CONILON Coffee

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The Coffea canephora produced in Brazil

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Irrigation and Water Management in Conilon Coffee

José Geraldo Ferreira da Silva and Edvaldo Fialho dos Reis

1 INTRODUCTION

The practice of irrigation has been an important strategy to optimize the world food production, for generating sustainable development in the field, with jobs and income in a stable way. Mantovani, Bernardo and Palaretti (2013) emphasize the importance of the irrigation technique by mentioning that 17% of the area under cultivation for food production is irrigated, which accounts for 40% of food production. Still, according to the same authors, estimates indicate that 5% of cultivated areas in Brazil are irrigated, which account for 16% of food production and 35% of the economic value of production.

In the past, the use of irrigation was a technique of water application that aimed mainly at fighting drought. Currently, irrigation, in the agribusiness focus, is part of a broader concept of irrigated agriculture, being a strategy to increase production, productivity and profitability in the agricultural property, in a sustainable way, preserving the environment and creating conditions for the maintenance of the man in the field through the generation of permanent and stable jobs.

In recent years, in Brazil, coffee cultivation has expanded to areas with water restriction. For this reason, the use of irrigation practice in coffee plantations has grown greatly in the last decade. This growth has also been reinforced by the climatic variability observed in coffee regions and also due to certain changes in temperatures and rainfall distributions, which makes the weather drier in regions that previously did not present significant problems of water supply to the coffee tree.

Irrigation water is a new input for Brazilian coffee growing, which is currently under constant debate due to an increasing and challenging demand for quantity and quality, conditioned by social, political, environmental and economic issues. Their rational use can provide a jump in productivity in small, medium and large coffee farms by favoring the availability of nutrients in the soil and even driving fertilizers and pesticides necessary for farming.

The soil moisture content influences several physiological processes of the plant, considering its direct effect on the growth and indirect in the absorption of nutrients in the soil solution. Coffee, as well as other agricultural crops, requires water readily available in the soil in its vegetative phase to promote the growth of lateral or plagiotropic branches, and in its reproductive phase (flowering, expansion and fruiting) to develop and produce satisfactorily.

Irrigation is such a significant technique for the coffee tree that it is already possible to locate it among the main irrigated crops in Brazil. Preliminary surveys indicate that 10% of the coffee-growing areas in the country are irrigated, mainly concentrated in northern Espírito Santo, the Triângulo Mineiro and Alto Paranaíba, in Minas Gerais, and in western Bahia (FERNANDES, 2011).

According to Martins et al. (2007), Brazilian irrigated coffee plantations represent approximately 200 thousand hectares, distributed mainly in the states of Espírito Santo (60 to 65%), Minas Gerais (20 to 25%) and Bahia (10 to 15%). Despite the concentration of irrigation projects in regions where there are water restrictions for a prolonged period, it is worth mentioning that there are a considerable number of projects being implemented in traditional coffee growing areas, which allows to obtain higher yields and better final quality of the product (MANTOVANI, 2001a).

In the state of Espírito Santo, more than 50% of the irrigated area refers to conilon coffee, which is cultivated in the hottest regions, where a period of few rains predominates from April to September. Despite the beginning of the rainy season, on average, in October, the irregularity of this rainy season has increased the risks of sharp declines in coffee yields in cultivated areas of the State.

The use of irrigation in coffee cultivation is a technology that has proven to be viable and indispensable over the years, especially in regions where rainfall distribution has caused a moderate to severe *deficit* that occurs in the period of floral buttoning to the seed hardening. This occurs, for example, in the northern and northwestern regions of the State of Espírito Santo, where rainfall is normally concentrated from October to March.

Considering also that the harvesting and pruning processes cause the removal of a large number of leaves, occurring together with the beginning of the dry period in the State of Espírito Santo, the plants can not, through new shoots, recover the leaves lost in time to ensure a good flowering, due to the stress that is established. Thus, it is essential at this time of the year to use irrigation to supply water to the plants so that they can recover.

2 WATER NEEDS OF CONILON COFFEE TREE

Although Brazil is one of the world's largest producers of conilon coffee, there are still few studies related to coffee irrigation. Thus, much of the information recommended for arabica coffee is being used for conilon coffee.

Matiello (1991) highlights that water deficiency is harmful to the coffee tree, especially during the fruiting period, when irrigation becomes necessary, and Camargo (1989) corroborates the assertion that accentuated water deficiency during the seed hardening phase produces badly hardened fruit, which even go wilting. Thus, irrigation, under these conditions, leads to satisfactory results, guaranteeing crop productivity.

Pezzopane et al. (2010), when analyzing the climatic risk for conilon coffee in Espírito Santo, verified that it is high when considering the water aspect. According to the same authors, 38%

of the State present high climatic risks in the flowering, seed hardening and vegetative growth phases. Considering the phases of flowering and seed hardening, there is 20% of area with climatic risk. In addition, the authors also verified that there are 17% of areas with climatic risk, considering only the flowering stage. Thus, the need to use irrigation to ensure a good harvest is confirmed.

Attentive to these climatic risks, the research has been searching for genetic materials that provide significant productivity responses when irrigated, as well as genetic materials more tolerant to the water *deficit* with little response to irrigation. Typically, these materials are less responsive to irrigation and, of course, the more sensitive ones respond more. In field observations[1], comparing genetic material in irrigated and non-irrigated conditions, it can be verified that the responses can vary from 20 to 260% of gain in the productivity while maintaining the same production system.

In years in which rainfall occurs in a well distributed way, it is verified that the crop does not present significant gains in productivity when an irrigated plantation is compared with a non-irrigated one, that is, it does not respond significantly to the irrigation. However, Santinato, Fernandes, A. and Fernandes, D. (1996) estimate that, in the absence of irrigation practice, in areas where the water *deficit* would compromise production, the country would stop producing about 2 million to 2.5 million of processed sacks per year.

It is important to emphasize that new conilon coffee varieties are being developed, seeking a greater tolerance to soil water deficit. This is of great importance, since only supplementary irrigation during the most critical periods of the year brings significant responses to productivity. It is important to remember that for a plant to obtain high productivity rates, it is necessary that it has a sufficient leaf area for this, besides, of course, other factors, such as favorable meteorological conditions, soil nutrients, pest, diseases and weeds control, pruning, among others.

Considering that the conilon coffee tree is more tolerant to the water *deficit* than the arabica and that it has been tried to select more and more tolerant plants, the concepts of the irrigation in this culture become a little different, because one can work with the concept of *deficit* irrigation and not total. The biggest problem is the question of how this management should be. It is necessary to establish to what extent the plant can suffer from the water *deficit* without, however, losing productivity, especially when considering economic and environmental issues as well.

Despite this tolerance, it has been observed that irrigated crops produce considerably more than non-irrigated crops, especially in those years when rainfall occurs in a poorly distributed form. According to Partelli (2015), irrigation, among other technological factors, has contributed to increase the productivity of conilon crops in the State of Espírito Santo.

It should be remembered that, due to the diversity of genetic materials in the coffee tree, the vigor of the crop and the responses to water supplementation through irrigation can be well differentiated. There are genetic materials that provide significant responses to irrigation,

[1]Data observed by the author, not published.

but others show slightly relevant results.

Thus, when thinking about irrigating a crop, one must first evaluate its productive potential before any decision, since irrigation alone does not solve the productivity problem; is only one of the fundamental technologies of the productive process. Irrigation is important, especially for maintaining productivity over the years. This is the conscience of most of the Capixabas producers, since much of the coffee producing area of the State of Espírito Santo is irrigated. However, in relation to management, there is no understanding that good irrigation management can contribute to increase productivity, reduce production costs, and contribute to reducing impacts on the environment.

This can be verified by analyzing the agroecological zoning map for the coffee crop in the State of Espírito Santo (DADALTO, BARBOSA, 1997), in which it is verified that all the possible area of robusta coffee production is subject to some water *deficit*, which can range from 50 to 550 mm/year. Thus, it can be affirmed that the region that produces robusta coffee from the State has some productivity limitation due to the water *deficit*, in which case the use of the irrigation technique may be necessary.

Santinato, Fernandes, A. and Fernandes, D. (1996), when discussing the water capacity of robusta coffee, stated that regions whose annual water *deficit* varies between 150 and 200 mm are considered suitable for coffee cultivation, but may require occasional irrigation. While regions with a *deficit* between 200 and 400 mm can also be considered suitable, provided supplementary irrigation is used. In regions with a *deficit* of 400 mm, the planting of robusta coffee will only be possible with the use of irrigation.

Saraiva and Silveira (1995) analyzed the variability and the effects of irrigation on conilon coffee production in the different phenological stages of the crop, and verified that the best periods to irrigate the coffee tree were those between bud formation until flowering and from flowering to the fruit survival, which corresponds respectively to the periods from March to August and from July to October, a period when the water *deficit* in the State of Espírito Santo is accentuated.

Silveira and Carvalho (1996) verified that the initial development of the floral bud is retarded, remaining dormant, when the conilon coffee tree is irrigated during the period corresponding to the induction and development of the floral bud. With this, they concluded that the flower buds reach the same development degree, causing a more uniform flowering.

From Figure 1, it is possible to observe that the most important phase to irrigate conilon coffee tree is the one that goes from the bud formation to the flowering. In this case, a productivity gain of approximately 37% was obtained in relation to the non-irrigated one. This demonstrates the importance of water management in the coffee tree to obtain a more uniform flowering and ensure a stable productivity over the years.

As an advantage of coffee irrigation, Mantovani (2001) cites the first harvest anticipation in up to a year, a reduction in the seedlings replanting rate, higher yields in the first harvest, fertigation possibility, and expansion of planting times, among others. But it should be noted that irrigation is one of the fundamental techniques for increasing productivity, among many others that must be associated with it.

Allied to irrigation, pruning, pinching, cover fertilization, weed, pests and diseases control must be done and genetic material compatible with the technology to be used. All these factors interact, contributing to high productivity and production quality.

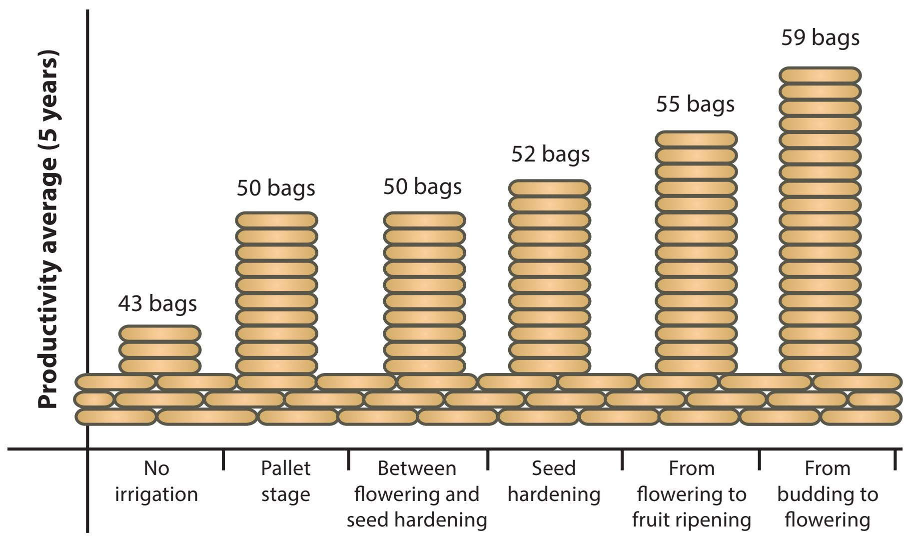

Figure 1. Irrigation effect on different vegetative phases of conilon coffee tree.

Source: Adapted from Sales and Pinto (1998).

2.1 ESTIMATE OF COFFEE TREE WATER NEED

2.1.1 Basic aspects of irrigation management

Considering the aspect of water storage for plants, the soil is equivalent to a water tank. It stores part of the water that infiltrates through its surface, so that it is absorbed by the plants later. Figure 2 schematically represents the water storage in the soil pores considering it as a box with exits.

When all the pores of the soil are filled with water, it is saturated; this usually happens after excessive irrigation or rain. In this condition, drainage of the surplus water occurs, a remaining part of the soil porous space empty, with no water. This water that has been drained is called percolation water. The remaining moisture at this point is called field capacity (FC).

When water is extracted from that point by the plants roots, the soil moisture continues to reduce until they reach a point where they can no longer absorb enough water to keep the plant turgid. When the total loss of turgescence occurs (wilting) and the plant no longer recovers, without replacement of water in the soil, the soil is said to have reached the permanent wilting point (WP). This occurs at pressure values close to 15 atm. Water that is retained with pressure between 1/10 and 15 atm (sandy soils) and between 1/3 and 15 atm (clay soils) is known as total available water for plants or total soil water capacity (TWC), and retained water with a pressure higher than 15 atm is known as inactive water.

It is worth noting that these valuesvary with soil type and should not be adopted as a fixed point of reference, since they are affected by soil-water-climate-plant interaction and also by soil spatial and temporal variability.

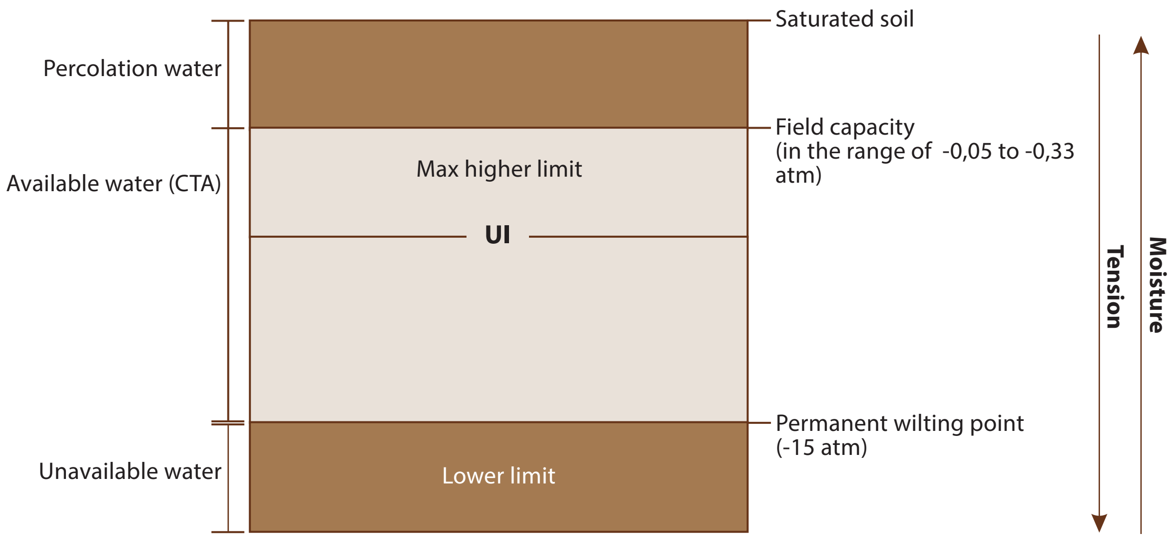

Figure 2. Soil scheme as a water box for plants.

Source: Adapted from Mantovani, Bernardo and Palaretti (2013).

It is known that plants begin to lose in productivity from a level of soil water extraction. Therefore, it is advisable to replace the water before the soil moisture reaches the WP. This point is called irrigation moisture (IM), which is very difficult to determine in practice, since it is variable with the soil type, the crop economic value, the expected productivity, the water availability, and may even be influenced by the type of irrigation system.

Table 1 provides some physical-water properties of different soil types used in the elaboration of irrigation projects. It is worth mentioning that these values should be used with great discretion and only when there is no other information. However the most correct is to obtain information for each solo in each project.

Table 1. Physical-water characteristics of different types of soils

Soil Texture	Infiltration (cm H^{-1})	Porosity total (%)	Specific apparent mass (g cm^{-3})	Field capacity (%)	Wilting point (%)	Available Water (cm m^{-1})
Sandy	5.00(2.5-22.5)	38(32-42)	1.65(1.55-1.80)	9(6-12)	4(2-6)	8(6-10)
Sandy loam	2.50(1.3-7.6)	43(40-47)	1.50(1.40-1.60)	14(10-18)	6(4-8)	12(9-15)
Loam	1.30(0.8-2.0)	47(43-49)	1.40(1.35-1.50)	22(18-26)	10(8-12)	17(14-10)
Clay loam	0.80(0.25-1.5)	49(47-51)	1.35(1.30-1.40)	27(23-31)	13(11-15)	19(16-22)
Sandy Clay	0.25(0.03-0.5)	51(49-53)	1.30(1.25-1.35)	31(27-35)	15(13-17)	21(18-23)
Clay	0.05(0.01-0.1)	53(51-55)	1.25(1.20-1.30)	35(31-39)	17(15-19)	23(20-25)

Source: Adapted from Mantovani and Soares (1998).

Note: The intervals used are in parentheses. The infiltration valuesmay vary more than indicated depending on the structure and stability of the soil aggregates.

The amount of water stored between the FC and the WP up to depth Z is called total soil water capacity (TWC) and can be defined by equation 1.

$$TWC = \frac{FC\text{- }WP}{100}\,\rho.Z.\,\frac{Pwa}{100} \qquad \text{eq. 1}$$

on what:
TWC = total soil water capacity, in mm;
FC = field capacity,% by weight;
WP = wilting point, wt%;
ρ = specific soil mass, in gcm^{-3};
Z = depth of the layer under study, in mm; and
Pwa = percentage wet area, in%.

In the case of sprinkler irrigation, water is applied throughout the project area, so the percentage of wet area is 100%. Thus, (Pwa/100) = 1.

As the plant extracts water from the soil, the matrix potential[2] is reduces itself, requiring the plants to increase the energy expenditure to extract it, thus reducing the partition of photoassimilates that would be converted into effective production, which are the coffee beans, or in the very growth of plants. Therefore, in order for crop productivity not to be significantly affected, only part of the total available water can be used by the plantation, according to equation 2.

$$RCS = TWC\ f \qquad \text{eq. 2}$$

on what:
RCS = real capacity of water storage in the soil, in mm; and
f = factor of water availability in the soil, always less than 1.

The factor of water availability in the soil or risk factor defines the minimum soil moisture (Mh) at which the crop can be submitted without significantly affecting its production. Many aspects influence the effective limits of the f factor, affecting crop development and productivity. Lower values are recommended for crops sensitive to water deficit. Another aspect to be considered, according to several authors, is the quantitative and qualitative development of the root system of the cultivation, which implies a lower or greater reaction capacity of the plant to face a reduction in the water availability. Therefore, this factor must be determined, through surveys, for each region.

When this factor is not known for a given region, the values recommended by Mantovani, Bernardo and Palaretti (2013) and presented in Table 2 can be used. For conilon coffee tree, which is a plant that presents a reasonable tolerance to soil moisture *deficit*, the values of the third group, which vary between 0.4 and 0.6, should preferably be used.

[2]Resulting from water retention forces by capillaries and soil particles (their value is always negative).

Table 2. Recommended valuesof water availability in the soil factor (f) for some crop classes

Culture groups	F values
Vegetables and Legumes	0.2 to 0.4
Fruits and vegetables	0.3 to 0.5
Grains and cotton	0.4 to 0.6

Source: Adapted from Mantovani, Bernardo and Palaretti (2013).

Araújo et al. (2011), studying the effect of water deficiency on the conilon and arabica coffee tree transpiration, verified that the transpiration of these crops reduced when the water availability in the soil factor was 0.7 and 0.9, respectively. Rodrigues et al. (2015) found that, for water availability factors between 100% and 50%, there were no significant differences in the initial growth of conilon coffee tree. This result is also in agreement with Oliveira, Pizetta and Reis (2012) who, when evaluating the influence of water deficiency on the initial development of conilon coffee tree, verified that there were no significant differences in the initial development of the plants with water availability in the soil up to 40%. These facts are good indicators of conilon coffee context in the third group. The availability of research on this subject is still low, especially for adult crop in the productive phase.

For irrigation management purposes, some authors consider as a rule of thumb is that half of the root depth of the adult culture for the first and second stages of development. However, for each study environment, it is necessary to know the function of the crop roots growth making periodic determinations in the field, until the plants reach the adult stage.

Before discussing properly the methods of estimating evapotranspiration, it is necessary to know some elementary concepts:

Evaporation (E) → is the process by which water in the liquid phase is converted into vapor and removed from the evaporating surface. For this process to take place, it is necessary to supply power to the system. In nature, this energy comes from the sun.

Transpiration (T) → is the process by which occurs water loss, in the vapor form, by plants. This water vapor transfer to the atmosphere occurs predominantly through the leaves. Transpiration is maintained by the replacement of the water lost through the stomata, by the water absorbed by the roots, which is carried to the leaves by the conducting system. In addition to the relative humidity of the air, other factors contribute to the process: solar radiation and air temperature, responsible for the energy required for evaporation and the wind speed, acting on this vapor removal. Other factors, such as water availability in the soil, management system, soil salinity, species and phenological phase, also interfere with the rate of transpiration.

Evapotranspiration (ET) → is the process of transfer of water to the atmosphere by soil evaporation and plants transpiration. In a moist soil, the partition between evaporation and transpiration depends on the solar radiation that reaches the soil surface, which, in turn, depends on the vegetation cover. When it is small, the evapotranspiration occurs predominantly by the evaporation of water in the soil; however, with the crop growth and increased soil cover, transpiration becomes the predominant process.

Evapotranspiration of reference or potential (ETo) → also called potential (ETp), is the rate of evapotranspiration that occurs from a reference surface (standard), whose characteristic that defines it is the extensive vegetated surface with grass, with height between 8 and 15 cm, in active growth (IAF = 2.88), totally covering the soil surface and well supplied with water. In these conditions, ETo is a variable exclusively dependent on the meteorological conditions, which also makes it a meteorological element, thus expressing the evapotranspiration potential of a place, at each time of the year, without taking into account soil and plant factors.

Culture evapotranspiration under standard conditions (ETc) → also called maximum (ETm), is the evapotranspiration that occurs in a crop, at any stage of its development, from sowing/planting to maturation, without the performance of factors that can compromise their development, such as the occurrence of pests and diseases, nutritional and/or water deficiency. Under these optimal conditions, ETc is a variable dependent on the meteorological conditions and the leaf area of the cutivation (LAI). Besides these factors, others, such as leaf anatomy, stomatal characteristics and albedo also affect evapotranspiration.

Evapotranspiration of the crop under unanticipated conditions (ETcadj) → is the evapotranspiration that occurs in crops that are in a non-standard situation, that is, under conditions of sensible heat advection, water deficit, nutritional, occurrence of pests or diseases or even of soil salinity. When the soil and phytotechnie conditions are good, but it is under the effect of sensible heat advection, the ETcadj becomes larger than the ETc, being called oasis evapotranspiration. Even under conditions of low fertility, water deficiency, with pests and diseases incidence or under salinity conditions, ETcadj becomes smaller than ETc, being called real evapotranspiration.

The irrigation shift, water shift or irrigation frequency is defined according to equation 3. on what:

$$IS = \frac{RCS}{ETc} \qquad \text{eq. 3}$$

IS= irrigation shift, in days;
RCS = real capacity of water storage in the soil, in mm; and
ETc = crop evapotranspiration, mm.day^{-1}.

It should always be borne in mind that evapotranspiration varies throughout the culture cycle, that is, the irrigation shift oscillates according to the stage of crop development, as well as the prevailing weather conditions. In general, in the project elaboration, the maximum evapotranspiration of the crop should be considered.

Evapotranspiration of a crop (ETc) can be estimated by several methods. The most widespread uses the evapotranspiration product of a reference culture (ETo) by a culture coefficient (Kc). There are other methods to estimate ETo, but they should be evaluated for each region.

Santinato, Fernandes, A. and Fernandes, D. (1996), studying Kc in irrigated crops in the Triângulo Mineiro, northeast of Minas Gerais and western Bahia, suggest, as a first approximation, the valuespresented in Table 3.

Table 3. Cultivation coefficient values (Kc) for coffee tree

Age	Spacing between lines and plants (m)	Kc
1. Adult > 3 years old	A) > 3.0 x > 1.0 - 2500 plants/ha > B) > 3.0 x > 0.5 to 1.0 - 3333 plants/ha C) 2.0 to 3.0 x > 0.5 to 1.0 - 6,666 plants/ha D) 1.0 to 2.0 x > 0.5 to 1.0 - 13,333 plants/ha	1.0 1.1 1.2 1.3
2. Young 1 to 3 years old	A) > 3.0 x > 1.0 - 2500 plants/ha > B) > 3.0 x > 0.5 to 1.0 - 3333 plants/ha C) 2.0 to 3.0 x > 0.5 to 1.0 - 6,666 plants/ha D) 1.0 to 2.0 x > 0.5 to 1.0 - 13,333 plants/ha	0.8 0.9 1.0 1.1
3. Young up to 1 year old	A) > 3.0 x > 1.0 - 2500 plants/ha > B) > 3.0 x > 0.5 to 1.0 - 3333 plants/ha C) 2.0 to 3.0 x > 0.5 to 1.0 - 6,666 plants/ha D) 1.0 to 2.0 x > 0.5 to 1.0 - 13,333 plants/ha	0.6 0.7 0.8 0.9

Source: Adapted from Santinato, Fernandes, A. and Fernandes, D. (1996).

In conventional irrigation systems, evapotranspiration is expressed in terms of daily water consumption for the entire irrigated area, but, in localized irrigation, the entire surface is not normally wet or fully shaded. Therefore, when calculating the average evapotranspiration in the project area, the percentage of area shaded by the plant and/or wet area should be considered, obeying equation 4.

$$ETc = ETp.\ Ks\ (0.0085.Ps + 0.15)\ Kc \qquad \text{eq. 4}$$

on what:
ETc = crop evapotranspiration, in mm.day^{-1};
ETp = potential evapotranspiration, in mm.day^{-1};
Ps = percentage of shaded or wet area, (consider the largest) in%;
Kc = culture coefficient; and
Ks = soil coefficient.

The percentage of area shaded by the plant is the relationship between the area of the horizontal projection of the plant crown and the area occupied by it. Normally, for coffee cultivation, adult crops reach a maximum shading value of 80%, but in very dense crops, this value may be even higher, reaching up to 100% soil cover.

The soil coefficient (Ks) works as a penalty factor of ETp, when the irrigation shift is more than one day, and is variable with the interval between irrigation and the root system depth, as can be seen in Table 4.

Table 4. Soil coefficient (Ks) as an interval function between irrigation and the root system depth

Roots depth (cm)	Days after last irrigation or rain						
	1	2	3	4	5	6	7
0 – 20	1.00	0.96	0.93	0.88	0.83	0.78	0.71
0 – 40	1.00	0.98	0.96	0.95	0.92	0.90	0.88
0 – 60	1.00	0.99	0.98	0.97	0.95	0.94	0.93

Source: Adapted from Mantovani and Soares (1998).

Knowing the actual water storage capacity, the total amount of water to be replenished in each irrigation will be determined by equation 5.

$$TIR = \frac{RCS}{Ef} \qquad \text{eq. 5}$$

on what:
TIR = total irrigation required, in mm;
RCS = real capacity of water storage in the soil, in mm; and
Ef = efficiency of the irrigation system, in decimal.

In sprinkler irrigation this efficiency can be obtained by equation 6.

$$Ef = Ed.Ec.Eap \qquad \text{eq. 6}$$

on what:
Ef = efficiency of the irrigation system, in decimal;
Ed = efficiency of water distribution, in decimal;
Ec = efficiency of water conduction from the source to the irrigated area, in decimal; and
Eap = potential efficiency of water application, in decimal.

In the case of sprinkler irrigation, the plant is generally allowed to consume all available water, that is, the water equivalent to the real water storage capacity in the soil. While in the case of localized irrigation, this condition is rarely achieved, since the interval between irrigation is smaller.

The irrigation systems efficiency is influenced by several factors, such as: project quality, corrective and preventive maintenance, terrain topography, equipment age, among others. In this way, it must be obtained in real field conditions. As an indicative of irrigation efficiency, it can be considered that, in conventional sprinkler irrigation with periodic movement, the efficiency varies between 70 and 85%; in self-propelled and conventional irrigation systems with hydraulic cannon, the efficiency variation is between 60 and 75%, and in fixed conventional systems, the efficiency should vary between 70 and 88%.

In the case of drip irrigation, there are no losses by wind drag, and evaporation losses can be neglected, so Eap = 1 can be considered. As the pipe is usually weldable, the losses in conduction are null. When Ec = 1, the irrigation efficiency in drip systems becomes equal to the uniformity of water application. When the system present leaks due to some connection assembly failures, it is necessary to estimate this loss or perform the necessary repairs.

The volume of water to be applied per plant will then be defined by equation 7.

$$Vp = ITN .Sp .Sf \qquad \text{eq. 7}$$

on what:
Vp = volume of water to be applied per plant, in L;
TIR = total irrigation required, in mm;
Sp = spacing between plants in the planting line, in m; and
Sf = spacing between planting lines, in m.

2.1.2 Evapotranspiration estimation

Irrigation is an agricultural activity whose objective is to provide water to crops in order to meet their water requirements at different stages of development, which will depend fundamentally on the current climatic conditions and the availability of water in the soil.

Irrigation is usually used to make agricultural exploitation feasible in semi-arid regions, in areas with regular droughts or even with occasional droughts (Indian summer), where production stability is provided, minimizing adverse effects caused by water deficiency in crops and consequently, the associated economic risks.

As the meteorological condition is the main conditioning factor of atmospheric vapor demand, the correct estimate of the crops water requirement and, from this, the amount of water determination to be returned to the soil to maintain the ideal conditions for growth and the development of the plants become fundamental to both planning (project design) and irrigation management (when and how much to irrigate).

Thus, several methods have been developed and are still being incremented to improve the estimate of the water requirements of the crops.

2.1.2.1 Factors affecting evapotranspiration

RIn short, they can be divided into three categories:

A - Climate factors

Radiation balance (Rn) → represents the amount of energy available to the physical and biological processes at the soil surface. It is the main source of energy for the evapotranspiration process. It depends on the incident solar radiation and the albedo of the vegetation.

Air temperature (T) → sensible heat contributes with part of the energy required to the evapotranspiration process, and the temperature is also directly linked to relative humidity and air saturation deficit.

Relative air humidity (RH) → acts together with temperature, determining the saturation deficit, one of the components of the air's evaporating power.

Wind (U) → responsible for the removal of saturated air near the evaporating surface of the leaves. In addition, it is in charge of transporting heat from drier areas (sensible heat advection). It is the other component of the air's evaporating power.

B - Plant factors

Species → related to foliar architecture, resistance to vapor transport in the stomata and other morphological aspects that interfere directly with evapotranspiration.

Reflection coefficient (albedo) → is the ratio between the amount of energy diffused or reflected by a surface and the amount that reaches it. It affects the balance of radiation, main source of energy for the evapotranspiration process.

Leaf area → related to the size of the leaf surface available for the transpiration process. The larger the leaf area, the greater the water requirement of the plant.

Plant height → interferes relationship between the plant and the atmosphere.. High plants interact more with the moving atmosphere, extracting more energy from the air.

Root system depth → related to the volume of soil explored by the roots, aiming to supply water to the plant.

C - Management and soil factors

Spacing/planting density → determines the competition level among individuals of the same species. The smaller the spacing, the more individuals and the higher water consumption per area.

Soil type → clay soils retain more water than sandy so they meet plant needs for longer. IN addition, the process of water transmission within this soil is faster.

Water availability in the soil → directly affects evapotranspiration when the stored volume falls beyond the critical limit, reducing it.

Mulch → reduces water loss through evaporation and, consequently, evapotranspiration.

Physical and/or chemical impediments → limit the crop's root system growth, reducing the volume of water available for use by the plants, that is, it limits the volume of soil explored by the roots.

2.1.2.2 Camargo Method

This method was proposed by Camargo (1971), which is a simplification of the method of Thornthwaite (1948). Thus, it presents the same advantages (it only uses average air temperature) and disadvantages (it does not consider the evaporating power of air) that the original method on which it is based. The additional advantage is that the Camargo method does not use the normal air temperature. This method was developed and tested in humid climate conditions, therefore underestimates in dry climate conditions. The ETo is estimated directly from equation 8.

$$ETo = 0{,}01Q_o.T_{av}.ND \quad \text{eq. 8}$$

on what:

Q_o = extraterrestrial solar irradiance (Table 5), expressed in mm of equivalent evaporation;
T_{av} = average temperature of the period considered, in °C;
ND = number of days in the period considered.

Table 5. Extraterrestrial solar irradiance (Q_o), expressed in $mm.dia^{-1}$ to the 15th day of each month, for the Southern Hemisphere latitude

Lat S	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0º	14.5	15.0	15.2	14.7	13.9	13.4	13.5	14.2	14.9	14.9	14.6	14.3
2º	14.8	15.2	15.2	14.5	13.6	13.0	13.2	14.0	14.8	15.0	14.8	14.6
4°	15.0	15.3	15.1	14.3	13.3	12.7	12.8	13.7	14.7	15.1	15.0	14.9
6º	15.3	15.4	15.1	14.1	13.0	12.6	12.5	13.5	14.6	15.1	15.2	15.1
8º	15.6	15.6	15.0	14.0	12.7	12.0	12.2	13.2	14.5	15.2	15.4	15.4
10º	15.9	15.7	15.0	13.8	12.4	11.6	11.9	13.0	14.4	15.3	15.7	15.7
12º	16.1	15.8	14.9	13.5	12.0	11.2	11.5	12.7	14.2	15.3	15.8	16.0
14º	16.3	15.8	14.9	13.2	11.6	10.8	11.1	12.4	14.0	15.3	15.9	16.2
16º	16.5	15.9	14.8	13.0	11.3	10.4	10.8	12.1	13.8	15.3	16.1	16.4
18º	16.7	15.9	14.7	12.7	10.9	10.0	10.4	11.8	13.7	15.3	16.2	16.7
20º	16.7	16.0	14.5	12.4	10.6	9.6	10.0	11.5	13.5	15.3	16.2	16.8
22º	16.9	16.0	14.3	12.0	10.2	9.1	9.6	11.1	13.1	15.2	16.4	17.0
24º	16.9	15.9	14.1	11.7	9.8	8.6	9.1	10.7	13.1	15.1	16.5	17.1
26º	17.0	15.9	13.9	11.4	9.4	8.1	8.7	10.4	12.8	15.0	16.5	17.3
28º	17.1	15.8	13.7	11.1	9.0	7.8	8.3	10.0	12.6	14.9	16.6	17.5
30º	17.2	15.7	13.5	10.8	8.5	7.4	7.8	9.6	12.2	14.7	16.7	17.6

Source: Sentelhas (2001).

2.1.2.3 Hargreaves and Samani Method

Method developed by Hargreaves and Samani (1985) for the semi-arid climate conditions of California. It is recommended by the Food and Agriculture Organization of the United Nations (FAO) as an option for estimating ETo when there is only availability of local air temperature data. Usually, it presents an overestimate in humid climate conditions. Like the Camargo method, it is not universally applicable and therefore must be calibrated for other climatic conditions.

Its formula for ETo's daily estimate is as follows:

$$ETo = 0{,}0023Q_o(T_{max} - T_{min})^{0{,}5}(T_{med} + 17.8) \qquad \text{eq. 9}$$

on what:

T_{max} = maximum air temperature in ºC;
T_{min} = minimum air temperature, in ºC;
T_{av} = average air temperature, in ºC;
Q_o = extraterrestrial solar irradiance, expressed in mm of equivalent evaporation (Table 5).

2.1.2.4 Class "A" Tank Method

The "Class A" Tank (DOORENBOS; PRUITT, 1977) is the method that has achieved the greatest application in the management of irrigated areas, due to the operational facilities and to initially consider that the evaporation process of a tank (EVt) is subject to the same ET variables of a cultivation by correcting the differences by means of a specific coefficient, K_t (Table 6), due to local climatic conditions and tank installation. This coefficient transforms the EVt into ETo, which is then multiplied by Kc to determine the ET of the irrigated crop.

Table 6. Conversion coefficient values of Class "A" Tank (K_t) for potential evapotranspiration estimate

Wind (Km/day)	Exposure A Tank surrounded by grass				Exposure B Tank surrounded by naked soil			
	Tank Position R(m)*	UR% Low <40%	UR% Medium 40-70%	UR% High <70%	Tank Position R(m)*	UR% Low <40%	UR% Medium 40-70%	UR% High <70%
Light <175	0	0.55	0.65	0.75	0	0.70	0.80	0.85
	10	0.65	0.75	0.85	10	0.60	0.70	0.80
	100	0.70	0.80	0.85	100	0.55	0.65	0.75
	1.000	0.75	0.85	0.85	1.000	0.50	0.60	0.70
Moderate 175-425	0	0.50	0.60	0.65	0	0.65	0.75	0.80
	10	0.60	0.70	0.75	10	0.55	0.65	0.70
	100	0.65	0.75	0.80	100	0.50	0.60	0.65
	1.000	0.70	0.80	0.80	1.000	0.45	0.55	0.60
Strong 425-700	0	0.45	0.50	0.60	0	0.60	0.65	0.70
	10	0.55	0.60	0.65	10	0.50	0.55	0.75
	100	0.60	0.65	0.75	100	0.45	0.50	0.60
	1.000	0.65	0.70	0.75	1.000	0.40	0.45	0.55
Very strong >700	0	0.40	0.45	0.50	0	0.50	0.60	0.65
	10	0.45	0.55	0.60	10	0.45	0.50	0.65
	100	0.50	0.60	0.65	100	0.40	0.45	0.50
	1.000	0.55	0.60	0.65	1.000	0.35	0.40	0.45

Source: Ometto (1981).

*Refers to the average distance of covered area, relative to the tank.

It is worth mentioning that this daily information is useful for irrigation management, but for project design, what matters is the crop maximum demand.

To obtain evapotranspiration by this methodology, equation 10 is used:

$$ETo = EVt.K_t \qquad \text{eq. 10}$$

on what:

ETo = potential evapotranspiration, in mm;

EVt = class "A" tsnk evaporation, in mm;

K_t = tank coefficient.

Allen et al. (1994), after analyzing the operational difficulties of using the standard cultivation in the measurements of ET in lysimeters, proposed the use of a new standard, defined by the Penman-Monteith equation. Due to the good ETo estimates of this equation

(ALLEN et al., 1989; JENSEN; BRUMAN; ALLEN, 1990) and the requirements and difficulties to obtain accurate results with lysimeters, the authors indicate that the idea of using the Penman-Monteith equation as standard is promising and necessary.

To use this equation, it becomes necessary the use of weather stations. Currently, these are already a reality due to its low cost and ease of communication, and can be fully automated.

3 IRRIGATION SYSTEMS

The economic and social situations inherent in each region and the different soil, water, climate and crop conditions to be exploited make it possible to use different irrigation systems, which can be grouped into three broad methods: surface irrigation, sprinkler irrigation and localized irrigation.

There is no answer as to the best method of irrigation, but a number of factors define which system is best suited for a particular situation. It is also argued that the coffee grower now has an offer of methods and brands of irrigation equipment, compared to that, which any producer in the most advanced countries in the agricultural area has access.

Coffee tree irrigation has been carried out normally with pressurized systems, with emphasis on sprinkler and localized irrigation methods (MANTOVANI; SOARES, 2003). Among these systems, we can highlight: conventional sprinkler, center pivot, loop, drip and micro sprinkler.

It is important that the coffee grower is aware of the various possibilities so that he can properly define the best system and equipment for his crop. This definition should take into account several aspects, such as: area, topography, water quantity and quality, soil type, climate, investment capacity, technological level of the products, crop spacing, available labor, technical assistance, among others.

3.1 SPRINKLER IRRIGATION SYSTEMS

In conventional sprinkler irrigation, the water is thrown onto the surface of the land, which resembles a rainfall because of the fractioning of the water jet into droplets. These systems are generally made up of fixed pipes in the main line and portable in the lateral lines, with characteristics that make them easy to transport, install and assemble, in such a way that the operations are manually feasible. It is a simple, low cost management system, and, therefore, widely used in small and medium properties (MANTOVANI; BERNARDO; PALARETTI, 2013).

In the literature, the main advantages of this system are adaptability to the different types of soil and topography, possibility of good control of the water to be applied and of fertilizers application and phytosanitary treatments, in addition to a low implantation cost. This happens when the equipment is well designed and handled in favorable wind conditions. As major limitations, high initial costs of operation and maintenance; distribution of water greatly affected by climatic factors, mainly by wind; favor the development of some diseases; risk of soil surface sealing; and impropriety for water with high salt content can be highlighted.

Depending on the length of the lateral line, its change of position may require from 20 minutes to 1 hour, resulting in a decrease in the useful irrigation time, as well as the mobilization of much of the labor available to perform the service.

Conventional sprinkler irrigation can use different types of sprinklers, ranging in size (small, medium or cannon), number of nozzles (1 or 2), material (plastic, iron), flow rate, droplet size, among others.

The fact that such a system is very common in the rural environment has involved several problems, such as installation of a system without an adequate engineering design, inadequate management of the system in terms of pressure regulation and sprinkler flow, sprinklers mix in irrigation lines, among others. It is a demanding method in labor for the change of sprinkler pipes. However, a good design can optimize its use by choosing the right sprinkler, using waiting lines, proper distribution of the systems in the field, use of appropriate accessories, among others.

Portable irrigation systems for coffee tree have been used, that is, those in which the pump and the main and lateral pipes, as well as the sprinklers, are moved from one point to the other of the irrigated area. Such a system, despite presenting lower initial cost, has presented a number of drawbacks to quality irrigation. The fact that total mobility brings a delay in the irrigation of several areas compromises productivity because of the difficulty of transporting the equipment quickly from one place to the other. In other words, much time is wasted in the system preparation. In addition, the design spacing for the sprinklers and the diameter of the pipes are often not respected, which severely compromises the irrigation quality.

In view of the aspects approached, it is recommended to install conventional sprinkler irrigation systems of the semi-portable type, that is, the pump and the most difficult pipes of quick assembly are fixed and the lateral line and the sprinklers move themselves. This assembly slightly increases the cost of the project (20 to 30%), but guarantees a right, quality and with less labor irrigation, compared to the portable Figure 3.

Conventional sprinkler irrigation systems are characterized by the need for labor in the change of lines and sprinklers, which in many production systems becomes a limiting factor. Several strategies can be used to minimize or eliminate the problem, and it is up to the designer to choose the most appropriate one for each situation. Among the most common possibilities we can cite the following:

- use of hydraulic cannon (greater spacing);
- use of hoses and tripods; and
- use of buried fixed systems (loop irrigation system).

The hydraulic cannon system (Figures 3 and 4) is a variation of the previous one, in which the modification consists in the use of large sprinklers, which allow greater spacing between lateral lines and sprinklers and, therefore, less use of labor, besides providing irrigation of larger areas. Such systems require greater energy consumption in relation to the others, due to the higher pressure required for the cannons operation.

According to Mantovani, Bernardo and Palaretti (2013), loop irrigation system refers to a project type characterized by the use of low-diameter PVC pipes that are buried and interconnected in a system. At each of the sprinkler installation points, a riser pipe is attached, as can be seen in Figures 5 and 6.

Figure 3. Conventional sprinkler irrigation system in coffee crop.

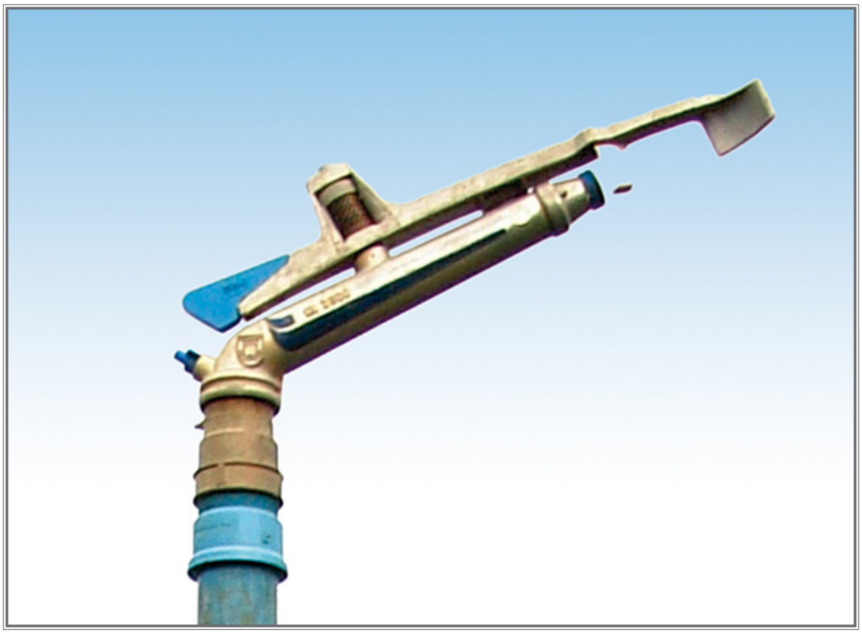

Figure 4. Hydraulic cannon used in coffee irrigation.

Figure 5. Sprinkler detail in operation and view of coffee plantation irrigated by the loop irrigation system.

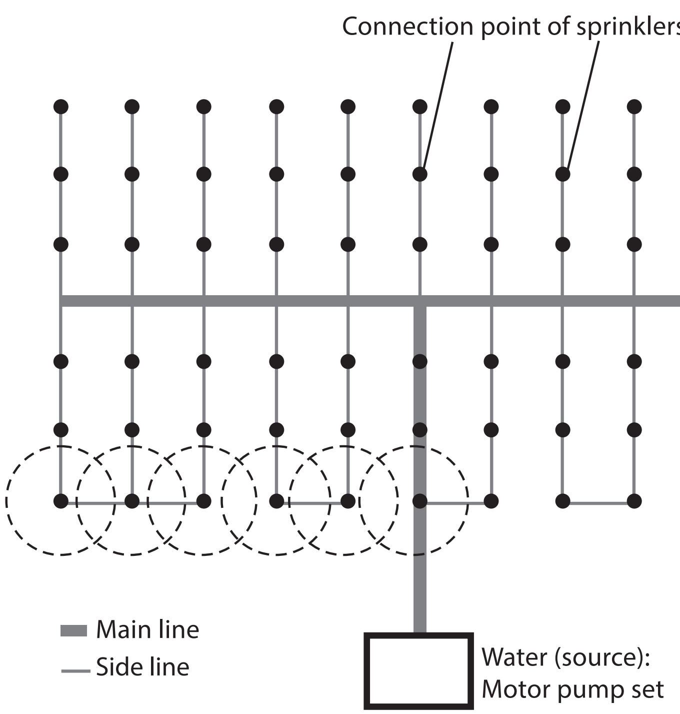

Figure 6. Loop irrigation system scheme.

In Brazil, the loop irrigation system has been disseminated in recent years, in pasture irrigation. This system has adapted very well to the coffee tree. It was initially used in the irrigation of small areas and it is currently used for medium and large crops because of the following advantages (DRUMOND; FERNANDES, 2004):

- adaptation to different types of terrain;
- low implementation cost when compared to other systems;
- low labor consumption (fixed system in which only the sprinkler moves; and
- Ease to operate and maintain.

Like every system, it also has disadvantages, such as:
- Impossibility of automation; and
- Opening of a large number of ditches if the system is buried.

3.1.1 Mechanized sprinkler irrigation systems

Mechanized sprinkler irrigation systems were initially designed to reduce work force in pipes movement. They have a propulsion mechanism, which ensures movement while applying water on the ground. There are currently several types of mechanized systems.

In the system with linear movement, the lateral line containing the sprinklers is equipped with propulsive mechanisms that assure its continuous or intermittent movement in the irrigated area. The systems with continuous movement are classified according to the direction of the displacement, that is, linear or radial (center pivot).

The self-propelled systems are characterized by a sprinkler (large, medium or small) installed in a metal structure (cart) with pneumatic wheels, which moves linearly, irrigating land strips. A flexible pressure resistant hose, traction and friction with the surface of the ground makes the connection between the structure and the hydrants for the water supply. Water under pressure activates the propulsion system (turbine, piston), promoting the winding of a steel cable anchored to one end of the irrigated strip. The sprinkler, known as a hydraulic cannon, requires high pressure for operation and, therefore, high energy consumption.

The center pivot system (Figure 7) has still been widely used in coffee irrigation in northern Espírito Santo. This system irrigates areas greater than 50 ha and presents competitive costs, in addition to optimizing the use of labor. Its use has been more efficient than conventional sprinkling. Being relatively ease to handle, it has made possible the production of a great diversity of cultures, since the application of water can be made in the quantity and frequency that best fits the system soil-plant-atmosphere and maximize the production.

Figure 7. View of a center (A) and linear (B) pivot used in coffee irrigation.

Over the years, the center pivot equipment has undergone technological improvements, becoming a reliable and simple operation machine. However, like any other mechanism, it needs a systematic maintenance routine. Center pivot irrigation systems have the capacity to irrigate, in only one revolution, areas of up to 130 ha or more. Preferably, these areas should have flat or slightly undulating relief. There is, however, equipment designed to operate in areas of uneven relief, with slopes up to 20%.

3.1.2 Components of a sprinkler irrigation system

A sprinkler irrigation system usually consists of pipes, sprinklers, motor pumps and accessories.

The pipes are usually made of aluminum, zinc plated steel, galvanized steel or rigid PVC, with a standard length of 6 m and a diameter ranging from 2 "to 8". Other materials such as cast iron can be used in buried fixed lines. With the function of conducting the necessary flow from the pump to the sprinklers, the pipes, according to the layout in the terrain, are classified in: lateral lines - generally they are provided with fast couplings, they lead the water until the sprinklers; secondary lines - aluminum, PVC or zinc plated steel feed the lateral lines from the main line; the main line - in PVC, zinc plated steel or aluminum - leads the water from the motor pump to the secondary lines.

The sprinklers are the main parts of the system, responsible for the distribution of water under the ground in the form of rain. Rotary sprinklers may be complete rotation (3600) or sector type, the latter being used in different areas of the field or under special conditions.

As for the angle of inclination, they have a jet ranging from 25º to 30º, and 6º in the case of a low flow impact sprinkler; are provided with one, two or three nozzles 2 to 30 mm in diameter. According to the operating pressure, it can be classified as: low pressure (<250 KPa), medium pressure (250 KPa to 500 KPa) and high pressure (> 500 KPa).

The medium pressure sprinklers are the most used and have a reach radius of 12 to 36 m. The choice is mainly based on the precipitation they provide (function of pressure, nozzle diameter and spacing). The arrangement in the most common field is the rectangular one, being able to be square or triangular. The spacing (multiple of 6 m) in the field can be defined by wind speed conditions. This spacing in the sprinkler line can range from 30 to 50% of the wet diameter, and between lines up to 65%.

The most commonly used motor-pumps in general, in conventional sprinkler irrigation are those of the centrifugal of horizontal axis type. They have the function of collecting water at the source and pushing it under pressure into the pipe to supply the sprinkler system. Attached to the pump is a motor, usually electric or diesel. The assembly shall be measured to provide sufficient flow to the system at the required manometric height. The water elevation from the source to the irrigated area is one of the main factors involved in energy consumption, and as the height increases, the higher the efficiency levels of the irrigation systems to result in a satisfactory energy consumption.

The most common accessories are end cap, sprinkler riser, quick coupling for sprinklers with outlet valve, curves, line valves, elbows, manometers, drawer registers, Tee, check valve, foot valve, rubber seal, among others.

3.2 LOCALIZED IRRIGATION SYSTEMS

It is a system that best fits the coffee irrigation. In general, it is used to distribute the polyethylene pipe to the side of the planting line on the soil surface (Figure 8).

Localized irrigation is based on the application of water in only a fraction of the cultivated area, in high frequency and low volume, maintaining the soil in the root zone of the plants under high moisture regime. The minimum wet area should be approximately 1/3 of the shaded area (or projection of the plants' crown). The area of wet soil exposed to the atmosphere is greatly reduced and, consequently, less water loss by direct evaporation of the soil. The water applied by these systems penetrates the soil and redistributes, forming a wet bulb, whose shape and size depend on the flow rate applied, the type of emitter, the duration of the irrigation and the type of soil. The infiltration occurs in all directions, but in the vertical direction, is more pronounced when the soil presents sandy characteristics.

Figure 8. Detail of irrigation located by *microspray* in coffee culture.

The main difference between the systems of localized irrigation and other systems is that in the first the balance between evapotranspiration and applied water is maintained in periods between one and three days (greater frequency of application). The drip, the *microspray* and micro sprinklers are the main representatives of irrigation systems located in commercial use in the State of Espírito Santo. There are other types of more restricted systems, such as drip tubing, porous pipes and laser tubing.

It is a system that requires water filtration to prevent the clogging of the emitters. The filters are installed in the control head, where flow and pressure control accessories, fertilizer injection system and other control accessories are also installed (Figure 9).

Localized irrigation offers a great potentiality of benefits to the plant, however, because it is a more sophisticated method, it presents operational and management limitations, which depend on technical, economic and agronomic factors.

Among the main characteristics inherent to the localized irrigation system, are the following:

• Economics and efficiency of water application: the reasons attributed to water savings include irrigation of only a fraction of the area under cultivation (mainly in tree plants), reduction of evaporation on the soil surface, reduced risk of superficial runoff and deep percolation loss. Compared with sprinkler systems, water savings can reach 20-30%, but it is clear that the amount required for the crop is the same regardless of the application process or system. Since it allows greater control of the applied water slide, and that losses are greatly reduced, it results in high efficiency in the application and use of this feature.

Figure 9. Control station components of a localized irrigation system.

• Higher production and better quality of the product: this is due to the high frequency of irrigation, which avoids the occurrence of water stress in the plant and, therefore, favors the crop development with increased production and better quality of the product.

• Lower risk of the salts effect on plants: minimizing the risk of salinity to the plants by localized systems can be attributed to facts such as dilution of the concentration of salts in the soil solution as a consequence of the high frequency of irrigation that maintains the moisture high in the root zone, elimination of damage to the leaves by sprinkler irrigation with saline water and salts movement beyond the region of root activity.

• Facility and efficiency in the application of fertilizers: the localized systems offer greater flexibility in the fertigation and make the use of the nutrients more efficient, since the fertilizers are frequently and directly applied in the irrigation water and in small doses directly in the root zone minimizing the leaching.

• Lower labor demand and lower energy consumption: systems can be easily automated, making operation easier when labor is limited or expensive. Since they operate with pressures and smaller amounts of water than other types of pressurized irrigation, they present reduced energy costs for pumping.

• Adaptation to different types of soils and topography: as the application of water is small, localized irrigation adapts better to different types of soil and topography, as well as facilitating cultural operations or practices allowing easy movement of machines and workers.

• Sensitivity to clogging: considered the main problem of localized irrigation, the occurrence of clogging of the emitters can affect the water distribution and, with that, damage the culture production. Low service pressure, small orifice diameter and low water speed facilitate clogging caused by physical, chemical and biological processes. Preventive maintenance (including water filtration and chemical treatment to clean the pipes) is an effective alternative to avoid obstructions. Other important problems such as obstruction include the breakage of pipes, failures in fittings and equipment, rodent animals and insects.

• Development of the root system: due to the formation of a constant volume of moist soil (wet bulb), the root system tends to concentrate in this region, reducing the plants stability, which can cause them to topple when subjected to high winds.

• Costs: the localized irrigation systems are fixed and require large quantity of pipes and accessories. Consequently, the initial and annual costs are high and can be compared to the expenses with the implementation of fixed sprinkler irrigation systems. Costs can vary considerably depending on the culture, the required amount of piping, filtration and fertilization equipment and the desired degree of automation.

3.2.1 Description of a localized irrigation system

A complete localized irrigation system consists of the following parts: emitters (drippers, *microsprays*, micro sprinklers, micro tubing), pipes (lateral, bypass and mainlines) for water distribution and control head (motor pump, the filter system, fertilizer injectors, pressure and flow control system), as well as accessories and connections indispensable for operation and the system management in the field.

The emitters are the devices that control the exit of the water in the lateral lines, in discrete and continuous points. They are distinguished in mini sprinklers (diffusers or microsprinklers), drippers, hoses or dripper pipes (dripping tubing, porous hose, soaker hoses) and the *microspray* , which is an intermediate emitter between the dripper and the microsprinkler. The fundamental characteristics that must be presented by an emitter and that define their choice consist of uniform and constant flow, reduced sensitivity to obstructions, high manufacturing uniformity, resistance to chemical and environmental aggressiveness, stability of the pressure-flow relationship, reduced load loss in connection systems, resistance to insect and/or rodent attack and low acquisition cost. The emitters, within the total cost of a system, correspond to the parcel of 5 to 10%.

In localized irrigation systems, the pipes are usually polyethylene (low and medium density) and PVC (main line), according to the order of operation (Figure 10). They must be very well measured, taking into account the required hydraulic and operating conditions.

In the system cost, they correspond to the share of 60 to 70% of the total value. The lateral lines are pipes of the last order in the system, on which the emitters are connected. They shall be measured in such a way as to allow the emitters to distribute the water with an adequate degree of uniformity, minimizing the flow variation along its length.

Usually, the lateral lines are made of flexible low density polyethylene, with internal diameters regularly marketed with 13 or 16mm. The bypass lines are pipes that feed the lateral lines. Hydraulically, they are equal to the latter, since they are of multiple outputs. They are measured and must allow adequate pressure at the beginning of each lateral, bypassing the necessary flow for each one.

Figure 10. Irrigation system located in the coffee culture.

The secondary lines are those that supply the bypass lines. The design should be based on economic criteria, the most common diameters being 20 to 80 mm. They can be made of polyethylene or PVC. The main line is the one that drives the water from the motor pump through the control head to the secondary lines. They can be PVC or even high density polyethylene, depending on the pressure conditions, which they will be submitted.

Control head is defined as the set of elements that allows the treatment of irrigation water, its filtration, measurement, pressure control and application of fertilizers. Its composition may vary in many cases. For example, there are facilities where fertilizers are applied from the control head, however, in some installations, the applications are performed in the irrigation units. Often, water presents some quality problems that limit its use in localized systems, which may cause the emitters obstruction.

In some cases, prior to filtration, chemical treatment is required to eliminate algae using oxidants, such as sodium hypochlorite. Another case is the application of acids to prevent the formation of calcium precipitates.

Sand filters are typical and indispensable elements for the algae, organic and vegetable impurities elimination and mineral particles retention retention. It is always convenient to install two filters to facilitate the entire system cleaning without stopping.

Screen filters are always needed right after the fertigation equipment, to remove mineral impurities that cross the sand filters and come from the dissolved fertilizers. Most of the filters available in the market are provided with mechanisms that facilitate cleaning. The fertigation equipment must not be installed before the sand filters.

Fernandes (2013) presents a detailed survey on the costs of implementing irrigation systems used in Brazilian coffee cultivation, which can be briefly seen in Table 7. It can be observed that costs can vary from R$2.200,00 (two thousand and two hundred reais) for the conventional sprinkler irrigation system to R$8.000,00 (eight thousand reais) for the self-compensating drip irrigation system in a coffee plantation.

Table 7. Implementation cost (R $ ha^{-1}) for irrigation systems used for coffee

Irrigation system	Implementation Cost (R$ ha^{-1})
Center Pivot	5.000,00
LEPA Center Pivot	5.500,00
Self-compensating drip in dense plantation	8.000,00
Conventional drip in dense plantation	7.000,00
Conventional Drip	5.000,00
Loop irrigation system	3.800,00
Conventional sprinkler	2.200,00

Source: Adapted from Fernandes (2013).

3.2.2 Efficiency of the localized irrigation system

The efficiency of a localized irrigation system can be defined as the ratio between the amount of water stored in the root system and the total amount derived from the source. The efficiency of a system must take into account the uniformity of application or distribution of water and the losses that may occur during and after the system operation.

Among the losses that can occur are those due to percolation, evaporation and due to the leakage in the water conduction system, since the efficient use of irrigation consists in the supply of water necessary for the normal development of the crops, so that the quantity applied does not exceed the adsorption and utilization capacity of the crop root system, since both excess and water deficiency cause economic losses in agriculture.

3.2.3 Uniformity of water application in a localized irrigation system

According to Silva, César and Silva, Cícero (2005), of the total volume of water that is applied to the soil, only a small part is absorbed and harvested by the crops, as leakage and deep percolation losses usually occur, depending on the management adopted and the uniformity of water application of the system. Therefore, it is necessary to determine the uniformity of water application in any irrigation system, since this parameter is used to measure the variability of water applied.

The uniformity of water distribution of an irrigation system is one of the main parameters for the diagnosis of the system operating situation, being one of the components for determining the level of efficiency in which the system works and by which the amount applied should be corrected to provide water so that the irrigated crop has a full development (MANTOVANI; BERNARDO; PALARETTI, 2013).

In localized irrigation systems, the uniformity of water application can be expressed by means of several coefficients, among which are the Christiansen Uniformity Coefficient (CUC) and the Uniform Emission Coefficient (UEC).

3.2.3.1 Christiansen Uniformity Coefficient (CUC)

The Christiansen Uniformity Coefficient (CUC), proposed by Christiansen (1942) and presented by Mantovani, Bernardo and Palaretti (2013), which considers absolute mean deviation as a measure of dispersion, is determined from equation 11:

$$CUC = 100\left\{1- \frac{\sum_{i=1}^{n} Q_i - Q_m|}{n\,Q_m}\right\} \quad \text{eq. 11}$$

on what:
CUC = Christiansen Uniformity Coefficient, in %;
Q_i = flow of each emitter, in L h^{-1};
Q_m = average flow of the emitters, in L h^{-1}; and
n = number of emitters.

This coefficient is considered by many authors as one of the main technical parameters that describe the uniformity of water application of an irrigation system, being the most used to determine the spatial variability of the water applied by the system.

3.2.3.2 Uniform Emission Coefficient (UEC)

The Uniform Emission Coefficient (UEC) proposed by Criddle et al. (1956) and quoted by Mantovani; Bernardo and Soares (2009), which correlates the mean of the lowest quartile, that is, the mean of 25% of the observations with the lowest values, with the total mean, is expressed by equation 12:

$$UEC = \frac{Q_{25\%}}{Q_m}\,100 \quad \text{eq. 12}$$

on what:
UEC = Uniform Emission Coefficient in%;
$Q_{25\%}$ = mean of 25% of the lowest flow values observed, in L h^{-1}; and
Q_m = mean of all the collected flows, in L h^{-1}.

The the performance classification of drip irrigation systems, according to the values of CUC and UEC, is presented in Table 8.

Table 8. Christiansen Uniformity Coefficient (CUC) and Uniform Emission Coefficient (CUE) classification for localized irrigation systems

Classification	CUC (%)	UEC (%)
Excellent	> 90	> 84
Good	80 – 90	68 – 84
Acceptable	70 – 80	52 – 68
Bad	60 – 70	36 – 52
Unacceptable	< 60	< 36

Source: Adapted from Mantovani, Bernardo and Palaretti (2013).

It is worth mentioning that the joint analysis of these uniformity coefficients is essential to evaluate the performance of drip irrigation systems.

The evaluation of the irrigation systems performance is a fundamental step in irrigation management, as it provides information on the efficiency of water application of the irrigation system in operation. It is one of the technical parameters used to correct the water line applied by the system according to the crop water requirements and the region edaphoclimatic conditions.

In order to evaluate the performance of any irrigation system, it is necessary to determine the Real Irrigation Required (RIR), the Water line applied (Wlin), the Deficient line (Dlin), the Percolated line (Plin) and the Stored line (Slin) with the methodology described by Bernardo, Soares and Mantovani (2006).

After determining the uniformity coefficients of water and lines application, a diagnosis of the localized irrigation systems operation is made, for example, through the technical parameters determination: Properly irrigated area percentage (Piap), AND *Deficit* coefficient (Dc), Percolation losses (Plos), conduction efficiency (Ce), project distribution efficiency for properly irrigated area (PDepia), irrigation efficiency for properly irrigated areas (Iepia) and application efficiency (Ae), according to the methodology presented by Barreto, Silva and Bolfe (2004) and Bernardo, Soares and Montovani (2006).

The following is an example of how to evaluate the uniformity and water application efficiency of a drip irrigation project in the conilon coffee culture, according to the field uniformity test results (Tables 9, 10, 11 and 12).

Project data:

Site: Alegre-ES	Culture age: 4 months
Q_m: 12 L h^{-1}	Irrigation time: 3 h
Spacing between drippers: 1.50	Spacing between lateral lines: 3.00 m
Root system depth: 20 cm	Number of drippers per lateral line: 24
Working Pressure: 98K Pa	Number of emitters per plant: 1
Conduction Efficiency 0.99	Piap: 90%
Collector diameter: 305 mm	Collector Area: 0.0731 m^2
Field Capacity (Fc): 17.87%	Soil Density (Sd): 1.21 g cm^{-3}
Current moisture (Cm): 14.79%	Kc = 0.40

Table 9. Result of the water distribution uniformity test (Lh^{-1}) of the Drip Localized Irrigation Project

	1st Lateral Line	1/3 Origin	2/3 Origin	Last Lateral Line
LL first emitter	12.64	12.46	12.50	12.56
Located 1/7 from the LL	12.32	12.58	12.56	12.44
Located 2/7 from the LL	11.18	12.52	12.46	12.36
Located 3/7 from the LL	12.40	12.35	12.30	12.26
Located 4/7 from the LL	11.28	12.34	12.18	11.98
Located 5/7 from the LL	10.46	12.22	11.90	11.40
Located 6/7 from the LL	12.34	11.62	11.35	11.22
LL last emitter	12.05	12.16	11.16	10.95

Source: Elaborated by the authors.

Table 10. Result of the water distribution uniformity test (mm) of the Drip Localized Irrigation Project

	1st Lateral Line	1/3 Origin	2/3 Origin	Last Lateral Line
LL first emitter	2.88	2.84	2.85	2.86
Located 1/7 from the LL	2.81	2.87	2.86	2.84
Located 2/7 from the LL	2.55	2.85	2.84	2.82
Located 3/7 from the LL	2.83	2.82	2.80	2.80
Located 4/7 from the LL	2.57	2.81	2.78	2.73
Located 5/7 from the LL	2.38	2.79	2.71	2.59
Located 6/7 from the LL	2.81	2.65	2.59	2.56
LL last emitter	2.75	2.77	2.54	2.49

Source: Elaborated by the authors.

Table 11. Valuesof the flow deviations in relation to the collected average flow (L h^{-1})

	1st Lateral Line	1/3 Origin	2/3 Origin	Last Lateral Line
LL first emitter	0.62	0.44	0.48	0.54
Located 1/7 from the LL	0.30	0.56	0.54	0.42
Located 2/7 from the LL	-0.84	0.50	0.44	0.34
Located 3/7 from the LL	0.38	0.33	0.28	0.24
Located 4/7 from the LL	-0.74	0.32	0.16	-0.04
Located 5/7 from the LL	-1.56	0.20	-0.12	-0.62
Located 6/7 from the LL	0.32	-0.40	-0.67	-0.80
LL last emitter	0.03	0.14	-0.86	-1.07

Source: Elaborated by the authors.

Table 12. Valuesof the flow deviations in relation to the collected average flow (mm)

	1st Lateral Line	1/3 Origin	2/3 Origin	Last Lateral Line
LL first emitter	0.14	0.10	0.48	0.11
Located 1/7 from the LL	0.07	0.13	0.12	0.10
Located 2/7 from the LL	-0.09	0.11	0.10	0.08
Located 3/7 from the LL	0.09	0.08	0.06	0.05
Located 4/7 from the LL	-0.17	0.07	0.04	-0.01
Located 5/7 from the LL	-0.36	0.05	-0.03	-0.14
Located 6/7 from the LL	0.07	-0.01	-0.15	-0.18
LL last emitter	0.01	0.03	-0.20	-0.24

Source: Elaborated by the authors.

1. Determination of the Drip Irrigation System Uniformity Coefficients:

a) Applying the uniformity test results to the Christiansen equation:

$$CUC = 100\left\{1 - \frac{\sum_{i=1}^{n}\left|Q_i - Q_m\right|}{n\,Q_m}\right\} = 100\left(1 - \frac{15{,}30}{32\,.\,12}\right) = 96{,}02\%$$

$$Qmcol = \frac{\sum_{i=1}^{n} X_i}{n} = \frac{12{,}64+\ldots+10{,}95}{32} = 12{,}02\ \mathrm{L\ h^{-1}}$$

b) Applying the data in the equation suggested by Criddleet al. (1956):

$$UEC = 100\,\frac{Q_q}{Q_m} = 100\,\frac{11{,}27}{12{,}02} = 93{,}76\% \cong 94\%$$

2. Determination of the water lines application by the system under study:

a) Real Irrigation Required (RIR):

$$RIR = \frac{Cc\text{-}Ua}{10}\ .\ Ds\ .\ Z\ .\ ETo\ .\ kc\ .\ 0{,}1\ .\ \sqrt{P}$$

$$RIR = \frac{17{,}87\text{-}14{,}79}{10}\ .\ 1{,}21\ .\ 20\ .\ 4{,}80\ .\ 0{,}4\ .\ 0{,}1\ .\sqrt{21} = 6{,}55\ \mathrm{mm}$$

b) Water line applied (Wlin):

$$Wlin = \frac{Qm\ T}{E_1 E_2} = \frac{12\ .\ 3}{1{,}50\ .\ 3{,}00} = 8{,}00\ \mathrm{mm}$$

c) Deficient line (Dlin):

$$Dlin = \frac{\sum \text{Negative deviations (mm)}}{n} = \frac{1{,}48}{11} = 0{,}13\ \mathrm{mm}$$

d) Percolated line (Plin):

$$\text{Plin} = \frac{\sum \text{Positive deviations (mm)}}{\text{n}} = \frac{2{,}09}{21} = 0{,}10 \text{ mm}$$

e) Stored line (Slin):

$$\text{Slin} = \text{IRN} - \text{Lper} = 6{,}55 - 0{,}10 = 6{,}45 \text{ mm}$$

f) *Deficit* Coefficient (Dc):

$$\text{Dc} = \frac{100 \,.\, \text{Dlin}}{\text{RIR}} = \frac{100 \,.\, 0{,}13}{6{,}55} = 1{,}98\%$$

g) Percolation losses (Plos):

$$\text{Plos} = \frac{100 \,.\, \text{Plin}}{\text{Lcol}_{\hat{m}}} = \frac{100 \,.\, 0{,}10}{2{,}75} = 3{,}64\%$$

3. Irrigation Efficiency Determination:

a) Project Distribution Efficiency for Properly Irrigated Area (PDepia):

$$\text{PDepia} = 100 + ((606 - 24{,}9 \,.\, \text{Pad} + 0{,}349 \,.\, \text{Pad}^2 - 0{,}00186 \,.\, \text{Pad}^3) \,.\, (1 - (\text{CUC}/100))$$

$$\text{PDepia} = 100 + ((606 - 24{,}9 \,.\, 90 + 0{,}349 \,.\, 90^2 - 0{,}00186 \,.\, 90^3) \,.$$

$$(1 - (96{,}02/100)) = 93{,}47\%$$

b) Irrigation Efficiency for Properly Irrigated Area (Iepia):

$$\text{Iepia} = \text{EDpad} \,.\, \text{Ec} \,.\, 100 = 0{,}9347 \,.\, 0{,}99 \,.\, 100 = 92{,}53\%$$

c) Application Efficiency (Ae):

$$\text{Ae}\,(\%) = \frac{\text{Stored Blade}}{\text{Applied Blade}} \,.\, 100 = \frac{6{,}45}{8{,}00} \,.\, 100 = 80{,}63\%$$

In view of the above, it is concluded that the irrigation project under study has a UEC higher than the recommended value for localized irrigation systems, which is 84%. Thus, it is classified with excellent performance (UEC = 94%) regarding the emission uniformity, despite having a water application efficiency of less than 90%, a value recommended by the literature as the ideal to meet the water demand of the irrigated culture. For several authors, among whom are Mantovani, Bernardo and Palaretti (2013) this is justified by the absence or deficiency of irrigation management.

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