

Chances and Opportunities to Reduce Maintenance Costs by Adjusting Irrigation Systems with Focus on Soil Characters and Plant Demands. Quality Management Ensures Durable and Sustainable Operation

Andreas Thon, Wolfram Kircher, Ina Thon

Anhalt University of Applied Sciences, Strenzfelder Allee 29, D-06406 Bernburg

Tel.: 0049-177 4977755, e-mail: schwimmteich@gmx.net

Automatic irrigation systems can support the vitality and improve the aesthetical value of green spaces. Optimizing irrigation systems by adjusting irrigation amounts and irrigation intervals by using on-site related factors like soils and plant water demands contribute to minimize the input of water. Simple calculations of irrigation amount and quality management methods can reduce maintenance costs.

Key words: irrigation, soil, plants, quality management, green areas.

Automatinės drėkinimo sistemos gali palaikyti želdynų gyvybingumą ir padidinti jų estetinę vertę. Drėkinimo sistemų optimizavimas reguliuojant drėkinimo apimtis ir drėkinimo intervalus, atsižvelgiant į lokaliai susijusius faktorius, tokius kaip dirvožemio ir augalo vandens poreikiai, padeda sumažinti tiekiamo vandens sunaudojimą. Paprasti drėkinimo apimtys apskaičiavimai ir kokybės valdymas padeda sumažinti priežiūros kainas.

Reikšminiai žodžiai: drėkinimas, dirvožemis, augalas, kokybės valdymas, želdynai.

Introduction

Water scarcity is one of the imminent resource limitations of the 21st century. Climate change, green house effect and smog are global problems but affect local spheres and will influence a change in quantity and the occurrence of natural precipitation. In areas of high building density, an increase of the Heat Island Effect, the amount of particular matter and low air humidity in cities are expected. Water supply for plants is limited by natural precipitation and thus urban green areas are affected. Trends of professional automatic irrigation solutions are increasing in landscape design. Handling the resource water needs to be done in a sustainable way. Irrigation in landscape is more than distributing water on vegetated areas. Irrigation design and management influenced by newest techniques and knowledge combined with a construction following precisely the demands of the vegetation techniques can secure a high quality of vegetation areas by modest maintenance expense.

Methods

The approach to the calculation of the irrigation amount is based on the results of literature investigation, above all in the fields of agriculture, horticulture, field sprinkler irrigation and fruit cultivation. The influences of the soil on irrigation and plant water demands have been determined by literature investigation, own test series and own experience gained over many years. The stipulations of DIN and Annex 2 of the FLL Guideline for the Planning, Execution and Upkeep of Green-Roof Sites have been used as basis for the assessment of soil characteristics. The calculation method for the uniformity of irrigation water distribution follows DIN EN 12484 part 5.

Results

The decisive climate factors for irrigation are evaporation (evapotranspiration) and precipitation. When the evaporation exceeds the precipitation, the amount of water accumulated in the soil (ΔS) is decreasing. Dry periods occur which have to be balanced by irrigation. With increasing precipitation, the soil water reservoir is filled again. The wind, which may cause a drifting of the irrigation water, also influences irrigation (Thon, 2010).

The soil water reservoir is re-filled by precipitation (P). When it is lower than the evaporation over a longer period so that the soil does not contain sufficient available water for the plants, irrigation is necessary. The daily amount of precipitation should be determined on a regional basis; even better by means of appropriate sensor equipment on site. The determination of precipitation amounts by web-based databases, as e.g. of DWD, should be dispensed with. The weather is relevant for irrigation. However, weather events may strongly vary between small regions. The resolution in the information sources available on the market is not sufficiently precise (Deutsches Klimarechenzentrum GmbH (2007), Thon, 2010).

Temperature, sun radiation, air humidity and wind have influence on evaporation. The higher the sun radiation and the temperature are, the more water evaporates. Strong wind also increases evaporation. The evaporation consists of interception and evapotranspiration (ET). When the soil is optimally supplied with water, more water can evaporate than when a small amount of water is available only. Thus the ET depends on the water supply of the soil and also from the plant cover, because every plant shows varying evaporation and interception values. Thus, for ET one differentiates between:

- Potential evapotranspiration (ET_p) = for optimum water supply and plant cover of short rye grass (*Lolium multiflorum*, Welsches Weidelgras)
- Real evapotranspiration (ET_R) = for current water supply and definite type of crop (BASSLER, R. 1997)

The drifting of the irrigation water is growing with increasing wind speeds. Irrigation controls, which stop irrigation as soon as a maximum wind speed is exceeded, are not available on the market. Frequently windy locations, an unequal water distribution by wind can be prevented by the arrangement of the irrigation sprinklers. At extremely windy locations, one should consider whether irrigation methods not susceptible to wind, e.g. drip irrigation, can be applied (THON.A. 2010).

Conclusion: For the irrigation demand, the real evapotranspiration (ET_R) at definite plant type and current water supply of the soil is decisive. Regional weather and wind conditions have to be considered in the planning.

Most of the plants take in the required water exclusively from the soil through their roots. The water is delivered from the roots to above by the transpiration suction. The power of this suction must be stronger than the suction tension by which the water is kept in the soil (Kuntze, 1994).

The adhesive water is attached to negatively charged soil particles (clay, humus), or is kept in the soil pores by capillary forces; i.e. it is subjected to a certain suction tension. The narrower the pores the stronger are the capillary and adhesion forces, and the higher is the suction tension. And consequently, the worse the water is available for the plants.

Depending on the soil type, the overall pore volume and the portions of the different pore sizes vary. Sand, for example, has a larger portion of coarse pores but a smaller overall pore volume; whereas loam has a higher portion of fine and medium pores and a larger overall pore volume.

When a soil contains the maximum water amount that it can keep against gravity, the so-called field capacity (FC) is reached. Now all fine, medium and slowly draining coarse pores are filled with water, the suction tension is, depending on the soil type, $pF=1.8$ to 2.4 . In this stadium, sand contains approx. 13 % water, whereas loam contains 40 % water.

If only the fine pores in the soil are filled with water, the still existing water is no longer available for cultivated plants, the suction tension is $pF=4.2$; the Permanent Wilting Point PWP is reached. At this point, the water content in sand is 3%, loam contains 13% water. The range between the FC and the PWP is the Usable Field Capacity UFC (Thon, Thon, 2007).

Conclusion: The water content of a soil (soil humidity) does not tell us anything about the water supply of the plants; here the relevant reference basis is the water condition indicated by the pF values.

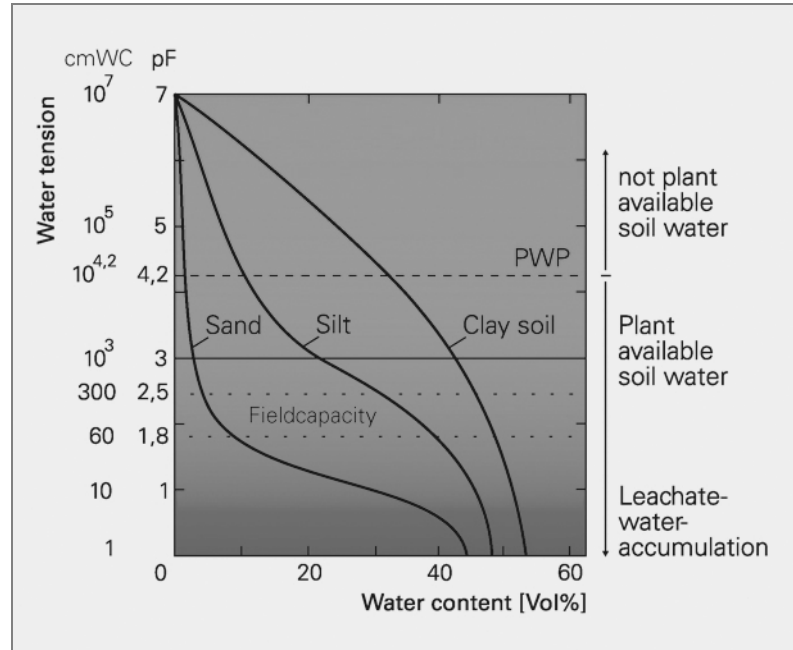


Fig.1. Water content of different soils
1 pav. Skirtingų dirvožemių vandens sudėtis

Experiences gained in agriculture and horticulture describe that at a soil humidity of 30 to 50% UFC, irrigation is necessary. The Deutsche Landwirtschaftsgesellschaft (*German Agriculture Society*) even recommends that for vegetables and special crops, the usable field capacity (UFC) should not drop below 70 to 75% and for agricultural crops 50 to 55% (Deutsche Landwirtschaftsgesellschaft e. V. 2007). In perennial and ornamental horticulture, a too strong drying-up should also be avoided, because the once dried-up gardening substrates can be wetted again slowly only. In landscape architecture and object planning, differing from agriculture or horticulture, no uniform areas or uniform plantations are planned. The plants selected for this purpose are adapted to the site conditions, however, and no yield is expected from the use of such plants. In correspondence with agriculture and horticulture, the soil humidity is a very suitable reference value for the control of irrigation, so that the irrigation is made in accordance to the demand. The irrigation up to soil humidity of 80% UFC and not more is intended, so that no damages caused by over-irrigation occur. The more soil pores are filled with water the fewer pores filled with air is there. This is especially the case in heavy soils which contain few coarse pores only. When these soils are irrigated with too much water a lack of air is generated for the plant roots, and decay damages may occur at the roots. The soil structure suffers too, when the soil is permanently kept too wet, because soil crumbs are disintegrated in their components then. In the case of too large and too strong water applications, nutrients, above all nitrate, may be washed out from the root area to deeper layers (Bassler, 1997; Kuntze, 1994; Mosler, 2007; Paschold, 2007; Thon, 2007; Thon, 2009).

Conclusion for irrigation: As the UFC in sandy soils is smaller than in loamy soils, sandy soils are irrigated with smaller water applications, but more frequently. Loamy soils get larger applications, but more rarely. When the water applications are too small, the plants suffer from drying stress, and the soil is not wetted deep enough. When they are too large, there is the risk that nutrients are washed out, and the water that the soil cannot store seeps in deeper layers. In addition to the soil characteristics, the size of the applications also depends on the rooting depth.

Kinds of plants have very differing needs regarding the water supply. Some can live in water only, other need permanently moist soils, some like a drier ground, and others are able to overcome long dry periods, but then they need water for “re-filling”. For example, plants of the biotope water banks will need more irrigation than plants of the dry open areas.

The water demand is also varying over a vegetative period. Cereals, for example, need 30% UFC until germination, during jointing until blooming 60 to 70% UFC, and until maturity again 30% UFC (Kuntze, 1994).

For most of the crops, the maximum suction tension by which they are able to take in soil water, is at 15bar = pF 4.2 = permanent wilting point. However, there are many types of plants which show a significantly higher maximum suction tension.

Plants have varying rooting depths; this is the depth up to which the soil is intensively rooted. Thus the rooting depth is decisive for the amount of water that a plant can utilize. The main rooting depth of the plant should be equal to the humidity plane so that the plant can develop roots typical for its species (Thon, 2009)

Conclusion for irrigation: The rooting depth of a plant/crop indicates how deep the soil must be wetted by a water application. In this way it is possible to determine the amount of the water application together with the UFC.

Generally the distribution curves must be known when using sprinklers, or only similar sprinklers should be combined. For green area watering, every corner of an irrigated area is usually equipped with a sprinkler. The spraying width of sprinkler 1 determines the location of the next sprinkler 2. This ensures that the total water distributed over the area by the sprinklers 1 and 2 achieves balanced and uniform irrigation intensity (l/m²) (Fig. 1.). So, the irrigation time can be calculated according to the irrigation target, and the control unit can be programmed (Thon, 2010).

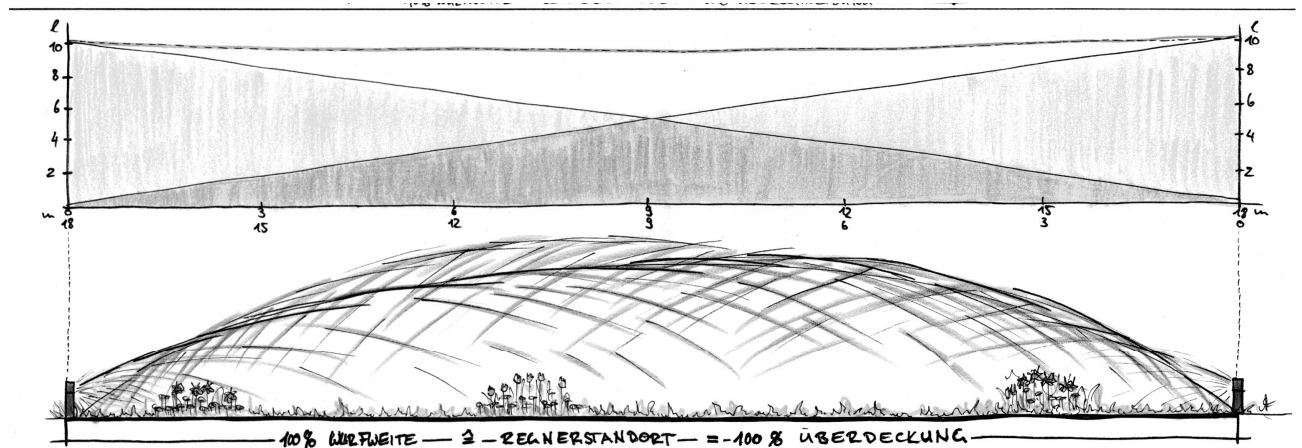


Fig. 2. Uniform water distribution at 100% spraying width = location of the next sprinkler (Flehmgig, Thon, 2010)
 2 pav. Vienodos vandens paskirstymas: 100% padengimas iki kito purkštuko (Flehmgig, Thon, 2010)

The distribution uniformity according to CHRISTIANSEN (CU value) should be 75% at least. The SC value (Schedule Coefficient) shall not exceed 1.75.

Discussion

To be able to calculate the irrigation demand of the vegetation in dependence on the site factors influencing the ET_R, it has to be determined when the end of the irrigation interval has been reached and the water application is useful. The application of irrigation water is necessary when the ET_R together with the interception is higher than the arising precipitation and the capillary ascend. By irrigation, the soil humidity in relation to the UFC and in accordance with the irrigation target (mostly 30-80% UFC) shall be kept at least above the absolute wilting point. The precipitation or the soil moisture, respectively, should be determined on site by means of regarding sensors. The ET_R can be determined by derivation from the evaporation values, available e.g. from the web. The biotope, the herbage and the sun exposition of the plant stands should be considered in the calculation of the irrigation demand.

Calculation of the water application

The water application is described by the irrigation amount and the irrigation intensity. The amount of the irrigation application shall consider the soil type and the desired wetting depth

Influence of the soil type

The soil humidity at definite pF values for a known soil type can be included in the control of the irrigation. An irrigation starting at 30% UFC and increasing the soil humidity to 80% UFC is desired.

Influence of the rooting depth

By using the UFC, the water amount can be determined which is required to fill a definite soil volume with water according to the irrigation target. The volume to fill depends on the size of the area and the depth up to which the soil must be wetted. This is the rooting depth.

Calculation

The irrigation amount is calculated by determining UFC according to the soil type. As the irrigation shall start at 30% UFC and a filling up to 80% UFC shall be reached, 50% of the UFC must be added. The UFC is given in vol. – %; which is also l/dm/m². The water amount can be calculated by the multiplication with the soil depth. By subtracting the actual soil depth, it is known how much water must be added for a definite soil type and rooting depth.

$$\frac{nFK}{2} * D = W, \quad (1)$$

here:

0.5 UFC (of the regarding soil type * rooting depth in dm = amount of water for the soil humidity to obtain)

Maintenance and quality management of irrigation systems

The irrigation system should be checked at least once a year. As a minimum, the main components should be visually inspected. It would be better to carry out a leakage test or a functional test of the system separator or the pressure increasing system, respectively, the water meter, the capacity of the filter, the piping, the valves and manifolds and the emptying valve.

The operation and the tightness of the drip pipes, micro-sprinklers, sprayers and rotating sprinklers should be checked every six months.

The installation height, the spray pattern and sector device as well as the uniformity (CU value and SC value, for better differentiation also the DU value) of the drip pipes, micro-sprinklers, sprayers and rotating sprinklers should be checked annually too. This shall be done in accordance with DIN EN 12484 part 5, to ensure irrigation as needed, and to decrease the operating cost (especially the cost of water).

For irrigation controls without weather station and specific sensor equipment, the irrigation intervals in spring, summer and autumn must be adjusted to the changed weather situation.

The distribution accuracy of irrigation systems can be presented by means of the uniformity coefficient according to Christiansen (CU value, also CC value). The degree of over-irrigation of partial areas is described by the Schedule Coefficient (SC).

The CU value compares the mean deviation from the mean value to the mean value. When the CU value is 100%, this means that the whole area is uniformly watered. The uniformity level of the distribution of the irrigation water according to CHRISTIANSEN should be 75% at least. When assessing irrigation systems by means of the CU value, three peculiarities must considered, above all.

8	8,67	6,67					
6,67	9,33	13,3	11,3	12,7	16,7	12,3	18,7
6,67	8,67	14,7	13,3	14,7	14,3	10,3	8
	10	12,7	10	10,7	13,3	12,7	13,3
	10	10	9,33	11,3	14	14,7	6,67
	9,33	9,33	12,7	14,7	13,3	13,3	8
	8	10,7	15,3	14,7	13,3	11,3	12,7
	8,67	12,7	13,3	12	16	12,7	10
	9,67	12	12	10,7	13,3	14,7	15,3
	4,67	8	10,7	9,33	14,7	14,7	9
	5,33	6,67	10	8,67	12	18,7	8
	5,33	8,67	11,3	9,33	11,3	12,7	10,3
		8	12	10	9,33	14,7	12,7
		9,33	12	10,7	9,33	11,3	8
		8,67	8	10,7	10,7	10	8
			7,33	9,33	11,3	10	10
		8,67	10	9,33	8	8	8,67
		10,7	12	10,7	8,67	9,33	4,67
		12	12,7	12	11,3	8	7,33
		12	10,7	10,7	10,7	10,7	9,33
		7,67	8,33	11,3	10,7	14,7	17,3
		6,67	9,33	10,7	13,3	13,3	10,7

Minimum value (min):	4,66
Maximum value (max):	18,67
Mean value (m):	10,81
Quantity (n):	
Christiansen Uniformity Coefficient in % (CC):	80,03
SC (m2%)	2,12
SC (m 5%)	1,53
SC (m 10%)	1,40

Exemplary measuring values in mm/m² of a lawn irrigation system

Fig.3. Uniformity calculation according to Christiansen (Thon, 2009)
3 pav. Vienodos paskaičiavimas pagal Christiansen (Thon, 2009)

The first peculiarity is that the CU value only considers the absolute values. Thus the under-irrigation and the over-irrigation are uniformly shown, because only the mean value of the deviation from the mean value is determined.

Secondly the differences from the mean value are shown by a linear function. Each measuring value is put in direct relation to the deviation from the mean value. Having a mean value of 10, the measuring values 8 and 14 are assigned to a “deviation value” of 2 or 4, respectively. It has to be considered that a twice as high deviation is assigned to the measuring value 14, because the deviation to the mean value is twice as high.

Thirdly it has to be considered that the CU value describes the uniformity of the whole irrigation system in the determination of the deviation from the mean value. The CU value does NOT describe whether there is an especially critical area in the system.

According to the CU value, the requirements to the uniformity in the example (Fig. 2.) would be fulfilled.

The SC value is determined by putting the 2%, 5% or 10% of the measured values of the highest deviation from the mean value in relation to the mean value. The SC value should be <1.75 . A presentation of the calculation, or the indication which % of values of the highest deviation from the mean value have been applied in the calculation, is inevitable for interpretation.

In the example, this means that when the 2% of the “worst” values are put in relation to the mean value, the requirements are not fulfilled. When the 5% or 10% of the “worst” values are put in relation to the mean value, the requirement of $SC <1.75$ is fulfilled.

The verification of the distribution accuracy shall be made by applying the test method described in DIN EN 12484 part 5 for lawns.

Conclusion

Today's irrigation systems apply water in insufficient uniformity. Silt or clay soils have a high horizontal capillarity, so that the water is distributed sub surface. Plants on sandy soils suffer from lack of water during dry times. Irrigation suppliers indicate very high irrigation rates to secure a pleasant vitality in their irrigation systems. Wasting water does not concern the irrigation advices.

Different law regulations try to counteract this movement by committing a distribution uniformity of $CC >75\%$ of irrigation water. Consumers claiming high water losses of the irrigation system who consider these laws will most likely achieve an optimization of the irrigation systems. The quality of the irrigation designers must be improved, and the consumers should be aware of high maintenance costs of irrigation systems if the arrangement, the compounds and the controls are not designed properly.

Turgor pressure and water demands of plants in working fields of crop production, like agriculture and horticulture, are well known. Hydrological characters of plants used in urban planting design and landscape are unknown. To optimize efficient and ecological automatic irrigation solutions, research about water demands of plants used in urban green structures must be put in the focus.

Many thanks to Dr. Seiler, HS-Anhalt, for translation and editorial suggestions.

References

1. Bassler R. Methodenbuch Band I – Die Untersuchung von Böden. Darmstadt, 1997
2. Deutsche UNESCO-Kommission e.V. 2003. Wasser für Menschen, Wasser für Leben. Weltwasserentwicklungsbericht der Vereinten Nationen. Resource of internet: <http://www.unesco.de/wwdr.html?&L=0> [reviewed on 22/10/2007]
3. Deutsches Klimarechenzentrum GmbH (2007): Klimaänderungsszenarien für IPCC AR4. Resource of internet: http://www.dkrz.de/dkrz/science/IPCC_AR4/scenarios_AR4_Intro; reviewed on 22/10/2007
4. DIN EN 12484: Automatische Rasenbewässerungssysteme – 1–5
5. DIN EN 1717: Schutz des Trinkwassers vor Verunreinigungen in Trinkwasser-Installationen und allgemeine Anforderungen an Sicherheitseinrichtungen zur Verhütung von Trinkwasserverunreinigungen durch Rückfließen
6. DIN EN 19655: Bewässerung- Aufgaben, Grundlagen, Planung und Verfahren
7. Kuntze H. U. A. (1994): Bodenkunde. Stuttgart: Ulmer
8. MLUV Brandenburg. 2005: Leitfaden zur Beregnung landwirtschaftlicher Kulturen. MLUV Potsdam
9. Mosler T. 2007: Gemüse, Praxisratgeber Bewässerung. München: Deutscher Landwirtschaftswirtschaftsverlag
10. Paschold P.–J. 2007: Damit das Wasser für morgen reicht. München: Deutscher Landwirtschaftswirtschaftsverlag
11. Roskam, F. U. A. 1995: Sportplatzbau und-erhaltung. Hanau/Main: Trimmhold & Drapper
12. Thon A. Automatische Beregnungsanlagen. Planen und installieren Schritt für Schritt. In: Deutscher Gartenbau26/2007, Stuttgart, 2007
13. Thon I., A.Thon. Skript für die Vorlesungsreihe „Beregnungstechnik“ ES 2007/2008 im Studiengang Landschaftsarchitektur und Umweltplanung, Hochschule Anhalt (FH), Bernburg 2007

14. Thon, A. Bewässerungsanlagen richtig konzipieren. Seminarunterlagen zum Vortrag „Dörren oder ertränken“ – Bdla-Bauleitergespräche in Potsdam, 15-01-2010, 11 p.
15. Thon, A. Richtig bewässern – aber wie? Einfluss der Pflanzenansprüche auf die Bewässerung im GaLaBau. In: Der Bauunternehmer 07/2007, Berlin 2009
16. Withers N., Vipond S., Lecher K. Bewässerung, 1st edition. Berlin/Hamburg, 1978

Galimybės sumažinti priežiūros kainas reguliavimo pagalba. Drėkinimo sistemos koncentruotos į dirvožemio savybes ir augalo poreikius. Kokybės valdymas užtikrina ilgalaikį ir gyvybingą procesą

Santrauka

Straipsnyje rašoma apie automatines drėkinimo sistemas, kurios gali palaikyti želdynų gyvybingumą ir padidinti jų estetinę vertę. Drėkinimo sistemų optimizavimas reguliuojant drėkinimo kiekius ir drėkinimo intervalus, atsižvelgiant į lokaliai susijusius faktorius, tokius kaip dirvožemio ir augalų vandens poreikiai, padeda sumažinti tiekiamo vandens sunaudojimą. Paprasti drėkinimo apimties apskaičiavimai ir kokybės valdymo metodai gali sumažinti eksploatacijos kainas. Vandens išteklių tvarkymas turi būti atliktas tinkamu būdu. Drėkinimo planas ir valdymas, pasitelkiant naujausius metodus ir žinias, gali užtikrinti aukštą želdynų kokybę su kukliomis priežiūros išlaidomis.