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FIXED CONVENTIONAL SPRINKLER IRRIGATION SYSTEM: COMPONENTS OF COST AND ECONOMY OF SCALE

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ABSTRACT

The costs involved in the implementation and operation of irrigation systems are of paramount importance for the economic planning of irrigated agriculture. Therefore, the objective of this work was to determine the implantation, fixed and annual variables costs, and the occurrence of economies of scale for a fixed conventional sprinkler irrigation system for different area sizes and slope in the impulsion line. Thus, irrigation projects were developed for areas of 1, 3, 5, 10, 15, 20 and 25 ha and slopes in the pumping pipe of 7 and 15%. Also, this work evaluated the implementation, annual fixed and variable costs and their components and the occurrence of economy of scale. The implementation, fixed and variable costs increased as the size of the area increased, but for the fixed and implementation costs, an increase was observed due to the exponential cost of the pipes and their greater participation in the total cost and the variable cost was because the maintenance follows the implementation cost. Therefore, the cost with the pipelines has greater participation in the implementation of the system. The cost of implementation and the total fixed and variable costs raised with the increases in the size of the irrigated area. The variable cost of energy is constant as area size is increased and the raise is by approximately 5.2%, as the slope increases from 7 to 15%. The increasing in the size of the irrigated area provides diseconomies of scale.

Palavras-chave:
custo de implantação
custos fixos e variáveis
declividade da linha de recalque
tamanhos de área

SISTEMA DE IRRIGAÇÃO POR ASPERSÃO CONVENCIONAL FIXA: COMPONENTES DE CUSTO E ECONOMIA DE ESCALA

RESUMO

Os custos envolvidos na implantação e operação de sistemas de irrigação são de suma importância para o planejamento econômico da agricultura irrigada. Assim, o objetivo deste trabalho foi determinar os custos de implantação, fixos e variáveis anuais e, a ocorrência de economia de escala para um sistema de irrigação por aspersão convencional fixa para diferentes tamanhos de área e declividades da linha de recalque. Para isso, desenvolveu-se projetos de irrigação, para áreas de 1, 3, 5, 10, 15, 20 e 25 ha e declividades da linha de recalque de 7 e 15%. Foram avaliados os custos de implantação, os fixos e variáveis anuais e seus componentes e a ocorrência de economia de escala. Houve aumento do custo de implantação, fixo e variável, com o aumento do tamanho da área, sendo que, para o custo fixo e o de implantação, houve aumento devido ao custo exponencial do valor das tubulações e pela sua maior participação no custo total. Já o custo variável devido à manutenção seguir o custo de implantação. Portanto, o custo com as tubulações possui maior participação na implantação do sistema; o custo de implantação e os custos fixos e variáveis totais crescem com o aumento do tamanho da área irrigada; O custo variável da energia é constante com o aumento do tamanho da área e aumenta em aproximadamente 5,2%, da declividade de 7 para 15% e o aumento do tamanho da área irrigada proporciona deseconomias de escala.

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INTRODUCTION

The use of irrigation has some advantages such as the lower risks of its use, the greater use efficiency and application of inputs, and, mainly, the elimination of the effects of water deficiency caused by the poor distribution of rainfall. Thus, it provides greater guarantees and increase in the productivity of agricultural crops (SOARES *et al.*, 2016).

Despite those advantages, Silva *et al.* (2007) state that irrigation requires significant investments besides being associated with the intensive use of agricultural inputs, therefore, one must consider the economic issues involved in its use, since the implementation and operation of irrigation systems involve several costs.

According to Fernandes *et al.* (2008), these costs refer to those related to the purchase of irrigation equipment, as well as its implementation, operation, depreciation and maintenance over its useful life, and these costs can be divided into fixed and variable.

The conventional sprinkler irrigation system is widely used by farmers, especially in small and medium-sized farms due to its wide applicability (MARTINS *et al.*, 2011). Farmers have shown a high interest in the conventional fixed sprinkler, mainly because of the lesser need for labor, since all the pipes remain fixed in the land covering the whole area; however, it should be stressed that the cost of implanting this system is higher than the conventional portable or mesh sprinkler systems (TESTEZLAF, 2017; ZHANG *et al.*, 2018).

Besides the cost of implementation, the variability of this cost and the total annual costs in relation to the irrigated area of the system have to be considered, as well. Castro Júnior *et al.* (2015) claim that as the irrigation project area increases, there is a tendency to decrease the cost per hectare, particularly because of the dilution of the fixed and implementation costs.

Thus, in the analysis of different irrigation equipment for coffee crop, Bonomo *et al.* (2000) observed that the increase in the system area from 25 to 125 ha caused a linear decrease in the costs of the equipment at the order of R$ 849.49 to R$ 344.56 ha $^{-1}$, on average. On the other hand, Vieira *et al.* (2011), also analyzing different irrigation systems, observed that the costs raised as the size of the irrigated area was increased.

When the size of the irrigated area is increased, the production follows this pattern and the average cost is reduced more than proportionally, therefore, it can be considered that there is na economy of scale. Nevertheless, if the costs increased more than proportionally with the increase in size of the irrigated area, it can be considered that there was a scale of diseconomies (DEMEU *et al.*, 2015).

This factor significantly influences decision making and irrigation planning for rural producers, because although the increase in the irrigated area results in the raise in the production, the costs may not show the same behavior.

Thus, obtaining costs related to irrigation and observing the occurrence of economies of scale may assist technicians and farmers in the economic analysis of projects and design of irrigation systems. As a result, the objective of this study was to determine the implementation costs, fixed and variable costs and the occurrence of economies of scale for the fixed sprinkler irrigation system in different area sizes and slopes in the impulsion line.

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MATERIAL AND METHODS

For the execution of this experiment, different irrigation projects were developed in a theoretical way to attend the basic project requirements according to the methodology of Biscaro (2009), considering the predominant characteristics of the soil, climate and topography of the Central-West region of the state of Rio Grande do Sul. Thus, to estimate the costs of the irrigation system, the conventional fixed sprinkler system (CFS) was used, considering areas (A) with 1, 3, 5, 10, 15, 20 and 25 ha and geometric slopes in the impulsion line e (D) of 7 (D7) and 15% (D15), totaling 14 irrigation projects.

It was adopted the values of 110 m of length for the impulsion pipe, 10 m of suction, geometric suction slope of 4 m and the main line and the lateral lines installed on flat (level) and regular ground, where, the main lines were placed in the center of the area, containing lateral lines on both sides. The installation height of the sprinklers in the irrigation lines was 2.5 m from the ground.

For the design of irrigation systems, the maximum daily evapotranspiration value of 8.4 mm, obtained from the average of five years calculated using the meteorological database of INMET automatic stations in the region considered.

The characteristics considered for determining the water demand were: field capacity (0_{FC} = 0.33 m^3 m^{-3}), permanent wilt point (0_{pm} = 0.16 m^3 m^{-3}), soil density (ds = 1.3 g cm^{-3}), water availability factor (f = 0.5), root system depth (z = 70 cm), efficiency of irrigation systems (Ea = 85%), in which this efficiency was considered adequate for the sprinkler irrigation system (BISCARO, 2009).

For irrigation, a 6-day irrigation shift was chosen, considering that a worker must have a day off during the week. From these data, the necessary application rate was determined to meet the demand of each developed project. The daily irrigation time was set around 8 daily hours due to the daily work period.

Similarly, for the best use of the resources and reduction of the costs with the irrigation systems, the sectorization of the irrigation systems was carried out, with different numbers of lateral lines operating simultaneously, serving the entire target area.

For the calculations of the losses of the main load or distributed over the pipes on the lateral line, principal line, impulsion line and suction, the equation of Hazen-Williams (equation 1) was used.

$$hf = 10.645 \frac{L}{D^{4.87}} \frac{Q^{1.85}}{C^{1.85}} \quad (1)$$

where,

hf = loss of the main load (m);
L = Length (m);
C = Hazen-Williams coefficient; and
D = pipe diameter (m) and Q – Flow (m^3 s^{-1}).

On the other hand, the losses of the secondary load or localized on the irrigation lines were determined through the piece coefficient method, equation 2.

$$hfloc = \sum K . \frac{v^2}{2g} \quad (2)$$

where,

hfloc = Local head loss (m);
v = Flow velocity (m s^{-1});
g = Acceleration of gravity (m s^{-1}); e
K = Coefficient of the piece.

The pipe diameters were defined so that the maximum flow velocity did not exceed 2 m s^{-1}, considering for the suction pipe, a commercial diameter greater than that used in the impulsion line. Also, in the lateral lines, the maximum variation of 20% of the service pressure of the sprinkler was allowed, which was 25 mca.

The pump set was selected in catalogs provided by the manufacturers, where it was identified the models that met the flow and the total head of each irrigation system with the best performance.

The purchase values of the equipment were consulted in stores in Santa Maria and Santiago, State of Rio Grande do Sul in Reais (Brazilian currency) in the months of August and September 2017, when the average price of the dollar was R$ 3.11. The costs considered were those related to the implementation of the irrigation equipment and the fixed and variable annual costs of the system.

The implementation cost was divided into the costs with sprinklers (SC), cost with pipes and parts (PPC) and cost of the pump set (PSC). Fixed costs represent the annual cost equivalent to the investment in purchasing the irrigation system, plus the cost with insurance. That is, depreciation cost (DC), cost with interest on the invested capital (IC) and insurance cost (IC), which were in R$ ha^{-1}.

The DC values were calculated using equation 3 (CONAB, 2010).

$$DC = \frac{(VN-VR)}{VUh} . HsTr \quad (3)$$

Where,

VN = Purchase value of the new equipment in R$ ha^{-1};
VR = Component residue value in R$ ha^{-1};
VUh = useful life of the component in hours; and
HsTr = Total of the worked hours by the component in hours.

The residual value was calculated as 20% of the purchase value of each component and the useful life used was 20 years.
The CJ values were calculated considering the remuneration rate of 6.0% per year, applied on the average value of the equipment, according to equation 4 (CONAB, 2010).

$$CJ = \frac{VN . QM . 0.5 . HsTr . J}{CAT} \quad (4)$$

Where,

QM = Quantity of the asset,
CAT = asset working capacity (h); and
J = the remunerating rate.

The CS value was determined as 0.35% of the average value of the new asset (CONAB, 2010), according to equation 5.

$$CS = \frac{VN . 0.5 . 0.35 . HsTr}{VUh} \quad (5)$$

The variable costs considered the costs with electric power (CVE), labor (CVMO) and maintenance of the system (CVMAN), in R$ ha^{-1}.
The electric power variable cost was calculated considering the power of the pump set and its efficiency, the kwh value charged by the power company and the time spent in the application of the irrigation depth for each irrigation system (equation 6).

$$CvE = Pw . Ee . T . w \quad (6)$$

Where,

Pw = Pump Power (kW h^{-1});
Ee = Price of the electric power (R$ Kw^{-1});
T = Time spent for the application of one millimeter of water (h mm^{-1}); and
w = irrigation depth (mm ha^{-1}).

The experiment used the mean value of 152 mm of irrigation depth obtained from the average of two field experiments with corn between 2015 and 2016 and 2016 and 2017, following Ben *et al.* (2019). The energy value of R$ 0.32 kW h^{-1} was the price charged in the green tariff established by the National Electric Energy Agency – ANEEL (ANEEL, 2017).
The cost of labor was calculated using the period proposed for conventional fixed sprinkler irrigation systems, which was 0.5 hours per hectare in each sector of the system and per irrigation (MAROUELLI; SILVA, 2011), considering the value of worked-hour equivalent to the rural minimum wage, according to CONAB (2010), as in equation 7:

$$CvMo = \frac{Ni.Ns.0,5.VSMin.w}{22000} \quad (7)$$

Where,

Ni = number of irrigations;
Ns = number of the irrigation system sectors; and
VSMin = value of the rural minimal wage in R$.

Six was the number considered for the quantities of irrigations, according to experiments mentioned above, the number of sectors of the projected irrigation system was six for all projects and the value of the rural minimum wage used was R$ 1,175.47 (Rio Grande do Sul, 2017).
The values of maintenance costs were calculated over 1% of the new value of the irrigation system plus 10% of the variable cost of electricity power (CONAB, 2010), according to equation 8:

$$CvMan = VN.0.01 + \left(\frac{CvE}{10}\right) \quad (8)$$

The cost of implementation and its components (sprinklers, pipes and pump set), the annual fixed costs (depreciation, interest on the invested capital and insurance), annual variables (electrical power, labor and maintenance) and annual totals - TC (fixed and variable sum) of each system were all obtained at the end of the simulation in unit values (R$ ha^{-1}), and then an indication of the lowest costs between areas and slopes was provided.
The occurrence of economy of scales was also observed through the behavior of the total annual cost, between the sizes of the area. In other words,

when the TC decreased as the irrigated area was increased, the economies of scale were considered. On the other hand, if the TC increased with the size of the area, it was considered that there was a diseconomies of scale and, if the TC remained steady, the economy was considered constant at the scale.

RESULTS AND DISCUSSION

The costs of each component of the irrigation system and the total implementation costs of each area and slope according to the irrigated area can be seen in Figure 1 in unit values (R\$ ha^{-1}).

The costs with sprinklers showed a relatively small variation in relation to the evaluated areas, with values between R\$ 334.93 ha^{-1} and R\$ 297.76 ha^{-1}. This is because the number of this component follows the increase in the area.

Regarding the cost with the pump set (R\$ ha^{-1}), it showed a downward trend in relation to the increase in the size of the system area up to 16.3 ha, where it was observed a value of R\$ 1.228.05 ha^{-1}, for the 7% slope, with an increase after this point. For the 15% slope, this cost was reduced to an area of 21.5 ha, where it presented a value of RS 1,309.02 ha^{-1}, with a further increase from this area.

For different areas, in some cases, the pump or the engine used are from the same model and have the same size, so the costs are similar and, when converted into units, they present a considerable variation, as for the areas of 15, 20 and 25 ha, where the same pump model was used, however,

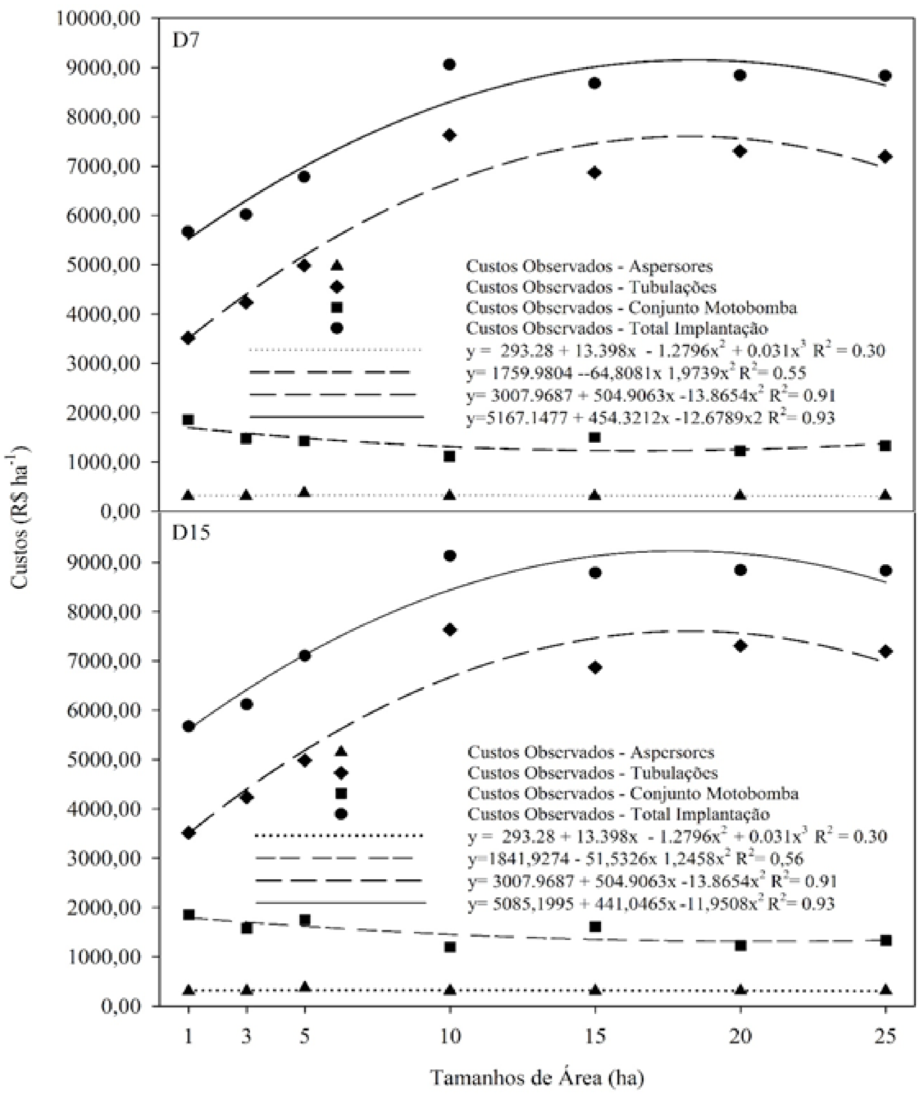

Figure 1. Costs of the sprinklers, pipes, pump set and total implantation (R\$ ha^{-1}) as a function of the irrigated area and for each slope of the impulsion line (D).

with different engines, representing a small raise in the total cost, which explains the reduction trend of the costs with the pump set.

Regarding the slope, the only variation found in the experiment is in relation to the cost of the pump set due to the need of choosing a larger pump and na engine with greater power for the D15 compared to D7. Although in some projects with the same area, as in the case of 01, 20 and 25 ha, the same set of pumps in each area was compatible for the two evaluated slopes, and no variation was observed in the cost of implantation as a function of the slope.

The cost related to the pipes showed a raise due to the increase in the size of the area up to 18.2 ha, therefore, reducing to areas larger than this one. It is observed that the costs of each pipe show an exponential raise as the diameter increases, considering that as the irrigated area is increased, the diameter of the tubes increases to attend the necessary flow, therefore, with a direct impact on the unit cost of the system implementation.

In relation to the total unit cost of the system implementation, na increase trend is observed as the irrigated area increases, with a maximum value of R$ 9250.99 ha^{-1} and R$ 9236.95 ha^{-1} for areas of 18.45 ha and 17.91 ha, D7 and D15, respectively, decreasing for larger areas. In addition, when observing the observed data (without the adjusted function), the areas of 10, 15, 20 and 25 ha showed similar values and higher than in the areas of 1, 3 and 5 ha, which also showed similar values. The cost of the 1, 3 and 5 ha areas between the two slopes ranged from R$ 5671.24 to R$ 6781.19 ha^{-1}, while for the other areas (10, 15, 20 and 25 ha), it varied from R$ 8833.13 to R$ 9137.62 ha^{-1}.

The magnification of this cost, in relation to the increase in the size of the irrigated area is the result of the costs related to the pipe components as it presents an exponential behavior in its prices due to the diameter, and also a greater share in the total cost of implantation in addition to the fact that the other components show a small considerable reduction, as the size of the irrigation system area is increased.

Such behavior is similar with those observed by Carrión *et al*. (2016), where they also observed an increase in the cost of implementation with the increase in the size of the irrigated area, also considering different spacing between sprinklers.

The total implantation cost observed in this work is comparable to the ones mentioned by Marouelli and Silva (2011), where for the fixed

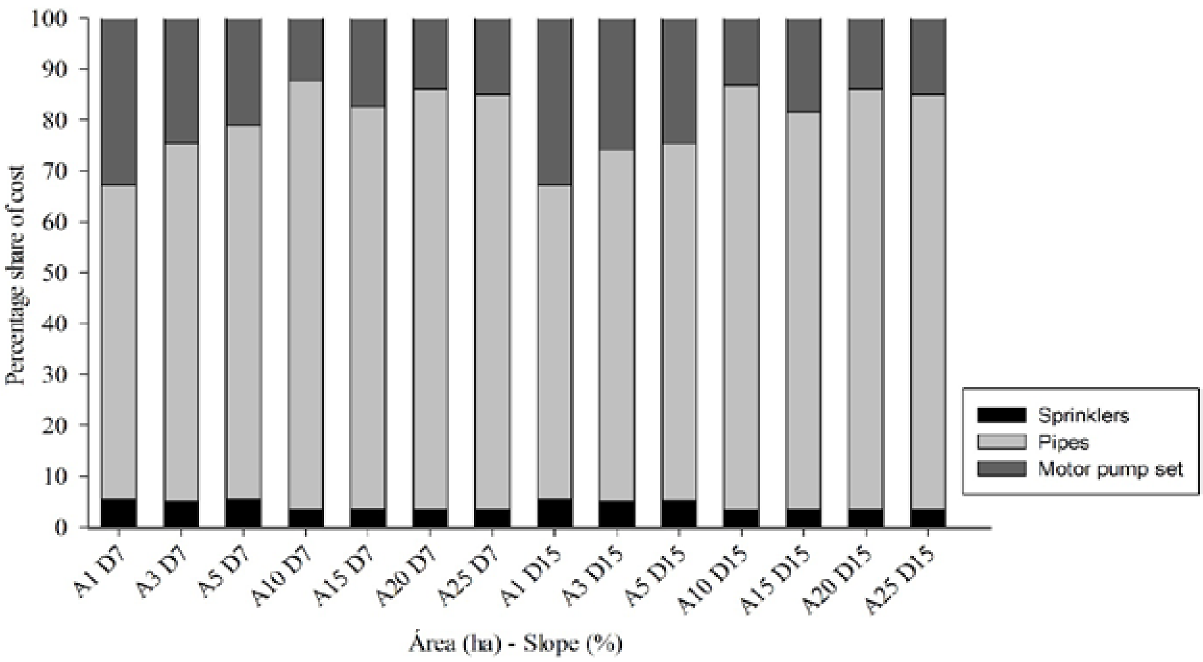

Figure 2. Percentage of the share of each component in the total cost of establishment for the áreas (A) and slopes (D).

conventional sprinkler system in a vegetable crop , they cited values between R$ 7,000.00 and R$ 15,000.00 ha^{-1} , which dependent on the size of the area, level of automation, quality of the equipment, among other factors.

The percentages of the participation of the components of the irrigation systems in relation to the total cost of implantation are shown in Figure 2.

Pipes are the components that have the largest share in the total implementation cost of the irrigation system, regardless of the size of the system area. A tendency to increase from 62 to 83.5% of this cost share was observed as the size of the irrigated area increases.

It is observed that the pump set is the second component with the largest share in the cost of implementation. This component varied between 12.4 and 32.7% and decreased with the size of the system area. It was observed that the cost of sprinklers provided a share of less than 5.4% of the total cost of implementation, with the least share among the evaluated components.

The annual costs, *i.e.*, fixed and variable costs, for each area size and slope of the analyzed impulsion line are shown in Table 1.

In relation to the total fixed cost, it is observed a tendency to increase as the size of the system area is increased, with the same behavior observed in relation to the cost of implementation, as in the elaboration of the fixed costs such as depreciation, interest and insurance, the value of the new equipment is considered. Thus, the lowest fixed cost was observed for the 1 ha area, while the highest was for the 10 ha area. In turn, the depreciation cost is the one that represents the greatest representation in the final composition of the fixed cost, which is the one that burdens the enterprise the most.

Castro Júnior *et al.* (2015) analyzed an irrigated area of 10 ha, whose irrigation system was similar to the one used in this experiment and observed a fixed annual cost of depreciation and interest over the invested capital of R$ 552.76 ha^{-1}. This value is below that observed in this work and considering the total FC for the 10-ha area, the observed values were R$ 713.51 ha^{-1}, for the slope of 7% and, R$ 719.59 ha^{-1}, for the 15% slope.

For variable costs, the application of a 152-mm

Table 1. Annual fixed costs. Total fixed costs, variable costs and total variable cost (R$ ha^{-1}) for each slope of the impulsion line (D) and size of the area.

D (%)	Area (ha)	Total Costs (R$ ha^{-1})							
		Fixed				Variables			
		CD	CJ	CS	Total	CVe	CVMO	CVMan	Total
7	1	226.85	170.14	49.62	446.61	97.88	146.13	66.50	310.51
	3	240.71	180.53	52.66	473.90	92.50	146.13	69.43	308.06
	5	271.25	203.44	59.34	534.02	102.27	146.13	78.04	326.44
	10	362.42	271.81	79.28	713.51	76.95	146.13	98.30	321.38
	15	347.21	260.41	75.95	683.57	103.22	146.13	97.12	346.47
	20	353.72	265.29	77.38	696.39	96.34	146.13	98.06	340.53
	25	353.72	264.99	77.29	696.01	104.95	146,13	98.83	349.91
15	1	226.85	170.14	49.62	446.61	117.14	146.13	68.43	331.69
	3	244.72	183.54	53.53	481.79	118.55	146.13	73.03	337.71
	5	284.29	213.22	62.19	559.70	126.79	146.13	83.75	356.67
	10	365.50	274.13	79.95	719.59	93.44	146.13	100.72	340.29
	15	351.63	263.73	76.92	692.28	121.38	146.13	100.05	367.55
	20	353.72	265.29	77.38	696.39	112.38	146.13	99.67	358.17
	25	353.3	264.99	77.29	695.61	120.06	146.13	100.34	366.53

CD – Cost with depreciation; CJ – Cost with interest; CS – Cost with insurance; CVe – Variable cost with electrical power; CVMO – Variable cost with labor and CVMan – Variable cost with maintenance.

irrigation depth and the number of six irrigations were considered. For the cost of energy, the highest value was observed in the 5 ha area for the slope of 15% and the lowest value in the 10 ha area. No tendency to increase or decrease the cost of energy in relation to the irrigated área was observed. Due to the higher power requirement for pumping at greater manometric heights, the greatest slope (15%) provided an increase in the cost of energy in relation to the slope of 7%.

For the cost related to the maintenance of irrigation systems, there was a tendency to increase with the size of the irrigated área. Such behavior was caused because part of this cost considered the value of implantation of the system, and, as it previously presented, this increases with the size of the irrigated area.

Labor cost was R$ 146.13 ha^{-1}, with no variation between the size of the area and the slope, since the same irrigation depth and number of irrigations was considered for the different systems. However, this cost showed the largest share in the final composition of the total variable cost.

The total annual cost, in other words, the sum of the fixed and the variable costs can be seen in Figure 3. The total annual cost tended to increase as the slope and the irrigated area increased. The highest value was observed for the 19.1 ha área and 15% slope, with a cost of R$ 1088.63 ha^{-1}, whereas the lowest values were observed in the 1 ha area, with R$ 763.86 ha^{-1}.

Because of the increase in the total cost with the size of the irrigated area, it was observed that there were no economies of scale, that is, this situation was configured as diseconomies of scale.

A behavior similar to the one observed in this experiment was found by Vieira *et al*. (2011), where implementation costs, fixed costs and annual variables, for the same type of irrigation system, increased with the size of the irrigation system area. These authors also observed that the cost with the pipes was responsible for this behavior.

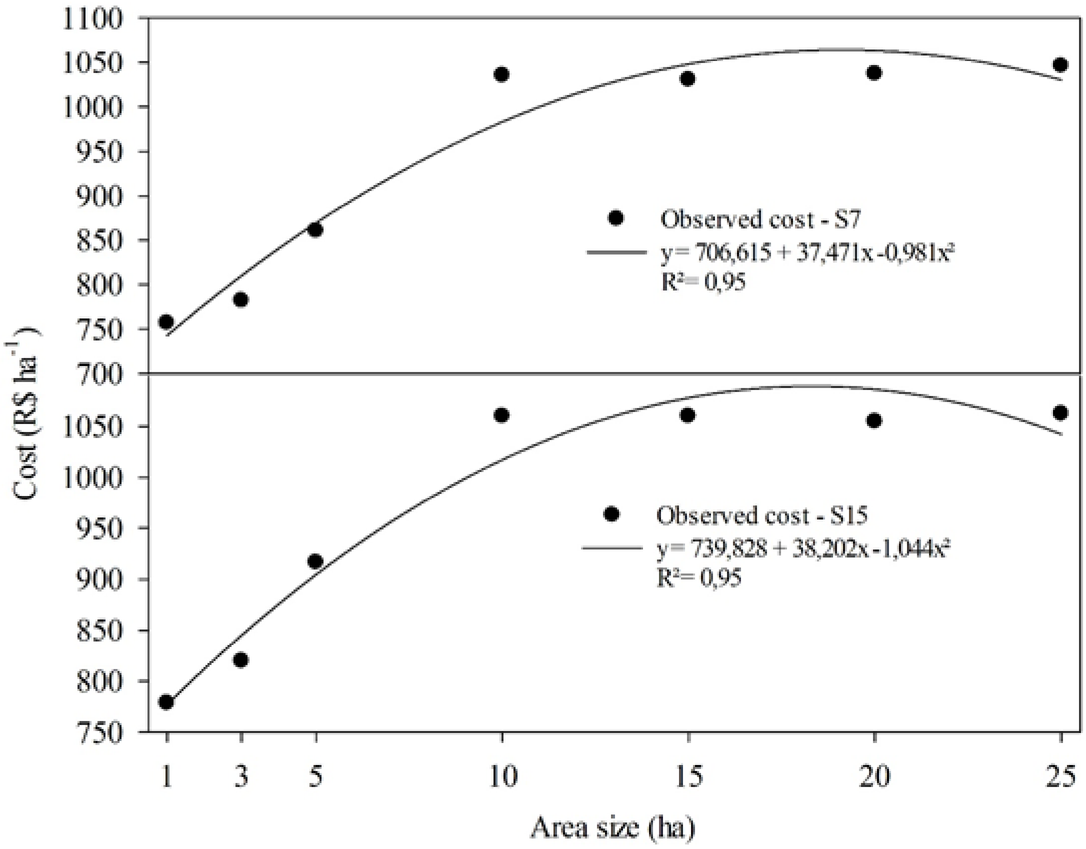

Figure 3. Total annual cost (R$ ha^{-1}) for the different area sizes and slopes.

CONCLUSIONS

- The cost of implementation and the annual fixed and variable costs raise with the increase in the size of the area of the irrigation system, being higher from 10 ha in relation to the areas of 1, 3 and 5 ha.
- Among the components, the cost of the pipes has a greater share in the implementation of a fixed irrigation system with conventional sprinkler.
- The variable cost of energy is constant. It is raised as the irrigated área is increased by 5.2% of the slope from 7 to 15%.
- The increase in the size of the irrigated area in the conventional fixed sprinkler irrigation systems provides diseconomies of scale.

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