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Agricultural and Urban Green Infrastructure Irrigation Systems Auditing - A case study for the Region of Epirus

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Abstract

FAO-AQUASTAT states that in Greece, about 70% of the available water resources are used for irrigation purposes. According to directive 2000/60/EC, action is needed to protect water in qualitative and quantitative terms. Among the several actions that are expected to contribute to the protection of water is the optimization of irrigation management. In this framework irrigation professionals are challenged to achieve maximum irrigation efficiency at scheme as well as at end-user (farm or landscape setup) level. Irrigation efficiency is a complex concept at upper levels as the losses of someone could be the gains for someone else. At end-user level, irrigation audits which register and analyze information regarding water and soil characteristics, the design, installation and maintenance of the system, the available flow, the operating pressure, the application uniformity and the irrigation schedule provide a useful tool for system evaluation and maintenance, upgrade decisions. In the framework of the present work, selected case studies, part of an irrigation auditing initiative, which is in progress and will include 100 audits at the Regions of Epirus and Western Greece, are presented. Extended literature review was made in order to design the auditing procedures. Special fact sheets have been prepared and pilot audits were used in order to evaluate them and make final adjustments. The audits have been applied on a variety of agricultural irrigation systems (big guns, sprinklers bubblers, drip lines, emitters etc) as well as on sprinkler irrigation systems for landscaping setups (parks and athletic facilities). After each audit, a report is handed to farmers and irrigation managers. The report contains information regarding the findings and proposals for improvements. The majority of the systems that were audited up to now presented serious problems regarding design, construction, maintenance and management. The feedback was positive and most of them agreed to keep records regarding water savings data. It has to be noted that no relevant national legislation or official standard exist in Greece. In this framework, an objective of the initiative is to develop a practical auditing guide and make it available to relevant stakeholders and policy makers.

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1. Introduction

In Greece, the total cultivated area is about 3.000.000ha and almost 1.000.000ha (33%) of this is irrigated, consuming about 7.000 hm^3 of water per year (Fig.1). These facts do not include irrigation of urban and recreational landscapes. Also, during the last years the demand of irrigation water is increasing. Due to uneven rainfall distribution or no rainfall and because a large part of the Greek agricultural production is planted, grown, and marketed during spring, summer and fall (normally the driest part of the year according to the Mediterranean climate), growers of high-per-hectare-value crops find it almost mandatory to provide supplemental water via irrigation for successful crop production. Besides preventing crop-water stress, irrigation systems are used to protect the crop against heat and cold and to apply fertilizers and pesticides. Iirrigation for urban and recreation landscapes is consistently increased over the last years, as more people migrate to cities, commercial and housing development expanded very rapidly up to 2010 and the tourist industry is under constant augmentation. The most common groundcover plant for all these cases is turfgrass which is notorious for its great water needs. Typical irrigation systems consist of subzones of pop-up, rotary or spray heads that are controlled via manually or electronically operated valves. Only the last 10 years, a few urban irrigation controllers have been used to improve irrigation including site specific and time specific capabilities as well as automatic shutoff rain sensors. Even fewer irrigation controllers are used in surface, sprinkler and drip irrigation in crop plants.

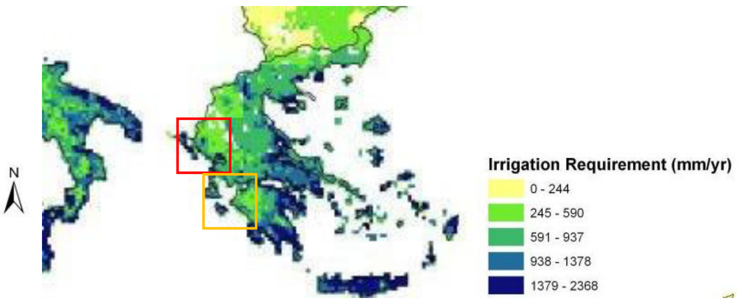

Fig. 1 Assessment of irrigation requirements in Greece (from Wriedt et al., (2008)). The red and the orange rectangles specify the Regions of Epirus and Western Greece respectively.

In irrigated crops and landscaping lawns, sprinklers (big guns, rotary, spray), micro-sprinklers, drip lines and independent bubblers and emitters are the most common types of outlets. That system's efficiency (Irrigation Efficiency - IE), is a measure of the amount of the water which is used advantageously from plants. IE is evaluated by measurements and interviews by which data regarding irrigation system characteristics and management practices are collected (Irrigation Work Group, 2005). This procedure is called an audit and it is completed after analysis of the data and presentation of the results to the irrigation manager in order to plan maintenance and upgrade activities. Irrigation audits have been proved to contribute to water-saving and thus various organizations have developed relevant procedures (eg ASAE - Mobile Irrigation Lab).

In irrigation systems, uniform distribution of water, reduces losses through deep percolation or runoff in parts of the region which are receiving more than the required water (McCready and Dukes, 2011). Indicatively, the typical application uniformity (or distribution) for sprinkler systems is around 65-75%, while in drip irrigation systems is 85-95%. Indicators of irrigation system uniformity provide a good estimation of its efficacy if a rational management in the irrigation system is applied (Burt et al., 1997; ASAE, 1999; Dukes, 2000). According to Dukes (2000) IE is difficult to overcome the uniformity of the system and an excellent uniformity distribution is the primary objective for irrigation systems (Melby, 1995; Smith, 1997; Hunter, 1998; Rainbird, 2000; Babilis, 2004; ICR, 2006).

2. Irrigation Uniformity

Numerous approaches to evaluate the uniformity of irrigation systems have been found in the literature. Uniformity could be determined either during the design phase using specific software (eg CIT's SPACEPro^{TM}) or after the installation of the system by field measurements using water containers (catch cans) or soil moisture sensors. The collected data are used to calculate uniformity indices. Three indices are applied in most situations for assessing uniformity: the uniformity coefficient of Christiansen (CU, Christiansen, 1942), the uniformity of distribution (Distribution Uniformity - DU, McCready and Dukes, 2011), which has two expressions (the lower half for home gardens and the lower quarter for professional systems) and the scheduling rate (Scheduling Coefficient, McCready and Dukes, 2011). It should be noticed that in most off all of the studied literature, all indicators for the statistical estimation of uniformity made use of the volume of water on the surface which is irrigated. However, after the entrance of water into the soil, a redistribution can occur which may lead to a different value of uniformity in the root layer (Wilson and Zoldoske, 1997, Williams, 2003).

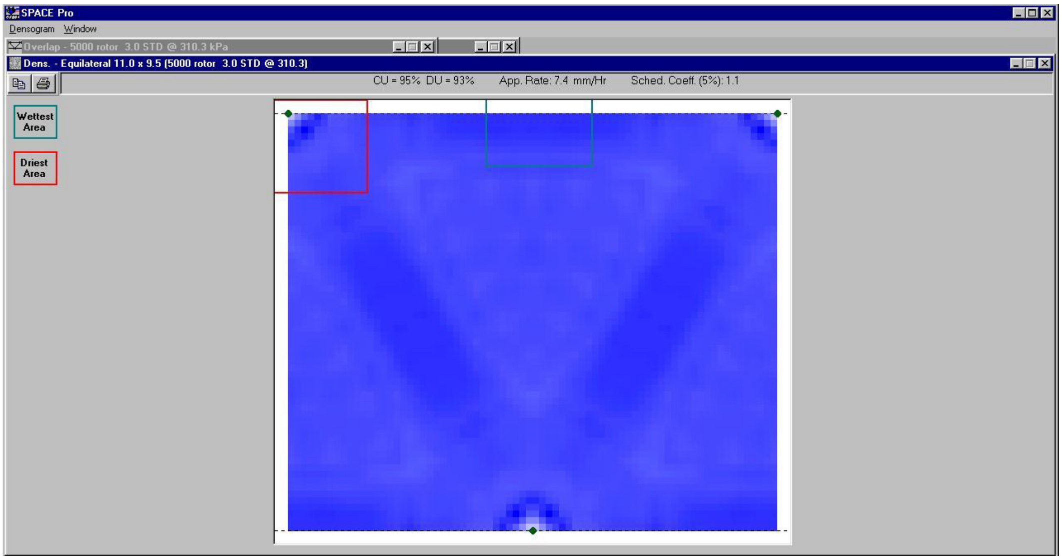

Fig. 2 Use of CIT's SPACEPro^{TM} for uniformity assessment during design phase (TEIEP).

Many irrigation managers attempt to overcome poor uniformity by applying more water than is necessary, so that an adequate amount is received at the driest location. This practice is one of the leading causes of deep percolation and surface run off losses. Some of the problems associated with this practice are:

- The amount of water available may be limited by regulation.
- The high cost of water (cost to buy it or energy and other cost to pump it)
- There is the chance of damaging plants in areas were water stagnates due to excessive water in the root zone
- In landscaping setups there is a potential of public danger by accidents that may occur by slippery pavements and roads.

Good distribution uniformity minimizes the amount of extra water needed to provide the driest location in the system with an adequate supply. An irrigation system has good uniformity when a nearly equal amount of water is deposited on each m^2 (or other reference unit) of irrigated surface area. This is important for plant materials such as turf, where every square inch of area is covered with a relatively dense root system. Trees and shrubs can get water from a wider and deeper root zone. In this case, uniformity can be lower at the reference area level but each plant can receive an adequate amount of water. Sprinkler selection during the system design influences uniformity. Examples of selection options include: spray vs. single nozzle vs. multiple nozzle, sprinkler pressure and pressure variation, sprinkler spacing, and sprinkler location with respect to landscape features. Other factors affecting performance include water pressure, wind, plant interference, and equipment damage. Installation and maintenance specifications must maintain the intent of the design to insure proper performance. In sprinkler systems for landscape project the main statistical means for evaluating uniformity of coverage are the distribution uniformity index (DU) and the scheduling coefficient index (SC). They both depend on the spacing of sprinklers and their distribution profile. The difference between SC and DU is the fact that SC uses a contiguous area (for example 1%, 5%, 10%, etc.) in defining the dry spot (critical) area to be used in establishing design and operational parameters. DU uses an arbitrary 25% (or 50%) of the lowest catch device measurements regardless of location. They may or may not define dry spots. A dry reading could be adjacent to a wet reading thereby modulating the dry spot effect.

Table 1 DU levels in relation to sprinkler type

Sprinkler type	Excellent (achievable)	Good (expected)	Poor
Rotary Sprinklers	80%	70%	55%
Spray Sprinklers	75%	65%	50%

3. Irrigation Efficiency

Although related, the concepts of efficiency and uniformity are different. For example, a system can have high uniformity, but have low efficiency because of excessive run times. Ideally, both high uniformity (giving good appearance) and high efficiency (providing minimum water use) should be achieved. Application efficiency is the amount of available to plants water, divided by the average amount of water applied during an irrigation event. The amount of available water depends on how long the system is operated as well as on how uniformly is applied.

To estimate the net amount of water that is stored in the root zone after irrigation, losses such as evaporation, wind drift, deep percolation, and low head drainage need to be determined. With a large number of irrigations occurring during a year, it is difficult to determine overall irrigation efficiency for an entire irrigation season.

While uniformity is mainly related to the design and mechanical performance of the irrigation system, efficiency is affected by both site management and equipment at the site. A modern irrigation system is typically operated by time programs (frequency and duration of irrigation events for each station/electric valve) which are executed by an irrigation controller. Usually the controller is also connected to appropriate sensors (rain sensors, wind gauges, soil moisture sensors, etc) in order to automatically adjust the program according to the actual environmental conditions. FAO, for the calculation of water needs of plants has published a standard commonly accepted methodology for estimation of evapotranspiration (water needs) of crops which can be applied to any plant (Allen et al, 1998, Allen, etc., 2011). Here it should be mentioned that in urban areas, the evapotranspiration of landscaping setups (which are typically more complex than agricultural cultivations) can be estimated by the procedure proposed by Costello et al. (2000).

4. Auditing Procedure

A concise and simplified irrigation auditing process, as suggested by several Irrigation Associations, Universities and private companies is presented here. The guidelines presented are intended to function as recommendations in the evaluation and performance of irrigation systems. They have been designed to aid irrigation professionals in fieldwork procedures and in performance calculations and techniques. Recommendations and projections from the guidelines and their accuracy depend upon the quality of measurements and data provided by each individual user.

Step 01 Preparatory activities

- Pre-site inspection.
- The irrigation system should meet all legislation requirements.
- The system should be audited after all the known operational defects have been repaired.

Step 02 Auditing

- Audit must be conducted under normal operation conditions (i.e. during scheduled for irrigation time of day).
- In case of open filed sprinkler systems, wind speed must be monitored systematically during the audit (the

maximum allowable wind speed for sprinkler system operation = 8 km h^{-1} or less (ASAE S398.1)).

- Pressure tests must be conducted at normal operating conditions at the sprinkler using the appropriate pressure testing device at the beginning, middle, and end of every zone audited.
- Water containers (catch-cans) should be uniform in size and type, numbered and allocated in the test area on a grid layout with numbered nodes. For sprinkler systems the catch-cans along the edge of the zones should be placed 30cm to 60cm in from the edge.
- Use of no less than 25 water containers (catch-cans) per zone.
- Water containers (catch-cans) spacing for sprinkler systems: for fixed spray sprinklers - near a head and half-way between the heads; for rotor heads, less than 12m radius - near a head and 1/3 of the distance between the heads; for rotor heads, greater than 12m radius - near a head and 1/4 of the distance between the heads. Typical recommendations: large areas, rotor sprinklers - uniform grid, 3 to 5m spacing (i.e. football field); small areas, spray sprinklers - uniform grid, 1.5m to 2.5m spacing (i.e., narrow turf area less than 2m wide)
- Test running times must be consistent and adequate in order that a minimum of 25 ml of water is collected in the water containers (catch-cans).
- For sprinkler systems when the test area contains multiple stations, the station run times must be adjusted to achieve a matched precipitation across the test area. Also rotor sprinklers must run for a minimum five rotations during the test.

Fig. 3 IRMA project Audit Toolbox (TEIEP).

The following data must be documented:

- Date and time of audit, owner and irrigation manager contact information.
- Field position and cropping system layout.
- Basic water quality indices (pH, EC), soil types and root zone depths (if possible).
- Other information (i.e. water table depth etc).
- System layout (water supply point, zoning, pipes, outlets, controller, sensors, various components etc)
- Applied irrigation schedules.
- Wind speed readings (in case of open field sprinkler systems).
- Water containers (catch-cans) locations.
- Water containers (catch-cans) readings.
- Testing run times.
- Pressure readings with locations.

Step 03 Data analysis

- Calculation of uniformity indices and analysis of results in comparison with pressure data.
- Setup of irrigation schedule and comparison with the applied.

Step 04 Report generation with suggestions for improvements (classified and costed) and relevant presentation to the owner and the irrigation manager.

5. Case study in Epirus

For the evaluation of irrigation practice in Epirus, four farms and four urban green spaces were studied. In order to evaluate them a detail program was applied:

1. Recording status quo (presentation and reference designs with photos, all necessary materials brochure, study etc.) found on:
   - Work (orientation, size, construction (windbreaks, buildings, grandstands etc.)
   - Plant (variety, conservation, crop rooting depth, problems (type, location), appearance etc.)
   - Soil (soil samples for finding engineering recommendation)
   - The irrigation system: design, abstraction, materials (pumps, filters, scheduler, sensors, piping, separation stops, shafts, rotors, etc.), condition and maintenance,
   - The irrigation schedule (duration, frequency, amplitude irrigation etc) and
   - The drainage system (device, depth, drainage etc.).
2. Collection of information regarding climatic conditions (temperature, relative humidity, radiation, wind speed and direction, precipitation) and reference evapotranspiration(ET_o) calculation using historical climatic data and the Hargreaves model (Allen et al., 1998). The applied irrigation schedule was compared to a typically developed schedule according to Brouwer et al. (1989) and Allen et al. (1998).

For the determination of the irrigation efficiency of the systems in each project about 25 catch-cans for collecting water were used. Inspections were held by teams of 2-3 persons which carried a relevant toolbox (containing leveler and tapes, numbered catch cans, measuring cylinders, tube manometer, direct sensor measuring soil moisture (ThetaProbe, Delta-T Devices Ltd, Cambridge, UK), camera and radio (walky-talky), etc). For the evaluation of the uniformity of each irrigation system the following actions were performed at the field:

1. A day without wind and rain and time is prior to the next irrigation was selected.
2. Soil and water samples were collected.
3. Sketches of the area and the system were designed.
4. Catch-cans were placed at predetermined points.
5. The system operated 10-30min (depending on the capacity of the catch cans) and during this period inspection regarding pressure and leakage, irregular operation, problems and wetting radius of rotation, problems size of the drop etc was performed. At the end, the volume of water collected in each container was measured.
6. Soil moisture at predetermined points was also measured.

Then, in the laboratory, the engineered soil structure, the calculation coefficients of uniformity and theoretical irrigation program that is comparable to the applied were calculated.

Regarding farms, the cultivated species were citrus trees, variety Klimerntini (three farms) and a kiwi fruit trees. Farms were in areas with important economic significance for the local residents. The characteristics of study areas are presented in Table 2.

Table 2 Characteristics of study Farms

Code	Crops	Pipes	Type of water outlet	Water output $Q(L\ h^{-1})$	Wetted diameter d(m)	Irrigation period	Irrigation frequency	Irrigation duration (h)
Farm A	Citrus trees	PVC Ø110 to Ø25	Microspinklers	140-160	10	April-September	every 15 days	6
Farm B	Citrus trees	PVC Ø110 to Ø26	Microspinklers	160	10	April-September	every 15 days	6
Farm C	Citrus trees	PVC Ø110 to Ø27	Microspinklers	90	10	April-September	every 10 days	7

Farm D	Kiwi trees	PVC Ø110 to Ø28	Microspinklers	90	6	April-September	every 2 days	1.5

During the inspection of irrigation systems it was found that the design, the study and the installation of systems was held by artisans rather than agronomists or other relevant scientists. Here, it should be noted that one of the four systems was installed recently (during the last 5years). The irrigation system in the design and implementation followed the telescopic method with larger pipeline diameters to be in the main conduit. The usual diameter of the main pipe was Ø110 and the irrigation networks were branch in secondary and tertiary pipelines. The total absence of filters in pipelines in the study farms was also a finding. At the same time control systems as controllers, rain sensors, electric valves, etc. were completely absent too. Also key components of irrigation systems such as check valves, air valves, drain valves, water meters etc were not identified. Regarding the irrigation pipelines, for all the study farms the composed material was PVC with standard 25mm diameter for the application pipelines. The outlets of the irrigation water for crops ware micro-sprinklers, with average water supply 90 - 160 Lh^{-1} and wetting diameter 6-10m according to the manufacturer's documentation with quadratic order in the field. A major problem that was observed during the audit of the irrigation systems was the light to heavy inclination from the vertical of the sprinklers in some areas of the study farms. Problems such as high pressure, leaking or defective connections were not observed.

Regarding the irrigation practice at the studied farms, the irrigation period was generally between April and September and the irrigation of the plants was performed every 15 and 2 days and lasted 6 and 1.5 hours for citrus trees and kiwi fruit respectively (Table 3). At this point it should be noted that although the irrigation dose and the duration of the irrigation are affected by the climatic-meteorological and the soil conditions of the fields, the farmers irrigate empirically with minor alterations of their irrigation routine.

Regarding, gardens, three of the studied cases were private and one was public. The plant material consisted mainly by turf grass and resistant plants in the case of public garden. Also here, the design and the implementation of the irrigation system in the gardens, was made by artisans. The public water supply system is used for covering the irrigation needs on the study gardens. Generally, the irrigation systems in the study gardens had low pressures so that irrigation was applied in more than one time steps. Nevertheless controllers in most cases were not available, and irrigation scheduling was made with electo-valves, which, operating manually. The pipes of irrigation system were underground made from PVC material 6atm. The outlets of the irrigation water were static or rotary sprinklers depending on the field characteristics. Generally problems as leaks, or drainage at the studied gardens were not observed, with an exception in Garden D. Like farms, control systems as controllers, rain sensors, valves, check valves, air valves, drain valves, water meters etc. were not found. In Table 3 the characteristics of the studied gardens were presented. Irrigation of gardens is taking place in the period of May or June to September-October each year, for every two or one day for a time period between 15 to 30 minutes. Also for this case as for farms the selection of irrigation dose and irrigation duration was made empirical.

Table 3 Characteristics of study Gardens

Code	**Crops**	**Pipes**	**Type of water outlet**	**Water output Q(L h^{-1})**	**Wetted diameter d(m)**	**Irrigation period**	**Irrigation frequency**	**Irrigation duration (h)**
Garden A	Lawn	PVC Ø20	Rotor and Spray Sprinklers	70	5.2	May-September	every day	15
Garden B	Lawn and resistance plants (public field)	PVC Ø25	Rotor and Spray Sprinklers	70	5.2	July-September	every day	20
Garden C	Lawn	PVC Ø25 to Ø16	Rotor and Spray Sprinklers	70	5.2	May-September	every day	35
Garden D	Lawn	PVC Ø32 to Ø10	Rotor and Spray Sprinklers	70	5.2	June-October	every day	20

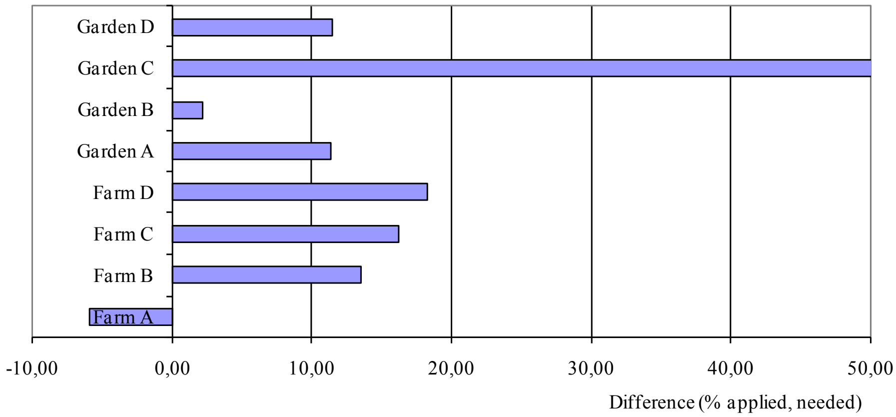

Fig. 4. Difference in irrigation volume application (empirical approach minus theoretical approach) for study Farms and Gardens

Based on the existing meteorological data of the study areas the theoretical irrigations needs both for farms and gardens were determined and were compared with the empirical methods. Also in order to evaluate the irrigation operation of the study systems CU, SC, DUlq and DUlh for each system were calculated. The results are presented in Table 5 and in Figs. 4, 5 and 6. Generally it is concluded that on farms, the irrigation quantities which are applied empirically are higher than the required. An exception was Farm A, where the applied irrigation water is higher than the required. Also in Garden C the applied irrigation water is greater than the required and this is because sowing of the turf took place one month before the inspection, and the owner thought it necessary to implement a higher quantity of water during that initial period. In Garden D, as it was already mentioned, drainage problems were presented because of the amount of the irrigation water which is higher than the required due to design problems in the irrigation system. Generally, for gardens things are better which is due to the better conditions of the water outputs and the pipelines.

The uniformity indices for the study cases are very heterogeneous, with those for farms to have lower values. Generally farms with installation and operation problems (wrong choices nozzle hole pipes, clogged filters, inclination of sprinklers etc.) resulted very low values for the calculated indices.

Table 5 Difference of empirical and theoretical irrigation needs and uniformity indexes

Code	% Difference between empirical and theoretical irrigation needs	CU (%)	DUlq (%)	DUlh (%)	SC
Farm A	-5.96	19	14	26	10.5
Farm B	13.50	57	40	58	5.25
Farm C	16.19	41	36	45	3.08
Farm D	18.26	60	74	74	1.91
Garden A	11.30	58	77	77	1.94
Garden B	2.16	64	61	61	1.72
Garden C	52.32	69	74	75	1.62
Garden D	11.44	31	33	11	3.63

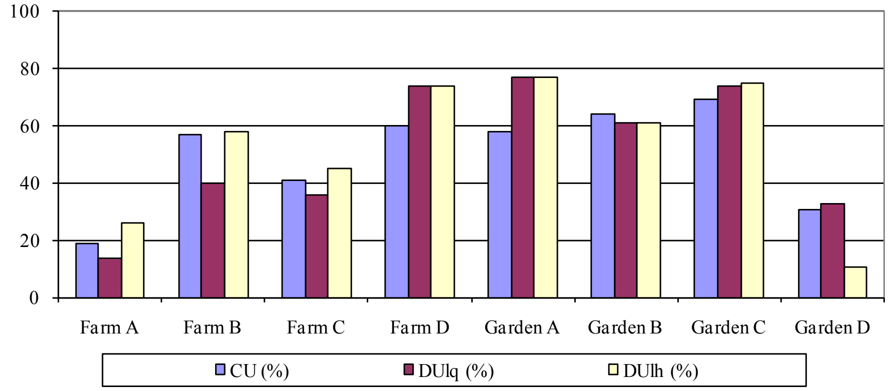

Fig. 5. CU and DU uniformity indices for the studied Farms and Gardens

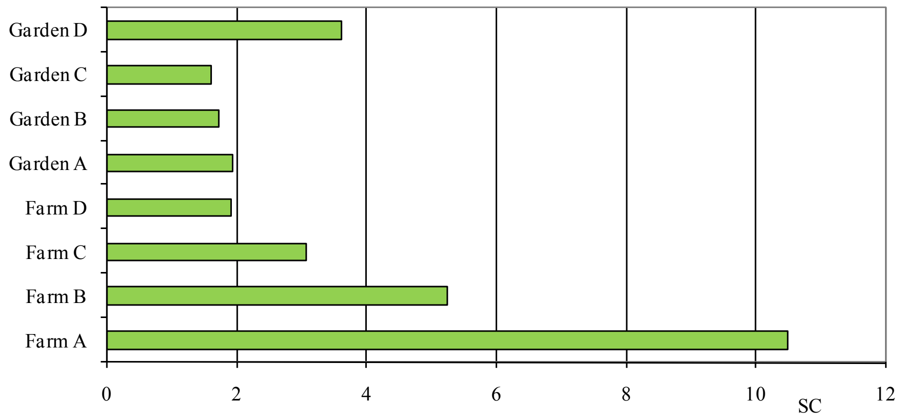

Fig. 6. SC Coefficient for the studied Farms and Gardens

The results concerning irrigation uniformity (Figs. 5 and 6) lead to the conclusion that three of the four farms had unacceptable indices' values. At the other hand the farm with the kiwi fruit cultivation has acceptable and relatively high values. The general audits of the systems revealed problems regarding installation and maintenance of the irrigation systems like wrong choices nozzles, nozzles with different characteristics and clogged pipes with the absence of filters, particularly for Farm A. Also, the low uniformity values for Farm C are attributed to the existence of sprinklers with different characteristics and to an altitude difference between various parts of the field. It should be noted that the differentiation of soil characteristics in the field and the transition from gravel to finer soils affects the soil moisture, which in its turn affects the uniformity of water in the soil. Finally is concluded that gardens have more uniform irrigation conditions in relation to farms. An exception was Garden D where wrong irrigation system planning (nozzles were blocked by trees) resulted uneven distribution of water and wet trunks.

6. Conclusions

In this paper the preliminary results -in the form of case studies- from the evaluation of irrigation practices on farms and urban green infrastructure in the region of Epirus are presented. Generally is concluded the necessity of implementing inspection and auditing methods and techniques for optimum crop irrigation and optimal water management. The theoretical elaboration of irrigation schedules and their regulation with the prevailing conditions can help to improve the presence of the green spaces and saving water. Among the various components of irrigation systems that would provide essential information to both the manager and the auditor is the water meter. If -which is the typical case- are not available in a system, they should be installed after the first audit in order to provide documentation data for every water conservation effort. The attainment of high uniformity, through proper design, construction and maintenance of irrigation systems plays a significant role for irrigation water conservation. This can be done only if specifically trained professionals are involved in these activities.

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