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Agricultural irrigation equipment — Sprinklers —

Part 3: **Characterization of distribution and test methods**

Matériel agricole d'irrigation — Asperseurs —

Partie 3: Caractérisation de la distribution et méthodes d'essai

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15886-3 was prepared by Technical Committee ISO/TC 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 18, *Irrigation and drainage equipment and systems*.

ISO 15886 consists of the following parts, under the general title *Agricultural irrigation equipment — Sprinklers*:

— *Part 1: Definition of terms and classification*

— *Part 3: Characterization of distribution and test methods*

Design and operational requirements and test methods for durability are to form the subjects of future parts 2 and 4.

Agricultural irrigation equipment — Sprinklers —

Part 3: Characterization of distribution and test methods

IMPORTANT — For any given sprinkler, a wide range of nozzle configurations, operating conditions and adjustments generates at least a theoretical need for a correspondingly large number of tests. Testing agencies and manufacturers may use interpolation techniques to reduce the number of actual test runs, provided accuracy standards are met.

1 Scope

This part of ISO 15886 specifies the conditions and methods used for testing and characterizing the water distribution patterns of sprinklers intended for agricultural irrigation. It deals both with indoor and outdoor, radial and full grid tests and is organized to deal first with conditions common to all the tests and then with those unique to indoor and outdoor testing, respectively.

The term *sprinkler* is used here in a broad, generic sense, as defined in ISO 15886-1, with the intent of covering the wide variety of products classified in ISO 15886-1. The specific performance measurements addressed in this part of ISO 15886 include distribution uniformity, wetted radius and water jet trajectory height: it is applicable to all irrigation sprinkler classifications for which uniformity of application, wetted radius and water jet trajectory height evaluation are required for the design objectives, as defined by the manufacturer. It does not address the specific performance testing required for sprinklers intended for frost protection use under freezing conditions, nor does it address the topic of drop spectrum measurement and characterization and the related questions of soil compaction, spray drift, evaporative losses, etc. It is not applicable to moving systems or sprinklers with a radius of throw of less than 1,0 m.

In order to use this part of ISO 15886 to evaluate irrigation coverage, all sprinklers must be identical and arranged in a fixed repeating geometric pattern.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 15886-1, *Agricultural irrigation equipment — Sprinklers — Part 1: Definition of terms and classification*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15886-1 and the following apply.

3.1
ambient temperature
temperature of the air surrounding a sprinkler test site

3.2
area of coverage
wetted area from a sprinkler operated as specified in the manufacturer's literature where water is deposited at rates greater than or equal to the effective application rates

3.3
Christiansen's coefficient of uniformity
UCC
method of characterizing the uniformity of water application of sprinklers from full grid data that utilizes arithmetic deviations

NOTE The concept was introduced in 1942 and has been widely accepted as a measure of how well designs relate, with 80 % considered as the minimum acceptable uniformity coefficient. The coefficient lacks physical significance, however. Full grid data can be developed by actual field testing or computer simulated from distribution curves. See A.2.2.

3.4
clean water
water processed so as to contain suspended particles no larger than 200 mesh equivalent (74 microns) and to contain no dissolved chemicals known to have short-term effects on the sprinkler materials

3.5
collector
receptacle used for collecting irrigation water discharged by a sprinkler during a water distribution test

3.6
contour graphs
method of representing the area of coverage that shows a set of contour curves, each connecting locations in a horizontal plane receiving water at the same application rate

NOTE The number of contour lines plotted needs to be large enough to convey a visual impression of the physical significance of the data. The concept is useful in constructing area of coverage diagrams.

3.7
densogram
method of representing the area of coverage that utilizes the density of dot shading as directly proportional to the relative application rates in the area of coverage

3.8
distribution curve
graph of application rate (ordinate) versus distance (abscissa), measured along a particular section (leg) or line of the area of coverage

3.9
distribution uniformity
DU
method of characterizing the uniformity of water application of sprinklers from full grid data by a coefficient that utilizes an arbitrary definition of the lower 25 % as the critical area

NOTE The concept has had some acceptance in agricultural crops, but continues to suffer from the arbitrary nature of the definition. See A.2.4.

3.10
effective application rate
application rate greater than or equal to 0,26 mm/h for sprinklers with flow rates exceeding 75 L/h and 0,13 mm/h for sprinklers with flow rates equal to or less than 75 L/h

3.11
flow rate
volume of water flowing through an irrigation component per unit of time

3.12
full grid collector arrays
number of collectors located at the intersection of a two-axis geometric grid pattern determined to give a desired statistical result and represent the area of coverage

3.13
inlet connection
nominal pipe size designation for commercial purposes with no specific relationship to actual dimensions except as may be defined by reference to a recognized standard

3.14
irrigation lateral
branch supply line in an irrigation system on which water distribution devices such as sprayers, sprinklers and emitters are mounted directly or by means of fittings, risers, or tubes

3.15
maximum working pressure
P_{max}
maximum pressure at which a device will properly function hydraulically and operate mechanically

3.16
minimum working pressure
P_{min}
minimum pressure at which a device will properly function hydraulically and operate mechanically

3.17
nozzle
aperture or adjutage of the sprinkler through which the water is discharged

NOTE A sprinkler can contain one or several cylindrical nozzles, or nozzles of other shapes. The term can refer to either a single nozzle or to a combination of nozzles in the case of a multi-nozzle sprinkler.

3.18
nozzle pressure
pressure as measured immediately upstream of the nozzle or as inferred by a pitot tube measurement at the nozzle orifice *vena contracta*

3.19
nozzle size
nominal size designation for commercial purposes with no specific relationship to hydraulic properties

NOTE Nozzles are more accurately defined by their hydraulic properties.

3.20
part-circle sprinkler
sprinkler with an adjustable feature that enables it to irrigate any sector of a circular area or the entire circular area

3.21
pop-up sprinkler
irrigation sprinkler designed for installation so that the sprinkler nozzle is below ground level when it is not pressurized and above ground level when it is pressurized

3.22
pressure tap
precisely fabricated connection for communicating internal conduit pressures to an external pressure-measuring device

NOTE Tap construction is shown, for example, in ISO 9644.

3.23
radial collector arrays method
number of collectors located only on the radial axis projected from the sprinkler centreline, used to characterize the distribution curves

3.24
radius of throw
wetted radius
distance measured from a continuously operating sprinkler or sprayer centreline to the most remote point at which the sprinkler or sprayer deposits water at a minimum rate of 0,26 mm/h, for a sprinkler or sprayer with a discharge exceeding 75 L/h, or 0,13 mm/h, for a sprinkler or sprayer with a discharge equal to or less than 75 L/h, measured at any arc of coverage, except near the arc extremes for part-circle sprinklers or sprayers

3.25
range of working pressure
all pressures between P_{min} and P_{max}

3.26
scheduling coefficient
SC
method of characterizing the uniformity of water application of sprinklers from full grid data by a single coefficient that utilizes a definition of critical dry area

NOTE The concept, especially well suited to lawn and turf management, gives a run-time multiplier based on critical dry area turf quality management. See A.2.6.

3.27
sprinkler spacing
distance between the sprinklers along an irrigation lateral and between consecutive irrigation laterals

3.28
statistical uniformity coefficient
UCS
method of characterizing the uniformity of water application of sprinklers from full grid data by one coefficient that utilizes standard deviation as a measure of dispersion in statistical theory

NOTE Although introduced in 1947, this coefficient fails to enjoy any wide base of acceptance. The method presupposes that the distribution data is normally (Gaussian) distributed. See A.2.3.

3.29
test pressure
pressure at the inlet of a sprinkler declared by the manufacturer as the pressure to be used for test purposes

3.30
trajectory height
maximum height above a sprinkler or sprayer of the trajectory of the water stream discharged from the sprinkler nozzle or sprayer operating at test pressure

3.31
water application rate
mean depth of water applied per unit time

3.32
wetted diameter
sum of the radii of throw on the same diameter

3.33
wind speed
speed of the wind at a test site averaged over the time required for a test of the distribution uniformity of a sprinkler or sprayer

3.34
working pressure
pressure shown in the manufacturer's catalogue literature at which the sprinkler is known to function mechanically as designed

NOTE Working pressure bears no relationship to hydraulic properties except as may be defined by the manufacturer.

4 Collectors

4.1 Design

All collectors used for any single test shall be identical. Each shall be designed to minimize water splashes in or out.

The height of each collector shall be at least twice the maximum depth of the water collected during the test, but not less than 150 mm. It shall have a circular opening with sharp edges free from deformities. The diameter shall be from half the height to the same as the height, but shall not be less than 85 mm.

Alternative collector designs may be used, provided that their measuring accuracy is not less than for those specified.

The catchment from a collector shall be quantified from a direct reading of mass, depth or volumetric determination, provided that the required accuracy standard is met.

4.2 Collector ring orientation

The openings of all collector rings shall be in a common horizontal plane, with a slope not exceeding 2 % in any direction. The difference in height between any two adjacent collector rings shall not exceed 20 mm.

For indoor testing, collector ring height is not critical. For outdoor testing, the collector ring height shall be sufficient to ensure that vegetation does not interfere with jet access to the collectors.

5 Installation of sprinklers under test

The sprinkler selected for testing shall be representative of general production capabilities — particularly as relates to speed of rotation. New sprinklers shall be operated before the test for a period sufficient to demonstrate that the time per revolution has stabilized to ± 5 %.

Mount the sprinkler on a riser with nominal size designation the same as the sprinkler inlet connection. Ensure that the riser is fixed rigidly vertically, and that it does not vibrate sufficiently to cause a visual effect on the sprinkler operation, bend or deviate from the vertical during the test. The maximum allowable deviation from the vertical during the test shall not exceed 2°.

A steel pipe riser should be used to provide the required mechanical strength and facilitate the installation of a standard pressure tap.

Sprinkler nozzle height above the collectors should simulate the conditions under which the sprinkler is normally used. For example, for turf sprinklers, the top of the sprinkler body should coincide with the top of the collectors.

For agricultural sprinklers used under a variety of field conditions, the height of the principal sprinkler nozzle above the openings of the collectors shall be 10 times the nominal diameter of the sprinkler connection, but not less than 300 mm or at a height as specified by the manufacturer.

If the manufacturer specifies any special test-related conditions (e.g. testing at a minimum riser height or with straightening vanes), these shall be observed if the items concerned are provided as standard equipment with the sprinkler.

For a sprinkler not riser-mounted as described above, the test mounting shall be as specified by the manufacturer.

For single-leg distribution patterns, a shelter may be used around the sprinkler to baffle jet action, provided

a) the shelter is large enough and so constructed as to trap the jet and not let it interfere with the sprinkler's operation,

b) the shelter is designed to allow air circulation to develop around the jets,

c) the shelter provides a minimum sector for unrestricted jet operation of 45° centred on the collector radius, and

d) no jet deflection or splash is directed into the collectors.

If the testing agency uses an angle of less than 45° in relation to c), it shall demonstrate that the integrity of the results are not compromised.

6 Measurement

6.1 Accuracy

The accuracy required for all measurements not specifically addressed in this part of ISO 15886 shall be ± 3,0 %.

Application depths within collectors shall be measured with an accuracy of ± 3,0 %.

The pressure shall be measured with an accuracy of ± 1,0 %.

The flow rate through the sprinkler shall be measured with an accuracy of ± 2,0 %.

The temperature shall be measured with an accuracy of ± 0,5 °C.

Time shall be measured with stop watches accurate to ± 0,1 s.

6.2 Pressure measurement

The test pressure shall be measured at the height of the main nozzle. The location of the pressure tap shall be at least 200 mm upstream of the sprinkler base. (See ISO 9644 for information on pressure tap construction.) There shall be no flow obstructions between the pressure tap and the sprinkler base.

6.3 Atmospheric measurements

Relative humidity and ambient temperature shall be measured at the start, midpoint and end of the test. For indoor testing, changes in temperature and humidity during the test shall not exceed ± 5,0 % pre-test ambient.

7 Test methods — Collector arrangement, spacing and number

7.1 Full-grid collector arrays

This method refers to the use of a square grid of collectors with a sprinkler located inside the grid. It is especially useful in characterizing the impact of wind on sprinkler performance and characterizing sprinklers that do not produce symmetrical areas of coverage.

The same collector spacing shall be used for both axes of the grid. Additional collectors may be located on the downwind edge of the collector array if required to cover the anticipated wetted area. A minimum of 80 collectors shall be located within the area of coverage.

The sprinkler shall be located midway between four adjacent collectors.

Alternatively, the sprinkler may be located at the intersection of the grid axis.

7.2 Radial collector arrays

This method refers to the use of collectors located along a radius or several radii (usually 4, spaced at 90°) for purposes of characterizing the sprinkler's water application rate as a function of radial distance from the sprinkler. It is especially useful for sprinklers with a symmetrical pattern and under no-wind conditions.

The objective of the test is to develop an accurate relationship between water application rate and radius. If the sprinkler is known to have discontinuities between combinations of nozzles, for example, sufficient collectors shall be used to adequately characterize these features. In all cases, a minimum of 10 collectors shall be used on each radius.

Maximum spacing of collectors along the radius shall be in accordance with Table 1.

Table 1 — Maximum spacing of collectors — Radial collector arrays method

Dimensions in metres

Sprinkler radius of throw	**Maximum collector spacing** (centre to centre)
1,0 to 3,0	0,30
3,0 to 6,0	0,60
6,0 to 12,0	0,75
Over 12,0	1,00

The sprinkler shall be located one collector spacing from the first collector and on the same radius.

For multiple-array tests, the wetted radius/diameter shall be the average of all of the arrays used.

8 Additional tests

8.1 Time of rotation

The sprinkler time of rotation shall be measured only while the sprinkler is rotating from its own drive mechanism. It shall be measured at the beginning, midpoint and end of the test. In addition, at the midpoint in the test, the time shall be measured through each quadrant. The quadrant locations shall be indexed to the collector grid. The time shall be measured by an instrument capable of giving accuracy in accordance with 6.1.

8.2 Trajectory height

The measurement is taken from a horizontal plane through the main nozzle. As with the radius of throw, occasional drops that achieve a greater height shall be ignored in favour of some general representation of the top surface of the main jet. Care shall be taken to insure that the sprinkler riser meets the 2° tolerance on verticality. The radial distance to the location of maximum trajectory height shall be noted. Both height and radius measurements require an accuracy of ± 5 %.

9 Test operation

9.1 Rotation of sprinkler riser

During the radial collector array test (7.2), the riser supporting the sprinkler shall be manually rotated a quarter of a revolution (90°) about the axis three times at equal intervals of time. This rotation shall be performed during the periods when the jet of the sprinklers is not passing over the collectors.

For sprinklers with special operating modes, riser rotation shall be accomplished so as not to bias the test.

The test period shall begin after the sprinkler has run for a time period long enough to establish stable conditions (e.g. all air is evacuated). This may be accomplished by shrouding the sprinkler during unstable start-up periods and removing the shroud to start the test.

The test pressure shall not vary by more than ± 4 % during the test period and the water temperature shall not vary by more than ± 5,0 °C during the test.

Care shall be taken in starting and stopping tests to avoid direct deposition in collectors by under-pressure jets or unstable rotational movement.

Care shall be taken also to avoid subjecting collector legs or portions of the grid to an unequal number of sprinkler rotations or cycles.

For sprinklers with programmed variations in operating characteristics, the duration of the test shall be long enough to subject all collectors to the same, identical operational sequences.

9.2 Test duration

A minimum number of 30 passes shall be made over all collectors. In general, test conditions not specifically covered by this part of ISO 15886 shall reflect first, the reality of how and where the product is to be used, and second, how the manufacturer defines the product performance testing. Considerations that fall in this category include, for example, sprinkler height in relation to crop canopy, riser or drop tube length, configuration or construction, and sprinkler orientation (supply flow up or down).

The test duration shall be long enough to generally allow the requirement for reading accuracy of the collectors in accordance with 6.1 to be met for a minimum of 80 % of the collectors. The water applications accounted for in the collectors shall be a minimum of 90 % of the theoretically calculated amount based on the sprinkler flow calibration.

10 Test location specifications

10.1 Indoor testing — Test building

In order to meet the assumption that test-building conditions represent no-wind conditions, there shall be no ventilating structures (doors, windows, etc.) that permit bulk air movement at velocities exceeding 0,10 m/s. In general, the building shall be of a size to permit unconfined jet development of the largest jet for which it is designed.

The test building's design shall meet the following criteria:

— floor slope as required to provide surface drainage not to exceed 1,0 % (collector ring inlet surfaces must be in a common horizontal plane);

— minimum length equal to 125 % of the maximum sprinkler wetted radius of throw;

— minimum width equal to 60 % of the sprinkler radius of throw measured at the actual radius of throw;

— minimum clear ceiling height equal to 125 % of the maximum trajectory height anticipated;

— no structural column or truss members of the building that mechanically interfere with the jet near the collectors.

10.2 Outdoor site

10.2.1 Test area

The test area where collectors are positioned shall be graded evenly in a horizontal plane with a maximum slope of 2,0 % in any direction. The surface shall be free of obstacles that could block the movement of airborne spray. Surface roughness, including vegetative cover, shall not exceed 100 mm to 150 mm in height, so as to not interfere with spray droplet access to collectors.

There shall be no trees, buildings, or other obstruction in the vicinity of the test site that could alter the normal wind patterns. There shall be a minimum clear area

a) *upwind* of the test site equal to six times the height of any wind break for each 0,45 m/s of wind speed, up to a maximum of 30 times the height for winds of 2,24 m/s or greater, and

b) *downwind* of the test site equal to five times the height of any downwind windbreak.

10.2.2 Measurement of atmospheric conditions

Relative humidity and ambient temperature measurements shall be taken during the test at equal time intervals that give a minimum of 10 readings during the duration of the test.

Wind speed and direction measuring instruments shall be set at a height corresponding to the maximum sprinkler trajectory height ± 10 %. The actual height used shall be measured and recorded on the data sheets.

The sensing equipment shall be located a maximum distance of 45 m from the edge of the wetted area. The location shall be selected as most representative of the test site exposure.

Wind speed and direction shall be continuously recorded or else measurements shall be taken at the beginning and end of the test and at regular time intervals not to exceed 10 % of the test period. Wind speed shall be recorded to the nearest 0,2 m/s and directions to the nearest 10°. Direction shall be referenced to one of the principal axes of the collector array layout. For single-leg tests, the maximum allowable wind speed shall be 0,4 m/s. For four-leg tests, the average allowable wind speed shall not exceed 1,3 m/s and in no case shall the maximum allowable wind speed exceed 2,2 m/s.

11 Characterizing distribution

11.1 General

This clause refers to developing the results from the full grid test procedure so as to effectively characterize the sprinkler performance. The objective for specific characterizations is determined by the sprinkler design objectives as defined by the manufacturer.

11.2 Application pattern coverage and uniformity

At least one of the following four methods for calculating pattern uniformity shall be used, with reference to Annex A:

a) Christiansen uniformity coefficient (UCC) — see A.2.2;

b) Statistical coefficient of uniformity (UCS) — see A.2.3;

c) Distribution uniformity (DU) — see A.2.4;

d) Scheduling coefficient (SC) — see A.2.6.

The method best suited to the design objectives of the sprinkler shall be selected.

Patterns of coverage may be shown giving geometrically accurate representations augmented by densograms or contour graphs, if required, to compare the actual performance to the design objectives.

11.3 Generating performance measurements from radial arrays

This part of ISO 15886 recognizes that the full grid method of characterizing sprinkler performance is preferred over the radial arrays method. If the testing agency decides to use the radial arrays method it shall satisfy questions of accuracy when compared to the full grid method. If wind is a factor in design, only the full grid method can be used. Wind is a factor by definition when the manufacturer warrants the sprinkler for general field use.

Computer-generated full grid patterns may be developed from radial array data provided that the results are identified as based on simulated data and the sprinkler can be demonstrated to have a generally symmetrical pattern. The radial array data is analyzed using a curve fit routine. The curve fit routine identifies a mathematical equation that gives water deposition as a function of radius from the sprinkler axis of rotation. This equation is used to calculate the deposition at the grid line intersections thereby simulating a full grid pattern.

Annex A
(informative)

Determining sprinkler pattern uniformity

A.1 Objectives

Testing for sprinkler performance is usually carried out to meet at least one of the following objectives.

- To provide a characterization of current levels of performance from which to judge the efficacy of changes in design or operating conditions. This is useful primarily to product engineers. Sprinkler mechanical and hydraulic changes can be valued for their potential contribution to product improvement.
- To provide data useful to manufacturers in the development of product specifications and performance literature. These data are used by system designers in designing system components, forecasting irrigation schedules, economic comparisons and product comparisons.
- To provide certified standards of performance that characterize specific products. These data are useful in the development of specifications in contract documents and ensure that products will perform at required design levels.
- To provide a standard for evaluating system field performance. This allows designers, engineers and growers to evaluate existing installations in an “as-built” context and is useful in determining whether or not construction meets contract requirements and acceptance test conditions. It is also useful in auditing system performance. Auditing studies are commonly used as a basis for improving application uniformity and efficiency.

A.2 Methods for characterizing uniformity of distribution

A.2.1 General

This part of ISO 15886 recognizes that there is no one best method for characterizing uniformity of distribution. The diversity of intended uses, and the associated requirements for each use, preclude setting a single standard for characterizing uniformity of distribution. The testing agency, manufacturers and users are free to use the procedure most appropriate for the intended use. Four methods are presented; at least one is to be used.

Other methods and calculating procedures may also be used as long as their logic is defensible in the context of the intended sprinkler use. This latitude in procedures presupposes that all sprinklers suited for a specific use will be evaluated by the same procedure in accordance with this part of ISO 15886.

In some situations, the geometry of the test pattern grid will not correspond directly to the pattern grid being characterized, and in these cases interpolation of catchment values shall be made. Interpolation procedures shall be used that do not unreasonably bias the results.

A.2.2 UCC

Christiansen[2] developed his uniformity coefficient (scientific notation, UCC) in 1942 to study sprinkler irrigation. UCC is one of the most common indicators of sprinkler uniformity, predominantly for historical reasons:

$$UCC = 100 \times \left(1 - \frac{D}{m}\right)$$

where

UCC is Christiansen's coefficient of uniformity;

m is the average value,

$$\frac{1}{n}\sum_{i=1}^{n} x_i$$

where

n is the number of values in the array being analyzed for uniformity;

x_i is the individual value in the array of values being analyzed for uniformity;

D is the average absolute deviation, equal to the average of individual absolute deviations,

$$\frac{1}{n}\sum_{i=1}^{n} D_i$$

where

D_i is the individual absolute deviation, equal to the absolute difference between x_i and m,

$$\left|\left(x_i - m\right)\right|$$

A.2.3 UCS

The statistical coefficient of uniformity (scientific notation, UCS) was first proposed by Wilcox and Swailes in 1947[3]. They preferred it to UCC because of the utility of the standard deviation as a measure of dispersion in statistical theory. It has also been called the Wilcox-Swailes coefficient:

$$UCS = 100 \times \left(1 - \frac{s}{m}\right)$$

where

UCS is the statistical coefficient of uniformity;

m is the average value,

$$\frac{1}{n}\sum_{i=1}^{n} x_i$$

where

n is the number of values in the array being analyzed for uniformity;

x_i is the individual value in the array of values being analyzed for uniformity;

s is the standard deviation,

$$\sqrt{\frac{1}{n}\left(\sum_{i=1}^{n}(x_i - m)^2\right)}$$

A.2.4 DU

Distribution uniformity (scientific notation, DU) is a uniformity concept that was originally proposed by the Soil Conservation Service of the US Department of Agriculture. At that time, it was called *pattern efficiency (PE), lower 25 %* (the modifier referring to the low quarter, another version of PE having been defined based on the upper quarter). Even though the word “efficiency” appeared in its name, PE is actually a uniformity coefficient, and not an efficiency measure. PE depends only on the uniformity of the irrigation application, and not on any assumed or actual irrigation management scheme (which would make it an efficiency measure).

Numerous other workers have used the PE concept, calling it by names such as distribution uniformity (DU), drip irrigation (DU) or emission uniformity (EU). The On-Farm Irrigation Committee of the Irrigation and Drainage Division, American Society of Civil Engineers recognizes DU and UCC as two recommended uniformity measures[4].

$$DU = 100 \times \left(1 - \frac{1q}{m}\right)$$

where

DU is the distribution uniformity;

m is the average value,

$$\frac{1}{n}\sum_{i=1}^{n} x_i$$

where

n is the number of values in the array being analyzed for uniformity;

x_i is the individual value in the array of values being analyzed for uniformity;

$1q$ is the average low quarter value,

$$\frac{1}{n_{1q}}\left(\sum_{i=1}^{n} x_i : x_i \in LQ\right)$$

where

LQ is the set containing the 25 % of the x_i values that are the smallest,

$\{x_1, x_2, x_3, \ldots x_j, \ldots x_q\}$

where

x_1 is the smallest value of x_i;

x_2 is the second smallest value of x_i;

x_3 is the third smallest value of x_i, etc.;

q is the integer closest to 25 % of n.

A.2.5 Linear relationships between UCC, UCS and DU

Several empirical studies of sprinkler irrigation uniformity have found essentially linear relationships between UCC, UCS and DU. Numerous studies have concluded that distributions of sprinkler application depths are often adequately described by a normal (Gaussian) distribution function. When application values are normally distributed, the following theoretical relationships between the coefficients are true (exactly), whereas the relationships are approximately true for many actual distributions of sprinkler application depths or micro-irrigation emission rates that do not deviate too much from the normal distribution.

$$UCC = 0{,}798UCS + 20{,}2$$

$$UCC = 0{,}63DU + 37{,}0$$

$$UCS = 1{,}253UCC - 25{,}3$$

$$UCS = 0{,}79DU + 21{,}0$$

$$DU = 1{,}59UCC - 59{,}0$$

$$DU = 1{,}27UCS - 27{,}0$$

A.2.6 SC

The scheduling coefficient (scientific notation, SC) is a measure of uniformity specially designed for physical significance in the circumstance of turf or lawn irrigation. In these instances, even relatively small areas of inadequately watered turf show up with high visual impact. Turf managers often "water to the dry spot", i.e. increase watering times until the unsightly critical area receives enough water to be visually satisfactory. By forming the ratio of field average to average in the critical area, SC tells in relative terms how much the irrigation time must be increased in order to overcome dry spot non-uniformity.

The SC is dependent on the relative size of the critical dry area and should be computed for different-sized critical areas. In the US, commonly used critical dry area sizes are 1 %, 2 %, 5 % and 10 % of the irrigated area. Even the largest of these is considerably smaller than the low quarter (25 %) used in the DU computation. Experience has shown that SC calculated on a 5 % window gives appropriate results in many practical situations. Experience has also shown that the contiguous dry area shape varies from rectangular to square. "Line"-shaped dry areas are not usual. This is probably due to the generally smooth shape of the sprinkler distribution pattern where discontinuities are rare.

$$SC = \left(\frac{m}{m_{\text{crit}}} \right)$$

where

SC is the scheduling coefficient;

m is the average value,

$$\frac{1}{n}\sum_{i=1}^{n} x_i$$

where

n is the number of values in the array being analyzed for uniformity;

x_i is the individual value in the array of values being analyzed for uniformity;

m_{crit} is the average of the values within the critical dry area, the contiguous area "dry spot" within the array being analyzed for uniformity that has the lowest average application rate or amount.

NOTE Because of pattern symmetry, there may be other areas of equal dryness, but nothing dryer.

Bibliography

[1] ISO 9644, *Agricultural irrigation equipment — Pressure losses in irrigation valves — Test method*

[2] CHRISTIANSEN, J.E. Irrigation by Sprinkling. *California Agricultural Experiment Station Bulletin* 670, University of California, Berkeley, California, 1942

[3] WILCOX, J.C., SWAILES, G.E. Uniformity of Water Distribution by Some Under-Tree Orchard Sprinklers. *Scientific Agriculture* 27(11):565-583,1947

[4] C1978, *Describing Irrigation Efficiency and Uniformity*. On-Farm Irrigation Committee, Irrigation and Drainage Division, ASCE. J. Irrig. & Drain. Div. ASCE 104(IR1):35-41.

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