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Water Yield of a Fog Harvester as Affected by Mesh Material and its Orientation

Donalyn M. Macaburas, Diostonee A. Balinte, and Editha D. Carlos

College of Engineering and Applied Technology, Benguet State University

Corresponding author

College of Engineering and Applied Technology, Benguet State University, Km. 6, La Trinidad, Benguet
Email: donalynmacaburas21@gmail.com (D.M. Macaburas)

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Abstract

To compliment the water shortages experienced by farmers during the dry season (November to April) for irrigation and application of chemicals, a fog harvester was constructed at the College of Engineering and Applied Technology in Benguet State University and installed in Sinipsip, Buguias, Benguet. The study analyzed the effect of two mesh materials (i.e., polyethylene mesh SAGN 60% shading and aluminum mosquito mesh) and orientation (i.e., portrait and landscape) on the water yield of the constructed fog harvester. Findings showed that the aluminum mosquito mesh has higher yield of water as compared to the polyethylene mesh, but the treatment mesh material has no significant effect on the water yield of a fog harvester. In terms of orientation, the portrait orientation has collected more water than the landscape orientation, and it has significantly affected the water yield of a fog harvester. Of its cost analysis, the treatment polyethylene mesh in portrait orientation has the highest return of investment of 50.5% while the treatment aluminum mosquito mesh in its landscape orientation has the lowest return of investment of 29.44%. Therefore, the best treatment is the structure with polyethylene mesh in portrait orientation.

Introduction

Many of the mountains in the Cordilleras are blessed with favorable climate ideal for terraced vegetable production and is the top producing region for highland vegetables (Cereceda & Schemeneur, 1994). The Cordillera Administrative Region (CAR) remains as the primary producer of cabbage, carrots, and white potatoes. According to the Philippine Statistics Authority-Agriculture and Fishery Statistics (2016), the Philippines produced a total of 305,850 metric tons of cabbage, carrot, and white potato for 2016. Out of the total production, CAR contributed the biggest share with 82.9% or 253,404 metric tons.

In Buguias, Benguet, vegetable terraces are very dominant. These are planted with different crops such as leafy vegetable, potato, carrots, and others. Vegetable production is dependent on the availability of water. In an interview conducted by Benguet State University in collaboration with the University of the Philippines-Los Baños on their research on the different varieties of potatoes in Buguias (2018), most of the farmers said that they are dependent on the rainfall (rain-fed irrigation system) that their farms receive. One farmer also said, *"Haan kami a nga agmula, isabat mi ijay panagtutudo* (We will not plant, we are going to wait for the rainy season)." It can be noted that farming is limited due to lack of water for irrigation and other activities like the application of chemicals. However, not all areas in Buguias have access to water especially those that are situated in higher grounds.

The mountains of the Cordilleras in the northern part of the country, being located in the high elevation places, have poor access to water and mostly rely on rainwater. Rainwater is only available for six months (May-October), while the remaining months, water is lacking (de Guzman & Grospe, n.d.) During these dry periods, the vegetables will potentially grow and produce better yield due to prolonged daylight; thus, increasing the photosynthesis. However, this is only possible if there is an adequate supply of water and/or moisture to satisfy the crop water requirements. The crop water requirement is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration (FAO, n.d.). In other words, it is the amount of water needed by the various crops to grow optimally.

Aside from rainwater, there is only one ground-level source of water from the atmosphere at high elevation places - fog. Fog is the same as clouds except that it touches the ground.

Benguet is known for having a thick fog covering the mountain ranges. A testimony from a traveler proves it with his statement: "Supposed to be, green mountains are seen at the background but the thick fog has selfishly occupied the space making the view hidden" (Guquib, 2012) and this fog can be converted to water. However, according to de Guzman and Grospe (n.d.) no attempt has been made to measure the amount of water in the fogs that cover the high mountains of the northern Philippines. During dry season these higher grounds are observed to have a thick fog which can be converted to water. These fogs which occur in the dry season months, are important to farmers who cultivate leafy vegetables and root crops in the terraced farms. Moreover, fog collectors can be introduced on the highest peaks to collect and store water to augment irrigation requirements during drought periods.

Materials and Methods

Site evaluation

Among the three places visited, (Mount Santo Tomas, Baguio City; Mount Jumbo, La Trinidad, Benguet; and Sinipsip, Buguias, Benguet), the chosen place as research site was Sinipsip, Buguias, Benguet because it has the densest vegetation. Further, production of most temperate vegetables has increased in the municipalities of Buguias, Atok, Mankayan, Bakun, and Kibungan (RSSOCAR, 2015). The Municipality of La Trinidad and the City of Baguio were not included in the data which proves that the Municipality of Buguias has the densest vegetation among the three places visited.

The site falls under Type 1 of the Philippine Climatic Category where there are two pronounced seasons: dry season from November to April; and wet season during the rest of the year. Further, the site has an elevation of 2,353 m above sea level. Farms in this place are vegetable terraces planted with high value crops such as cabbage, chinese cabbage, broccoli, cauliflower, and root crops such as potato, carrots, and others. However, their source of irrigation is pumped from a distant reservoir, and there is no source of water during dry season (November to April). The presence of fog is very dominant, and the wind speed is also observably high during this season.

Accordingly, Buguias is literally a municipality of vegetable plantation with gardens covering plateaus, mesas, and strips of leveled plots and creeks and gentle slopes. Buguias has emerged as the highland vegetable capital of the Philippines where carrots, potatoes, cabbages, pechay, wombok, beans, and other vegetables are transported to La Trinidad, Baguio City, Dagupan City, Laoag, Metro Manila, and other provinces in the Philippines. However, Benguet is not an exception from water crisis, as Lapniten (2015) citing Provincial Agriculturist Lolita Bentres stating: "Drought started since January and the rains we felt are actually late." Moreover, Bentres said that in the past years, the planting season for most farmers was usually signaled by the rains during holy week around late March. In April 2015, however, the rain came only the latter part which delayed the planting of crops in many parts of Benguet, especially in more elevated areas far from Agno River and its tributaries. Further, Lapniten (2015) further noted that on April 18, 2015, the Philippine Atmospheric Geophysical, and Atmospheric Services Administration (PAGASA) warned that dry spells could intensify in the coming weeks and would peak in May.

Structure Preparation

The mesh was placed on the frame and was pulled tightly over the frame. Immediately under the frame was the collection trough for the fog water (Figure 1). The trough was slightly sloped to drain the water to one end where there is an opening with a connection to a plastic tube to the tank.

Parts and Construction

Mesh. The mesh used was the aluminum mosquito mesh and the SAGN polyethylene mesh, green 60% shading. One structure is made up of 3m x 1m mesh and was attached to the frame.

Frame. The frame supports the mesh with 1m x 3m on the outside. The frame itself is 1 cm in diameter and is made up of galvanized iron.

Posts. Two posts are used in each of the fog collector to support the structure. The post is made up of galvanized iron with 1.5 inches diameter.

Plastic Tube. This connects the trough and the tank with 0.5 inches diameter. A clear level hose is used to enable observation during the fog harvesting.

Trough (Catcher). The trough is a triangular cross section made up of galvanized iron sheet with

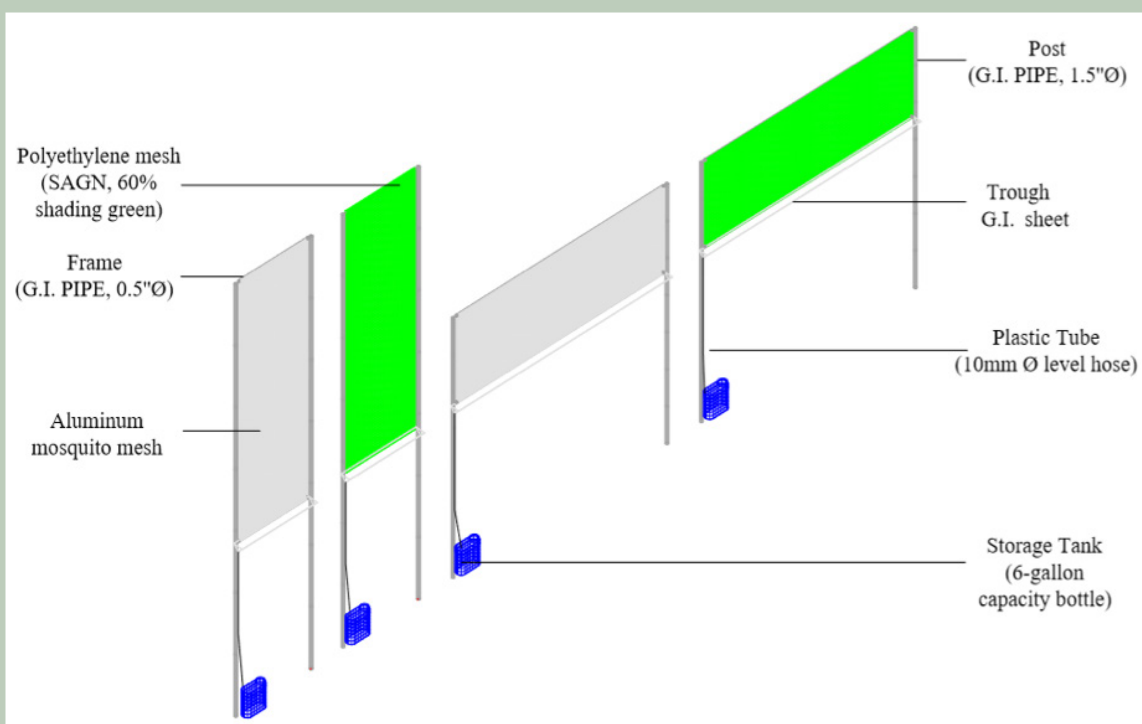

Figure 1. Parts of a fog harvester

3.05 meters long if the mesh is in a landscape position and 1.05 meters if the mesh is in a portrait position.

Storage Tank. It is used to store the collected water. A six-gallon capacity is used as the storage tank.

Structure Installation

The frame was supported with its base 2 meters above the ground. The height of the collector base was set as such for the practical purpose of servicing it. The structure was on a southwest orientation because during this season prevailing wind is in a northeast direction. The structures were installed at the peak of the mountain around more or less 500 meters away from the intersection of Halsema Highway and Sinipsip Elementary School (Figure 2).

Principle of Operation

The fog harvester was installed in the site perpendicular to the wind speed. As the wind blows, the fog through the structure will be trapped in the mesh and it will be condensed; therefore accumulating into water droplets. Due to gravity, the water drops down into the trough, from which they will flow down through a plastic tube into a storage tank (Schemenaner & Cereceda, 1994).

Collection of Data

The water for each treatment replication was measured using a graduated cylinder with a capacity of 0.5 liter and with a graduation of 5 ml. The water at the storage tank at the time of the collection was measured. The collection of data was 6:00 a.m. and if necessary when there is an intense amount of fog and when the wind speed is observably high.

Rosenblatt (2011) describes that most often, the research will be analyzed through quantitative data first and then use qualitative strategies to look deeper into the meaning of the trends identified in the numerical data. In the case of the study, the water were collected for each treatment combination. After this, qualitative data was utilized through observation. Evaluative observation wwas used in the

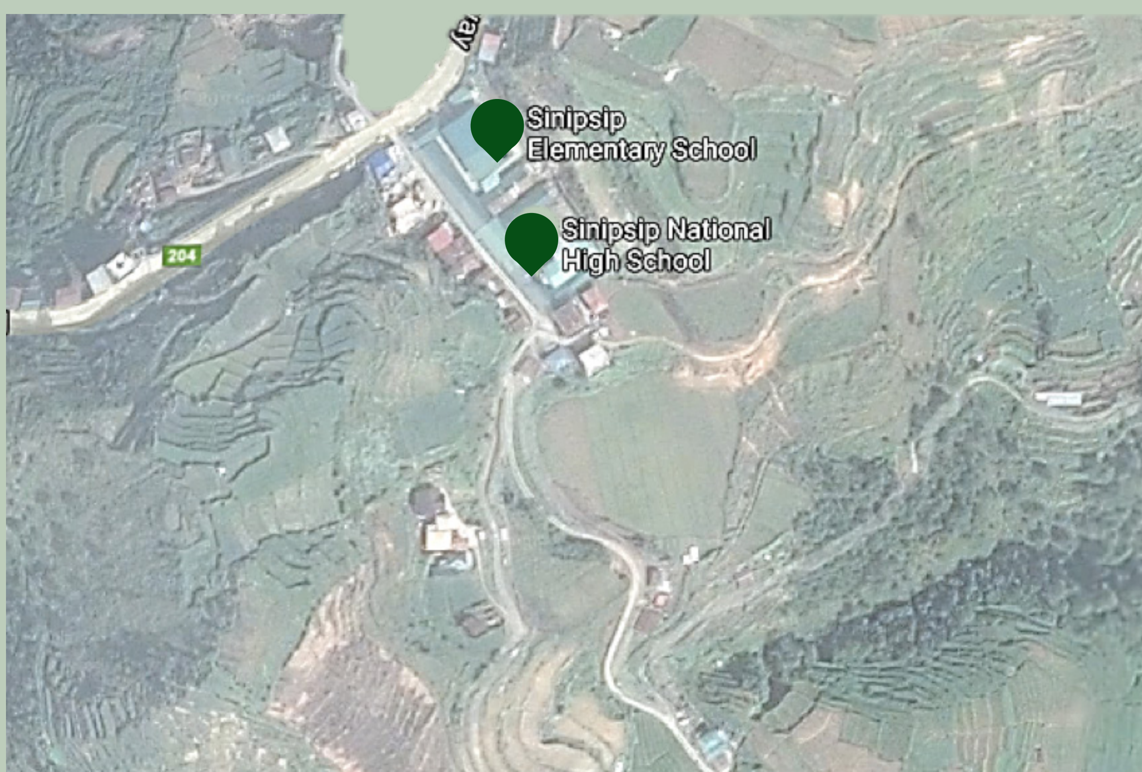

Figure 2. Fog harvesters installed in the intersection of Halsema Highway and Sinipsip Elementary School

study collecting data more frequently during an event of intense fog and high wind speed.

Statistical Analysis

The statistical tool used for the study was the 2x2 Factorial in Completely Randomized Design between two factors. Factor A was the material, which are polyethylene mesh and aluminum mesh, and Factor B was the orientation, which are landscape and portrait, resulting to four treatments. Three replications were given to all the factors.

The formula used in computing the return of investment are as follows:

Net income per year = ([Water yield x Custom rate] – Depreciation) x 181 days

Total cost per year = Total cost per day x 181 days per year

Return on Investment = (Net income per year)/(Total cost per year) x 100%

Results and Discussion

Evaluation and Comparison of Two Mesh Materials on Fog Collection

The aluminum mesh has a mean yield of 52.575 liters while the polyethylene mesh has a mean yield of 51.735 liters (Table 1) resulting to a difference of 0.84 liters. Based on their statistical analysis (Table 2), this difference is not significant. Shanyengana, Sanderson, Seely and Schemenauer (2003) state that aluminum mesh is better. Accordingly, it must be about three or four times the thickness of a human hair, and with a spacing of about twice that. The aluminum mesh that was used has about 1mm x 1mm spacing. Vernall (1961) states that a Chinese human hair has a mean of 10105.2 x 10^{-6} mm. Thus, 1 mm^2 is more or less 98 strands. This spacing is far larger than what is being used in fog harvesting. If the spacing is closer, for example quartered, then the collection might increase four times or even higher. Moreover, the recommended aluminum mesh is similar with polyethylene mesh, the only difference is that it is treated thereby producing an aluminet. This aluminet collects more water because the construction of the thread is comparable with the construction of the polyethylene mesh. However, this aluminet is not locally available. The closest locally available material is the aluminum mosquito mesh.

In addition, Shanyengana et al. (2003) mentioned that a good drainage characteristic must be present. It was observed that the polyethylene mesh has this characteristic due to the construction of the thread that forms a triangular pattern.

Evaluation and Comparison of Structure Orientation on Fog Collection

The portrait orientation has a yield mean of 59.57 liters while the landscape orientation has a yield mean of 44.89. From this, the difference is 14.68 liters and based on their statistical analysis using 2x2 Factorial Experiment (Table 2) this difference is highly significant on the water yield of a fog harvester.

Table 1

Total Water Yield (L) of the Fog Harvester as Affected by Mesh Material and Its Orientation

Orientation	Mesh Material		Total	Mean
	Aluminum mesh (L)	PE mesh(L)		
Portrait	59.83	59.31	119.14	59.57[a]
Landscape	45.32	44.46	89.78	44.89[b]
Total	105.15	103.47	208.92	
Mean	52.575[a]	51.735[a]		

Note: Different grouping denotes that the means has a significant difference

It was observed that fog will move more freely at higher heights because at lower elevation the wind that carries the fog tends to undergo friction as it passes through obstacles. The portrait orientation with a height of 5 m collected more water as compared to the structure with landscape orientation, having a height of only 3 m. This can be proven by Walmsley, Schemenauer and Bridgman (1996) as they claimed that the wind speed increases as the height increases.

Interaction (Mesh material x Orientation) on Fog Collection

The interaction has no significant effect on the water yield of a fog harvester (Table 2). From Table 3, given the four treatment combinations, it shows that the structures with portrait orientation regardless of the mesh material have higher collection (portrait x aluminum mesh= 4.98107 liter, and portrait polyethylene mesh= 4.94 liters) as compared to the structures with landscape orientations (landscape x aluminum mesh=3.777 liters, and landscape x PE mesh= 3.708 liters). It is inferred that the yield of a fog harvester is affected mainly by the orientation and that the mesh material has no significant effect. Consequently, the interaction has no significant effect on the water yield of a fog harvester.

Water Yield Efficiency of the Fog Harvester

Figure 3 shows the volume of water collected in liters for each treatment replication. It was observed that the fog was very intense both at night and day. The highest wind speed recorded on January 27, 2018 resulted to high water collection. The same was observed on January 15, 25, 26, 28, and February 12 and 13 when the only difference was that fog was not that intense during the day. Further, the fog was observed only at night on the days not mentioned but with the least volumes.

There was no recording of data collected from January 17-18 and January 29-31 due to the effect of Northeast Monsoon, 'Amihan' (i.e., it rained).

Table 2

Analysis of Variance of the Water Yield Given Two Factors (Mesh Material and Orientation)

Source of Variance	df	SS	MS	Fc	F0.05
TRTS	3	933.1759417	311.0586472	8.652938551*	4.07
Orientation	1	644.1605333	644.1605333	17.91906948*	5.32
Mesh material	1	1.3068	1.3068	0.036352181^{ns}	5.32
Interaction	1	0.122008333	0.122008333	0.003393992^{ns}	5.32
ERROR	8	287.5866	35.948325		

Note: * = Significant at 5% level, ns = not significant

Table 3

Average Daily Collection of Water per Treatment Replication, ml

Treatment	Replication			Total	Mean
	R1	R2	R3		
Portrait x Al mesh	5807	4559.2	4577	14943.2	4981.07
Portrait x PE mesh	4968	4946	4915	14829	4943
Landscape x Al mesh	4065	3348	3918	11331	3777
Landscape x PE mesh	3767	4257	3090	11114	3704.67

Similarly, there was no recording done two days after the rainy days because it was observed that there was no fog present. According to Chu (2015), as a raindrop falls through the atmosphere, it can attract tens to hundreds of tiny aerosol particles to its surface before hitting the ground. These tiny aerosols are responsible for the formation of fog. That is why after the rain the sky is clear and there is no fog present.

Cost Analysis

The treatment aluminum mosquito mesh in a portrait orientation recorded the most cost (Table 4) among the four treatment combinations amounting to PhP 2,595, followed by PhP 2,331 polyethylene mesh in portrait orientation, then PhP 2071 aluminum mesh in landscape, and lastly the polyethylene mesh in a landscape orientation with a price of PhP 1,807. The water yield for each treatment replication is shown in Table 4. Water is priced at PhP 35 per liter based on the prevailing rate of water delivery per drum or equivalent to 200 L. The result shows that polyethylene mesh with a portrait orientation has 50.5% return of investment (ROI); polyethylene mesh in landscape orientation with 45.51% ROI; aluminum mosquito mesh in portrait orientation has a 36.23% ROI; and aluminum mosquito mesh with landscape orientation, 29.44% ROI. It can be noted that the polyethylene mesh with a portrait orientation attained the highest ROI. Higher ROI

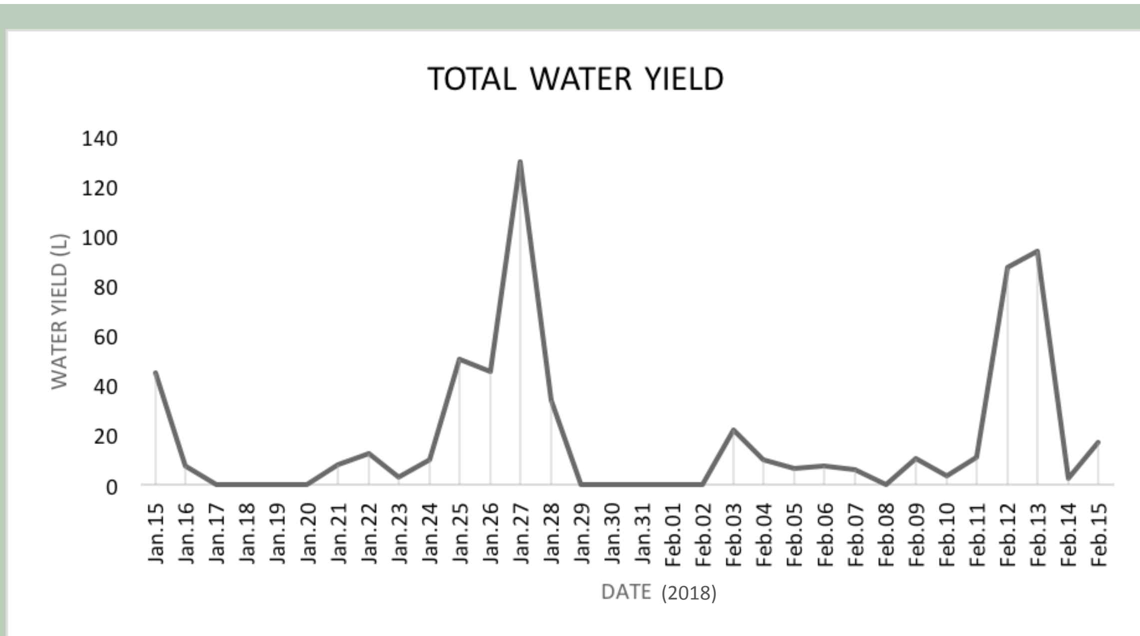

Figure 3. Total daily water yield of the structures, L

Table 4

Return on Investment (ROI) of the Fog Harvester

	Al. mesh x portrait orientation	PE mesh x portrait orientation	Al. mesh x landscape orientation	PE mesh x landscape orientation
Water yield (L)	4.98107	4.943	3.777	3.70467
Investment cost (PhP)	2595	2331	2071	1807
Custom rate (PhP/L)	0.175	0.175	0.175	0.175
Total cost (PhP/day)	0.640	0.575	0.511	0.446
Depreciation =	0.640	0.575	0.511	0.446
Net Income (PhP/yr.)	41.9602	52.5367	27.2075	36.6988
Operating cost (PhP/L) =	0.128	0.116	0.135	0.120
Total Cost (PhP/yr.)	115.82	104.03	92.43	80.65
ROI (%)	36.23	50.50	29.44	45.51

Note: The ROI computation considers 181 days/year in 10 years at PhP 35/200liters indicates a more profitable structure.

In terms of irrigating an agricultural farm, it is shown in Table 3 that the aluminum mosquito mesh with a portrait orientation yielded the highest volume of water, which is 4981.07 ml. With this data alone, it can be inferred that scaling the structure, for example, ten times will yield around 50000 ml or 50 liters a day. For example, carrot and radish have an irrigation requirement of 3.2 mm/day. Available moisture from the deposition of fogs on the leaves is 2.9 mm/day. From this, the difference of irrigation requirement and the available moisture is 0.3 mm/day. Given 0.3mm/day deficit, the 50 liters volume of water can irrigate an area of about 166.67 m^2.

Scaling up the surface are of the collecting mesh material ten times may result to higher water yield; however, it does not guarantee a tenfold increase in water volume.

Conclusions

The results of this research show the difference between the water yield of the two different mesh materials. Analysis of the recorded data shows that the difference of the yield is 0.84 liters and it does not significantly affect the yield of the fog harvester.

Moreover, the research highlighted the difference between the two orientations. Portrait orientation yields 14.68 liters higher than the yield of landscape orientation and it significantly affect the water yield of the fog harvester.

Further, given the four treatment combinations (landscape x PE mesh, landscape x aluminum mesh, portrait x PE mesh and portrait x aluminum mesh), it shows that the effect of the mesh material does not change as the orientation changes and vice versa. Based on the cost analysis, polyethylene mesh in its portrait orientation is the most cost effective.

Recommendations

The polyethelene (PE) mesh in portrait orientation which has water yield of 9.92 L and ROI at 50.5% is effective; thus, it is highly recommended for fog harvesting. Although the aluminum mesh in portrait orientation has the highest water yield compared to PE mesh, their interaction does not significantly affect the water yield.

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