months this percentage increased up to 88%. The study also showed that setting irrigation controllers with respect to historical turfgrass seasonal water needs resulted in a 30% reduction in irrigation water applied (Haley et al., 2007). During this study it was observed that the homeowners did not have a clear understanding of when and how much to irrigate. With the combination of substantial microirrigated landscape planting areas, and irrigation based on historical evapotranspiration rates, irrigation water use was reduced on average by 50% (Haley et al., 2007).

Sensor based technology can result in irrigation water savings. A soil moisture sensor is buried in an irrigation zone, and an adjustable threshold controller is mounted near the irrigation system time clock. This sensor can result in the bypass of scheduled irrigation events based on soil moisture content in the particular irrigation zone. Soil moisture sensors have been shown to reduce irrigation water use under rainy conditions up to 92%, with no decline in turf quality (Cardenas-Lailhacar et al., 2007). Rain sensors are the most common type of senor used in conjunction with automatic irrigation systems. They should be installed in an area unobstructed from rainfall and after a rain event the sensor causes the system to bypass to prevent unnecessary irrigation similar to soil moisture sensors. All irrigation systems in Florida installed since 1991 are required to have a functioning rain sensor (Florida Statutes, Chapter 373.62). However, this statute is not typically enforced (Whitcomb, 2005). According to University of Florida research, systems which incorporate mini-click rain sensors set at the 6 mm threshold can save up to 34% more water than systems without a functioning rain shut-off device (Cardenas-Lailhacar et al., 2007).

The objectives of this study are to assess the effect of soil moisture sensor control, rain sensors, and educational materials for irrigation scheduling on residential irrigation water application on cooperating homes in Southwest Florida.

Materials & Methods

The homes included in this research project are all located in the City of Palm Harbor in Pinellas County (Figure 1), within SWFWMD. Fifty-nine residential cooperators with automatic in-ground irrigation systems have been recruited. The area was divided into four quadrants, based on distance from the coast and natural groupings of homes and labeled as follows: Northwest quadrant (L1), Southwest quadrant (L2), Southeast quadrant (L3), Northeast quadrant (L4), these are displayed in Figure 1.

Pinellas County has a humid subtropical climate, with frost and freezing temperatures occurring at least once annually. The average annual rainfall within the SWFWMD is 1350 mm, with 60-65% occurring June through August (SWFWMD, 2005) when evapotranspiration rates are highest. The groundwater supply in southwest Florida comes from the Floridan aquifer. This aquifer is primarily dependant on the rainfall which occurs in the district as the sole source of natural replenishment (SWFWMD, 2005).

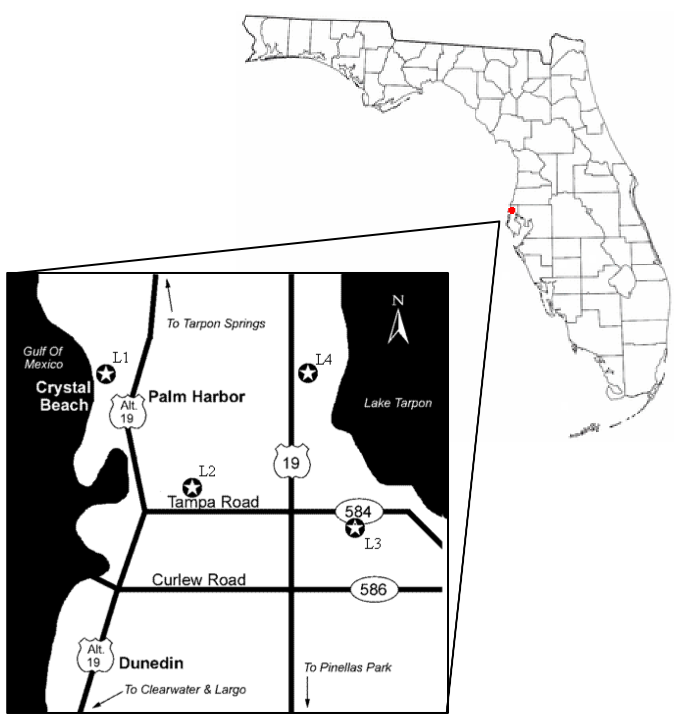

Figure 1. Geographical position of irrigation research site and location names within research site.

A weather station was installed at each of the four locations to measure the climactic parameters. The stations were centered approximately within a 2 km radius of the homes. The station sites are county owned and managed properties, with flat-grassed areas and minimal tree canopy and other structures at least 61 m away if possible. Date, time, relative humidity and temperature (model HMP45C, Vaisala, Inc., Woburn, MA), solar radiation (model LI200X, Li-Cor, Inc., Lincoln, NE), wind speed and direction (model WAS425, Vaisala, Inc., Sunnyvale, CA) and, precipitation (model TE525WS, Texas Electronics, Inc., Dallas, TX), are recorded in 15 minute intervals via a CR10X data logger (Campbell Scientific, Inc., Logan UT).

To determine the actual amount of irrigation needed, evapotranspiration was calculated from the weather parameters logged from sensors at each weather station. Since the calculated ETo relies on the quality of the weather data, integrity and quality assurance of these data must be assessed (ASCE-EWRI, 2004). In addition to data assessment, routine maintenance is performed to ensure the proper functionality of the weather station. Technical maintenance includes the evaluation, repair and replacement of equipment, while non-technical site maintenance includes removal of debris from tipping bucket, cleaning solar panel, bird prevention, mowing, etc. Common methods for quality assessments are done by comparing incoming parameters against relevant physical extremes, employing statistical techniques to find extreme or anomalous values, and comparing neighboring stations. Quality control for the weather data collected in this study, evaluated three primary weather parameters: solar radiation, temperature, and wind speed.

Household water consumption, both total and water used for irrigation is recorded by weekly flow meter readings. All of the homes included in this study obtain water from Pinellas County Utilities. The utility water meter is used to determine the total (indoor plus outdoor) amount of water consumed by the household. A flow meter was also installed in the irrigation mainline to determine the volume of irrigation water used. Positive displacement flow meters were purchased (Baum et al., 2003), and installed by a local contractor, on each of the cooperating residential homes. The meters were installed with no obstruction within approximately ten diameter lengths from the inlet and outlet of the meter when possible. Irrigated area for each home was determined as the pervious area from county property appraisal records. The irrigation water use for the homes was calculated as a depth of water applied (mm) by dividing the volume usage (m^3) by the irrigated area (m^2) of the home.

Irrigation system evaluations were conducted for each home included in the study. The evaluation is a means of quantifying the irrigation system performance. Irrigation cycle water consumption was computed by recording the actual flow rate for each zone multiplied by the zone run time. During this evaluation any required maintenance resulting from broken heads and leaks is noted. Any maintenance that would compromise the uniformity test was fixed before the testing began. An estimation of system distribution uniformity (DU) was calculated by performing a catch-can test following the Mobile Irrigation Lab Handbook guidelines for Florida (Micker, 1996). Uniformity of water distribution measures the relative application depth over a given area. This concept can assign a numeric value to quantify how well a system is performing. The term uniformity refers to the measure of the spatial differences between applied waters over an irrigated area.

Treatments

The homes were divided into four experimental treatments. The treatment classifications refer to the additional educational materials or sensor based technology incorporated into the systems. Treatment one, T1, homes have an Acclima TDT RS-500 soil moisture sensor set at the 10%

threshold, coupled with the timer-based irrigation controller. Treatment two, T2, homes have a mini-click rain sensor coupled with the timer-based irrigation controller. Treatment three, T3, homes are a comparison group and do not have any special control technology other than the existing time clock common to all homes. Treatment four, T4, homes have the current irrigation system with a mini-click rain sensor and educational materials. The educational materials include brochures of outdoor water saving tips developed by the SWFWMD and a customized irrigation run time card. The run time card is based on the home's specific system design and zone layout (i.e. application rates) and gives system run times for each season. The card is laminated and can be affixed to the controller box.

To limit variability, each treatment had an even distribution of previous water use trend and landscape level. Total residential water use data were analyzed based on two year historic data for each home. Bimonthly data, from April, 2003 to October, 2005, was provided by Pinellas County Utilities. To estimate the bimonthly irrigation water use, the indoor water use was subtracted from the total water consumption by assuming that indoor water use was the minimum bimonthly consumption over the two year period if less than 36,600 L. This value was determined as the average indoor water use for the population sample. The irrigation water use in volume was then divided by the calculated irrigated area to determine the irrigation application per given time period. The non-structural land area for each home was calculated from county parcel records and it was assumed that all of this area was irrigated. Once the bimonthly irrigation water use was estimated, each home was then categorized into an irrigation tendency classification. These classifications were based on quartiles where the low quartile was "low", two next quartiles (2 and 3) were "medium" and the upper quartile was classified as "high" irrigation users. Homes from each of these water use tendencies were approximately evenly distributed across the four treatments. From the provided data, 26% of the homes were low irrigation water users and had an average irrigation water application of 30 mm per month of water for outdoor use. Medium water users accounted for 48% of the homes and consumed an average of 62 mm of water for outdoor use monthly. The high water users had an average of 134 mm of water per month for outdoor use and comprised the upper 26% of the sample. Compared to a study in the Central Florida ridge, the water usage for the data analyzed here was considerably less. The average outdoor water use for the homes in the SJRWMD study ranged from 80-140 mm/month (Haley et al., 2007) compared to 30-134 mm/month here.

Initially every home was given a visual inspection and assigned a numeric value based on landscape level (Figure 2). The landscape level is based on the percentage turfgrass versus bedded areas: (LL1) turfgrass comprises a greater area then bedded landscape area, (LL2) turfgrass and bedded areas comprise equal parts of the landscape, and (LL3) turfgrass comprises a lesser area then bedded landscape area.

Figure 2. Landscape level examples, from left to right LL1, LL2, LL3.

The statistically significant differences between the treatments were performed within SAS (SAS, 2003). Bivariate data analysis was used to determine mean weekly irrigation water use presented by month. Pearson's correlation coefficient was used to determine additional effects that variables may have on the water use. The affect of water use and the interactions between and treatment and additional dependant variables was analyzed using multivariate analysis. The PROC GLM procedure was used with Duncan's Multiple Range Test to determine mean differences.

Results

Water Use

Results of the bivariate analysis are reported of the irrigation water application for the July 2006 through March 2007 time period (Fig. 3). Incorporation of a sensor clearly decreased water use. As the treatments were applied the plotted lines diverge (note arrows in Figure 3). The soil moisture sensor treatment (T1) showed reduced irrigation relative to the meter only treatment (T3) in September 2006 when the sensor installations commenced. After this point, the cumulative water use for T1 plateaus because of sensors bypassing scheduled events. The difference between the two rain sensor treatments (T2 and T4) is the distribution of the educational materials (T4). These materials were distributed during late November. An initial decrease in T4 water use can be observed during the December data collection month.

From Table 1 and Figure 3, it can be observed that the treatment without any additional sensor (T3) consistently used the most irrigation water, with a cumulative amount of 518 mm and a weekly mean consumption of 15 mm. The rain sensor treatment (T2) had cumulative irrigation of 418 mm for the given time period, averaging 11 mm per week. The soil moisture sensor treatment (T1) had total irrigation of 300 mm with a weekly mean use of 7 mm. The treatment with the lowest water use was that with the rain sensor plus educational materials (T4) with cumulative and monthly mean irrigation of 275 mm and 6 mm, respectively. It is likely that the irrigation on this treatment (T4) is lower because the materials were provided just prior to winter, when the run-time card suggests a large reduction in run times. Since most of the T4 homes did not previously have a functional rain sensor, it is unknown how only providing cooperators with educational materials would have affected the results.

Table 1. Mean weekly irrigation water use presented by month for each treatment. Duncan letters denote statistical differences at the $P < 0.05$ level.

Month and Year	Mean Weekly Usage (mm)				Mean Weekly ET_o (mm)	Mean Weekly P_{eff} (mm)
	T1	T2	T3	T4		
Jul-2006	.	3	12	.	30	32
Aug-2006	.	3	17	.	28	29
Sep-2006	0	6	8	.	28	41
Oct-2006	3	16	22	.	24	3
Nov-2006	9	14	17	.	21	0
Dec-2006	14	13	15	8	10	6
Jan-2007	6	11	11	6	13	4
Feb-2007	6	12	20	4	15	5
Mar-2007	11	18	17	8	21	1
Average	7 b	11 a	15 a	6 b	21	13

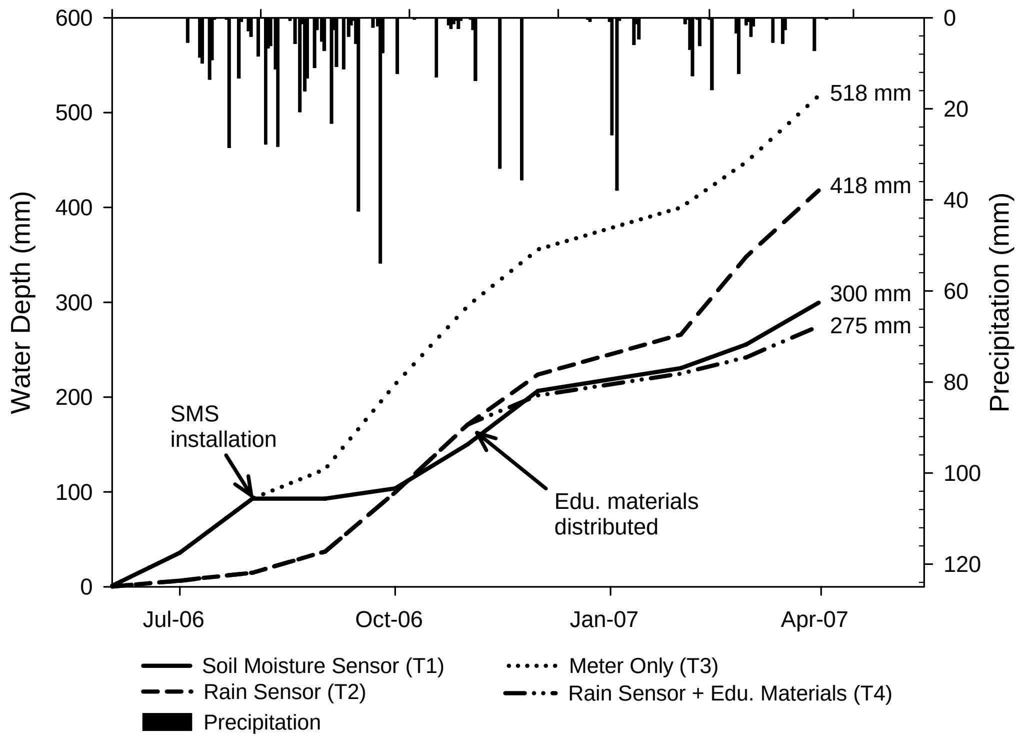

Figure 3. Cumulative water use by treatment.

Paying closer attention to the statistical analysis, the primary difference was with respect to treatment ($p<0.001$); T2 and T3 both applied more irrigation water than T1 and T4 (Table 1). Correlations were determined using the Pearson's correlation coefficients, for location and irrigated area as well as location and water use. Location quadrant and irrigated area were correlated ($p<0.001$). There was also a correlation between location quadrant and weekly water usage ($p=0.002$). During this data collection period, the weather was consistent across all locations; therefore, it is likely that socio-economic differences played a key role in the water use. The literature suggests higher socioeconomic levels have less regard for water costs and a greater desire for landscape aesthetics at the result of greater irrigation application amounts (Campbell, 2004). From these correlations, the interaction between location and treatment was evaluated with the multivariate GLM analysis, where a significant difference ($p<0.001$) was observed as well.

In Table 1 and Figure 4, the average weekly irrigation application by each treatment plus the effective precipitation can be compared to the average weekly ETo by month to determine if over irrigation is occurring. From this comparison it can be seen that, aside from the month of December, T1 and T4 consistently applied irrigation amounts plus effective precipitation below the ETo curve. The treatment with no additional sensors (T3) resulted in irrigation plus rainfall exceeding ETo 7 out of the 9 months of data collection. Turfgrass water requirement is less than ETo, indicating that this treatment resulted in substantial over-irrigation.

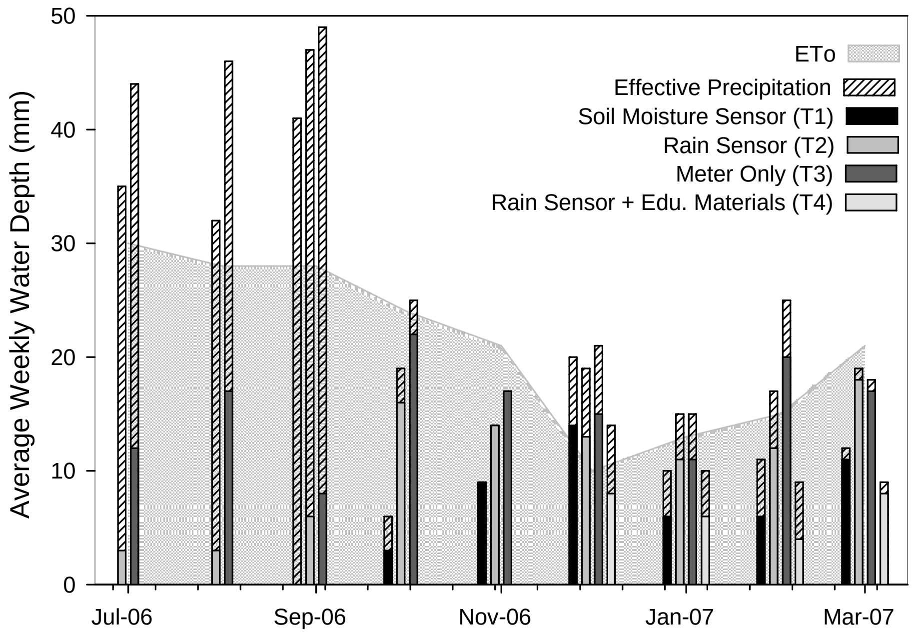

Figure 4. Average weekly irrigation application plus effective precipitation compared to average weekly reference evapotranspiration (ETo). Note that the first months displaying the installed treatments T1 and T4 are Sep-07 and Dec-07, respectively.

Evaluations and Ratings

System evaluations were completed on the 59 homes included in the study. The evaluation is a means of quantifying the irrigation system performance. Irrigation cycle water consumption was computed by recording the actual flow rate for each zone multiplied by the zone run time. During this evaluation any required maintenance resulting from broken heads and leaks was noted. Any maintenance that would compromise the uniformity test was fixed before the testing began. System distribution uniformity (DU) was calculated by performing a catch-can test following the Mobile Irrigation Lab Handbook guidelines for Florida. Of the 59 homes in which evaluations were conducted, 8 homes did not have sufficient areas in which a DU test could be performed.

Uniformity of water distribution measures the relative application depth over a given area. This concept can assign a numeric value to quantify how well a system is performing. The term uniformity refers to the measure of the spatial differences between applied waters over an irrigated area. The average DU of the sampling of the 51 homes tested to date is 0.60, ranging from 0.29 to 0.85. Compared to the Irrigation Association distribution uniformity quality ratings for an irrigation system (IA, 2005), 59% the homes in this study can be classified as at least good. Less than acceptable irrigation system DU ratings do not necessarily result in poor landscape quality in Florida (Baum et al., 2005).

Initial turf quality ratings were taken for each home during the irrigation evaluations, as a baseline standard of comparison for each home. Continuous seasonal turf quality ratings commenced summer 2006. To date, there have been no notable differences between turf quality and irrigation treatment.

Preliminary Conclusions

Preliminary results show that sensors are successful for irrigation water use savings at the single family home level. Data reported here are since the beginning of the research project, in June 2006, through March 2007. In homes with a rain sensor (T2) the water used was 19% lower than homes with an irrigation time clock only (T3). A further decrease in the amount of water use occurred after the distribution of the educational materials (T4) in November 2006, with a difference of 58% between the two rain sensor treatments (T2 and T4). It is likely that the irrigation on treatment T4 was lower because the materials were provided just prior to winter, when the run-time card suggests a large reduction in run times. On the other hand, since the installation of the soil moisture sensors (T1), water savings of 51% have been recorded compared to T3. Thus, both the incorporation of a sensor to the irrigation system and the distribution of educational materials have decreased the water use. In this early data collection period, there have not been any changes in turf quality as result of the treatment installations.

Acknowledgements

The authors thank the Pinellas-Anclote Basin Board of the South West Florida Water Management District, Florida Department of Agriculture and Consumer Services, Florida Nursery Growers and Landscape Association, Florida Turfgrass Association, and the Florida Agricultural Experiment Station for funding support. In addition, the authors appreciate the assistance of the Pinellas County Utilities alternative water sources meter reading team, and the following from the University of Florida: Bernardo Cardenas, Larry Miller, Danny Burch, Wayne Williams, Mary Shedd, and Stacia Davis.

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