On the Wind Reduction Effect of Windbreak Nets in Front of the Simple Greenhouse for Planting Fruits and Vegetables

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Abstract

The island of Taiwan experiences frequent strong winds coming with typhoons in the summer and with northeast monsoons in the winter. The strong winds are hazardous to the structure of a simple greenhouse that is widely used for vegetable and fruit plantation. The damage may reduce agricultural yields. Windbreak netting is a practical procedure for protecting a greenhouse from strong winds. The purpose of this study is to carry on the wind tunnel simulation test of windbreak nets in front of the simple greenhouse. Windbreak nets of densities 50%, 40%, 30% and 20% had a uniform dimension of 10 cm (per unit 1 h) in height and 29.2 cm in width. A windbreak net was tested at tilt angles of 0^o, 5^o, 10^o and 15^o. The wind tunnel simulation test is carried on at 10 m/s of reference wind velocity. The wind velocities at different horizontal distances and vertical distances front and behind the windbreak net are measured. The relative wind velocity is calculated. The wind reduction effect at different horizontal distances behind the windbreak net is analyzed and discussed. From the test results, it is known that when the tilt angle of windbreak net is 0^o and the height of windbreak net is 1h, the corresponding wind reduction effect of windbreak nets with 20%, 30%, 40% and 50% porosity is 62%, 61%, 59% and 52% respectively at 2h horizontal distance. The corresponding wind reduction effect of windbreak nets with 20%, 30%, 40% and 50% porosity is 46%, 45%, 40% and 32% respectively at 10h horizontal distance. However, the increase of tilt angle of windbreak net does not have much influence on the wind reduction effect.

Keywords: windbreak net, porosity, tilt angle, wind tunnel test

1. Introduction

In order to prevent the cultivation of the crops influenced by external climate and pest etc., the simple greenhouse is often used to plant the fruits and vegetables. Taiwan is located in the subtropical zone. It is often attached by typhoons in summer and there is strong monsoon in winter. Whenever the strong wind is coming, it often causes serious wind damage. In order to reduce the damage, the windbreak equipment can be erected in front of the simple greenhouse to reduce the wind velocity, so that the simple greenhouse and fruits and vegetables can get suitable protection, and reduce the damage of crops from the wind disaster. The most common windbreak equipment is the windbreak net, which can reduce the direct impact of strong wind on crops and simple greenhouse, and increase the output and quality of the crops [1-2].

The mesh of windbreak net item is often revealed by the porosity. The porosity represents the percentage of porosity in a porous material and can be expressed as the ratio of the open area divided by the total area of the net sample. The common material of windbreak net is high-density polyethylene (HDPE). When windbreak net is set up, it is necessary to consider the

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porosity, height, width and distance between nets etc., in which the porosity has a higher impact on wind reduction effect [3-6]. In addition, the setup of windbreak net is mainly to reduce the wind velocity, but it shall be able to bear the wind pressure generated by strong wind. So the pillar material of windbreak nets must also be assessed and screened in detail, in order to improve its strong wind protection function and lengthen its service life. When the air current flows into the windbreak net, part of air current will flow through the windbreak net, and part of air current will flows upwards due to the obstruct of windbreak net. After the air passes over the windbreak net, the air current begins to move downwards, the wind velocity increases gradually as the distance away from the windbreak net. When part of air current passes through the windbreak net with porosity, the perturbation will be formed behind it, which can reduce the wind velocity, and reduce the damage of fruits and vegetables in the simple greenhouse [7].

A lot of papers were adopted in the wind tunnel simulation test to study the windbreak equipment, their results can be applied to the actual field, and can provide reliable references [8-11]. Among them, the windbreak net has already been applied widely, such as being used for preventing wind disaster, sand and snow disaster. It has been proved more effective than windbreak forest. Because the erection of windbreak net is convenient, cheap and fast, and can produce the windbreak effect at once, so it is the basic and convenient windbreak equipment [12].The purpose of this study is to carry on the wind tunnel simulation test for the windbreak net in front of the simple greenhouse for planting fruits and vegetables. Under a constant wind velocity, let the air current passing through the windbreak net with different porosity and tilt angle, the wind velocities at different horizontal distances and vertical distances front and behind the windbreak net are measured. The relative wind velocity is calculated. The wind reduction effect at different horizontal distances behind the windbreak net is analyzed and discussed.

2. Materials and Method

2.1. Experimental materials

The wind tunnel machine used for simulation test is the blowdown-type. The fan of this wind tunnel equipment is driven by a motor with 5 hp, and a regulating valve is installed at the air inlet to adjust the wind velocity. The maximum wind velocity in wind tunnel can reach 15 m/s. The wind tunnel testing machine with the length of 10 m is made up of steel plate. The fan is the wind source, which produces the reference wind velocity for carrying on the test. The whole body can be divided into the contracting section, rectifying section, testing section and diffusing section. The cross-section of the testing section is 0.5 m in high, 0.3 m in wide and 4.8 m in long. In addition, there are two transparent observation windows in 0.5 m in high and 2.0 min wide at the side. The illustration of wind tunnel testing machine is shown as in Fig. 1.

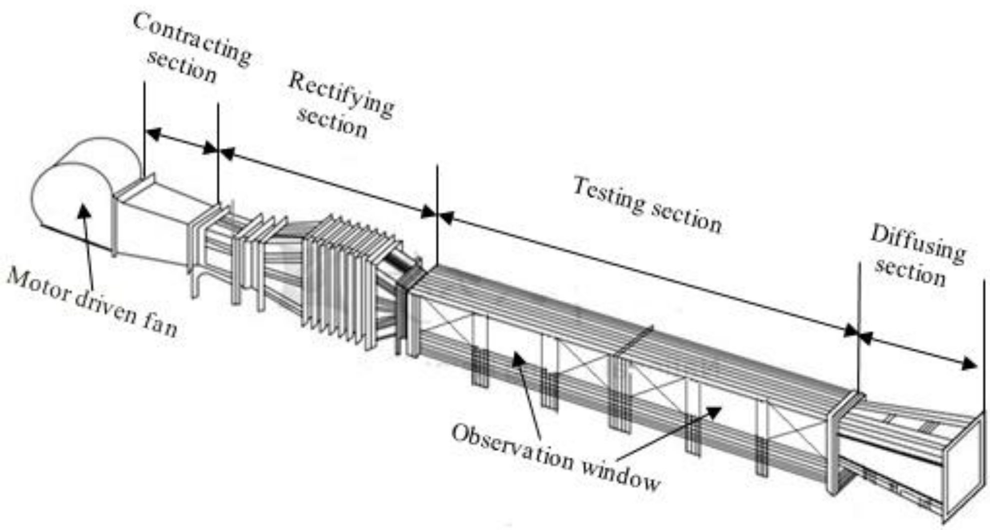
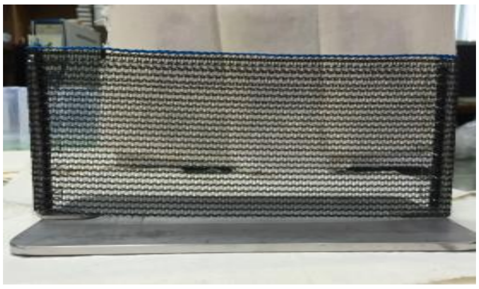
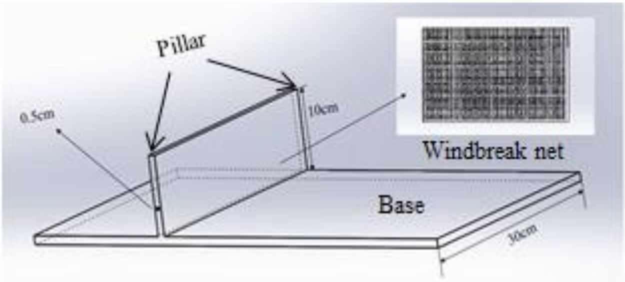


Fig. 1 Illustration of wind tunnel testing machine

The net of the windbreak net adopts common nylon knitted net, as shown in Fig. 2. The material of model pillar and the base is stainless steel. The thickness of pillar with height 10 cm is 0.5 cm. The width and length of the windbreak net model base is 30 cm and 50 cm. The windbreak net is fixed on the pillar to get the windbreak net model with different porosity. The tilt angle of windbreak net is changed by replacing the pillar with different tilt angle. The porosity of windbreak net is 50%, 40%, 30% and 20%. The tilt angle is changed at 0^o, 5^o, 10^o and 15^o at wind tunnel simulation test.



(a) Windbreak net sample with 50% porosity



(b) Windbreak net model with 0^o tilt angle for pillar

Fig. 2 Windbreak net model with 0^o tilt angles and 50% porosity

According to the statistics of Central Weather Bureau in Taiwan, the average wind velocity is about 5.1 m/s~20 m/s for the northeastern monsoon. The wind velocity of 10 m/s is selected as the reference wind velocity for testing after assessment. The 10 cm height of windbreak net model is referred to as 1h. The central surface of windbreak net model is used as the measurement position of wind velocity in wind tunnel. The horizontal distance X 20 cm in front of windbreak net model is regarded as -2 h. The horizontal distance at the place of the model is regarded as 0 h. There are 10 measurement points of horizontal distance at 2 h, 4 h, 6 h, 8 h, 10 h, 12 h, 16 h and 20 h behind the model. The vertical distance Z from the base of windbreak net model is taken at the height of 0.1 h, 0.2 h, 0.3 h, 0.4 h, 0.5 h, 0.6 h, 0.7 h, 0.8 h, 0.9 h, 1.0 h, 1.15 h, 1.3 h, 1.45 h, 1.6 h, 1.75 h, 1.9 h, 2.1 h and 2.4 h. There are 18 measurement points of vertical distance, and 180 test points in total, as shown in Fig. 3.

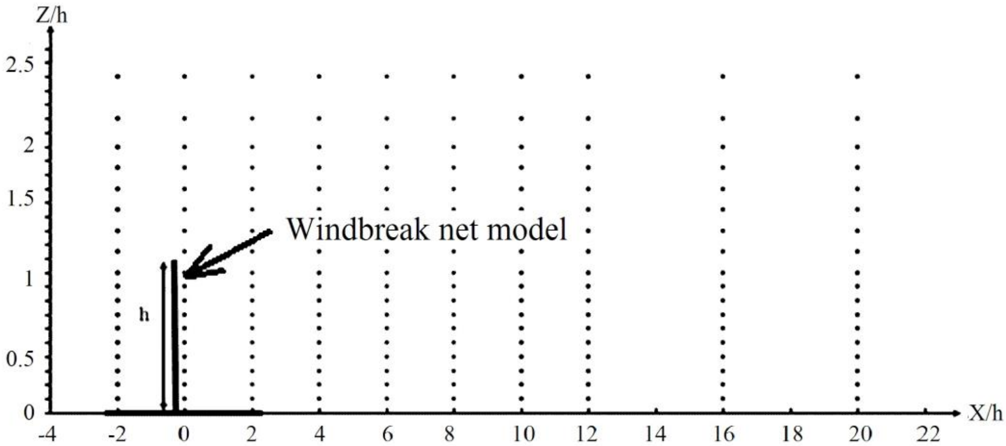


Fig. 3 Measurement position of wind velocity at the central surface of windbreak net model and distribution position diagram of measurement points (where h is the height of windbreak net model, Z is the vertical distance, X is the horizontal distance)

2.2. Experimental method

Generally, outside the boundary layer, the velocity of the fluid is close to a definite value without changing with position, but inside the boundary layer, the velocity at the fixed surface is 0 m/s, and the velocity of fluid approaches a definite value far away from the fixed surface. Before the wind tunnel simulation test, the inner air current state of wind tunnel should be tested first to understand the thickness of boundary layer. In order to increase the thickness of boundary layer for facilitating the wind tunnel simulation test, the spoiler and carpet are placed at the air inlet of rectifying section as the rectifying equipment. After the wind tunnel test, the flow field approaches steady-state at about 60 cm behind the rectifying section, and the thickness of boundary layer is about 20 cm. So the windbreak net model is placed at 100 cm behind the rectifying section for carrying on the wind tunnel simulation test.

The windbreak net model with specific porosity is placed in the wind tunnel testing machine at the position 210 cm away from the wind open of fan, as shown in Fig. 4. The revolution of the fan was adjusted to maintain 10 m/s of wind velocity in front of the windbreak net model in wind tunnel before the simulation test. The wind velocity was measured according to the planned measurement points at a horizontal distance and vertical distance. The measurement points of horizontal distance are at 20 cm (-2 h) in front of windbreak net model and every 20 cm (2h) behind windbreak net model until 200 cm (20h). The measurement points of vertical distance are every 1 cm (0.1h) from the base of windbreak net model until 24 cm (2.4h).

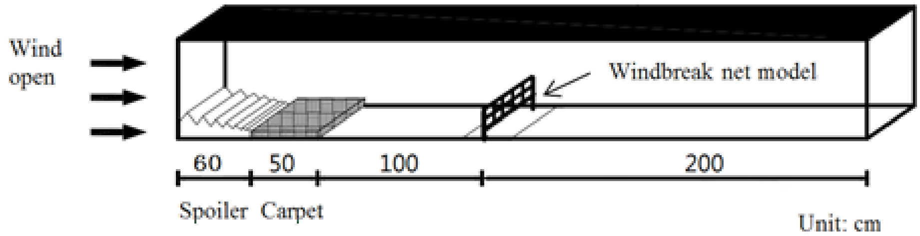


Fig. 4 Illustration for configuration position of windbreak net model in wind tunnel

The measurement apparatus of wind velocity in wind tunnel is composed of an anemometer (Dwyer, No. 400, America) and pitot tube. The wind velocity of every measurement point was measured by the pitot tube in wind tunnel. The pressure difference measured by pitot tube is transferred to the pressure converter (DF103-14) through the pressure indicator (VAL-CD23). The data for that position are acquired by the signal acquisition device (CDAQ-9174), and transferred to the computer for calculating and displaying its wind velocity finally. The triple repeated measurements are carried in wind tunnel test. The average value is taken as the value and record of wind velocity at the measurement point. The ratio of wind velocity (U_Z) measured at different vertical distances in wind tunnel and 10 m/s of reference wind velocity (U_{ref}) is defined as the relative wind velocity (U_Z/U_{ref}) as Eq. (1). In the subsequent data analysis, the relative velocity is used as the correspondence value of wind reduction effect.

$$\textit{The relative wind velocity} = U_Z / U_{ref} \tag{1}$$

3. Result and Discussion

3.1. Empty flow field in wind tunnel test

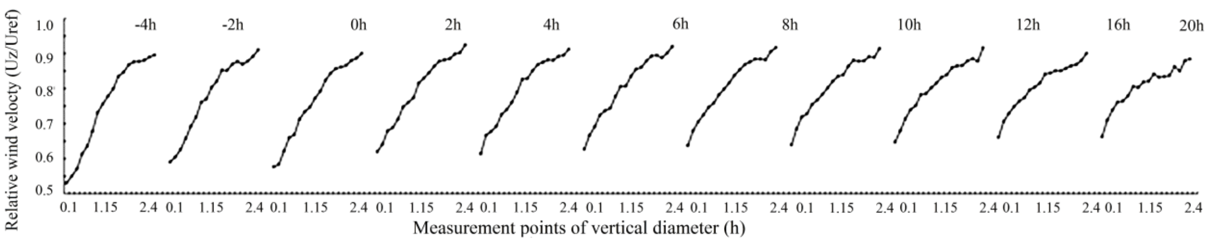
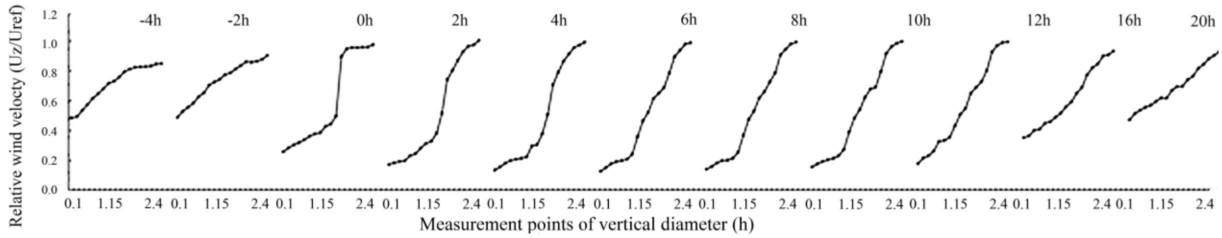


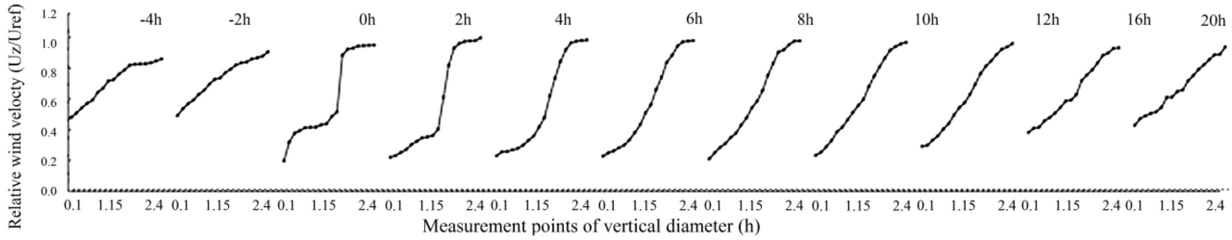
Fig. 5 The relative wind velocity of empty flow field at every horizontal distance and vertical distance in the wind tunnel testing machine

Fig. 5 illustrates the relative wind velocity of the empty flow field at every horizontal distance and vertical distance in the wind tunnel testing machine without placing windbreak net model. It can be found out that under every horizontal distance, its corresponding relative wind velocity presents the curve distribution trend associated with the measurement point of vertical distance, and the relative wind velocity is increased with the height of vertical distance. Though the ideal air current will generally be assumed to flow uniform in the field, but the flow field will be influenced by the wind tunnel wall of testing section actually. When the air is flowing in the testing section, the wind tunnel wall will produce resistance to the air current, and the surface velocity on wind tunnel wall is 0. The velocity will increase slowly away from wind tunnel wall and approach a definite value. This will make the profile of wind velocity presenting curve distribution.

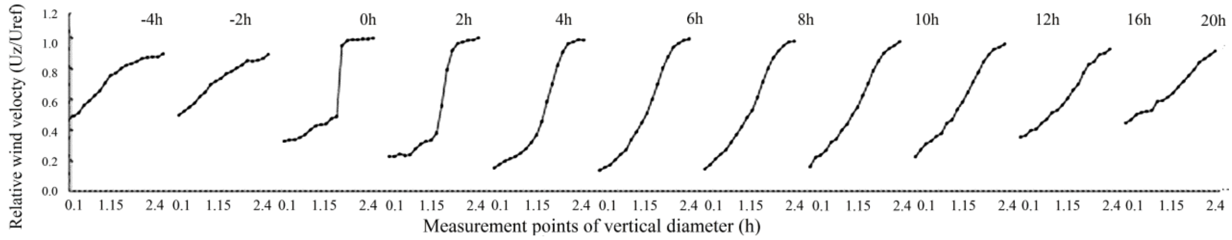
3.2. The relative wind velocity of windbreak net with 0^o tilt angle and different porosity



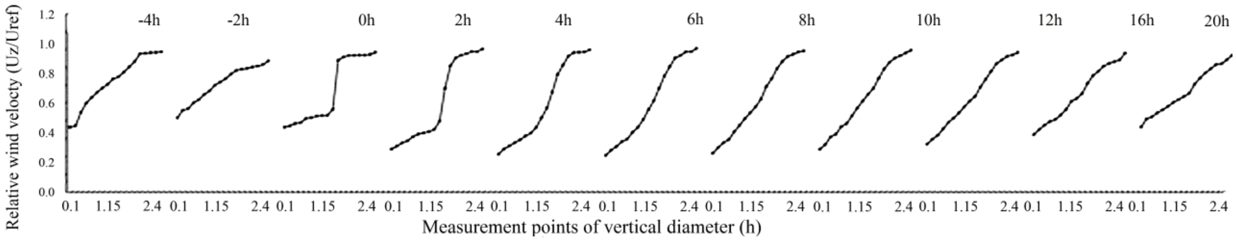
(a) 20% of porosity



(b) 30% of porosity



(c) 40% of porosity



(d) 50% of porosity

Fig. 6 The relative wind velocity of windbreak net with 0^o tilt angle and different porosity at every measurement point of horizontal distance and vertical distance

Fig. 6 illustrates the relative wind velocity of windbreak net with 0^o tilt angle and different porosity at every horizontal distance and vertical distance. Fig. 6(a) illustrates the windbreak net with 20% porosity, at 0h horizontal distance, the relative wind velocity is lower below 1h vertical distance of windbreak net. This is because when the air current flows into the windbreak net, part of air will flow through the porosity of windbreak net, and part of air will flows upwards due to the squeezing action of windbreak net. After the air passes over the windbreak net, the air current begins to move downwards. Comparing this with relative wind velocity of the empty flow field, the relative wind velocity at 0h horizontal distance is dropped significantly. This reveals the wind reduction effect behind the windbreak net with 20% porosity. In addition, at 0h horizontal distance, when the air current closes the windbreak net, part of air will flow through the windbreak net due to the porosity of windbreak net, its squeezing action is smaller, so that the rising phenomenon of air current is not obvious at the vertical distance above 1h of windbreak net. Part of air current will flow through the porosity of windbreak net evenly, so the wind velocity still can be measured at the vertical distance behind the windbreak net.

At 2h, 4h and 6h horizontal distance, the relative wind velocity at 0h~1.0 h vertical distance is 0.20~0.40, 0.26~0.57 and 0.25~0.63 respectively. This reveals under the same horizontal distance, the relative wind velocity behind the windbreak net with 0^o tilt angle and 20% porosity will increase with the increase of vertical distance. At 12h horizontal distance, the relative wind velocity at 0h~1.0 h vertical distance is about 0.33~0.65. Behind 12h horizontal distance, the variation curve of relative wind velocity is similar to the horizontal distance at -4h. Its relative wind velocity will increase gradually with the increase of horizontal distance. This reveals the wind reduction effect decreases gradually with the increase of horizontal distance, and the windbreak net does not have the wind reduction effect behind 12h horizontal distance. Fig. 6(d) illustrates the relative wind velocity of windbreak net with 0^o tilt angle and 50% porosity at every horizontal distance and vertical distance. At 2h horizontal distance, the relative wind velocity at 0h~1.0 h vertical distance is 0.28~0.48. Under the same horizontal distance, the relative wind velocity of windbreak net with 50% porosity will increase with the increase of horizontal distance that similar to the windbreak net with 20% porosity. Under the same horizontal distance, the relative wind velocity of windbreak net with 50% porosity measured from 0h~1.0 h will be higher than that of windbreak net with 20% porosity.

3.3. The wind reduction effect of windbreak net with different porosity

Table 1 The relative wind velocity of windbreak net with 0^o tilt angle and different porosity at different horizontal distance and 1h vertical distance

The relative wind velocity (U_Z/U_{ref})		Porosity (%)			
		50	40	30	20
Horizontal distance measurement (h) [1]	2 h	0.48 ± 0.006^a	0.41 ± 0.007^b	0.39 ± 0.015^b	0.38 ± 0.005^b
	4 h	0.58 ± 0.005^a	0.47 ± 0.010^b	0.44 ± 0.010^c	0.39 ± 0.014^d
	6 h	0.62 ± 0.005^a	0.55 ± 0.005^b	0.51 ± 0.010^c	0.52 ± 0.005^c
	8 h	0.63 ± 0.000^a	0.58 ± 0.010^{ab}	0.53 ± 0.011^b	0.55 ± 0.037^b
	10 h	0.68 ± 0.015^a	0.60 ± 0.015^b	0.55 ± 0.005^c	0.54 ± 0.009^c
	12 h	0.66 ± 0.006^a	0.62 ± 0.005^b	0.58 ± 0.013^c	0.55 ± 0.005^d
	16 h	0.68 ± 0.010^a	0.62 ± 0.000^b	0.60 ± 0.000^{bc}	0.59 ± 0.010^c
	20 h	0.68 ± 0.010^a	0.66 ± 0.020^a	0.63 ± 0.015^b	0.68 ± 0.011^a

[1] Mean±Std. with different superscripts in the same row are significantly different(P<0.05),using the Scheffe test.

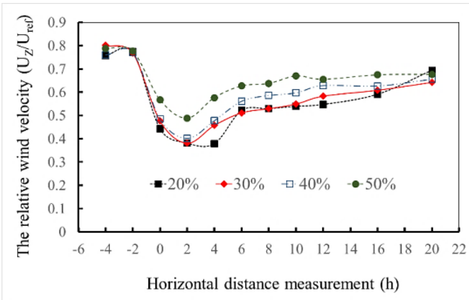


Fig. 7 The relative wind velocity of windbreak net with 0^o tilt angle and different porosity at different horizontal distance and 1h vertical distance

The relative wind velocity of windbreak net with 0^o tilt angle and different porosity at different horizontal distance and 1h vertical distance is shown in Table 1. From the Table, it can find out that the relative wind velocity of windbreak net with different porosity is increased progressively with the increase of horizontal distance. At 2h horizontal distance, the relative wind velocity of windbreak net with 20% porosity does not have significant difference with respect to that of 30% and 40%, but have significant difference with respect to that of 50%. The relative wind velocity of the windbreak net with 20%, 30%, 40% and 50% porosity is 0.38, 0.39, 0.41 and 0.48 respectively, and the corresponding wind reduction effect is 62%, 61%, 59% and 52% respectively. At 6h horizontal distance, the relative wind velocity of windbreak net with 20% porosity has significant difference with respect to that of 50% and 40%, but does not have significant difference with respect to that of 30%. The relative wind velocity of the windbreak net with 20% and 30% porosity is 0.52 and 0.51 respectively, and the corresponding wind reduction effect is 48% and 49% respectively. The relative wind velocity of the windbreak net with 40% and 50% porosity is 0.55 and 0.62 respectively, and the corresponding wind reduction effect is 45% and 38% respectively. At

10h horizontal distance, The relative wind velocity of the windbreak net with 20%, 30%, 40% and 50% porosity is 0.54, 0.55, 0.60 and 0.68 respectively, and the corresponding wind reduction effect is 46%, 45%, 40% and 32% respectively.

Fig. 7 illustrates the relative wind velocity of windbreak net with 0^o tilt angle and different porosity at different horizontal distance and 1h vertical distance. It can find out that the relative wind velocity of windbreak net with 4 kinds of porosity is decreased significantly from 0h to 6h horizontal distance behind the windbreak net. It reveals that there is good wind reduction effect at the interval of 0h to 6h horizontal distance. At 2h horizontal distance, the windbreak net with 20%, 30% and 40% porosity has higher wind reduction effect. Behind 6h horizontal distance, the wind reduction effect of windbreak net with 4 kinds of porosity is decreased progressively with the increase of horizontal distance. The windbreak net with 20% porosity has lower relative wind velocity, which represents its wind reduction effect is better. For the windbreak net with 50% porosity, the relative wind velocity behind 6h horizontal distance 6h is higher than that of 0h horizontal distance. Then the higher relative wind velocity is maintained, so its wind reduction effect is poorer.

3.4. The wind reduction effect of windbreak net with the different tilt angle

The relative wind velocity of windbreak net with 20% porosity and different tilt angle at different horizontal distance and 1h vertical distance is shown in Table 2.It can find out that the relative wind velocity of windbreak net with different tilt angle is increased progressively with the increase of horizontal distance. At 2h and 4h horizontal distance, the relative wind velocity is 0.38, 0.37, 0.37, 0.37 and 0.38, 0.39, 0.40, 0.38 respectively for the windbreak net with 0^o, 5^o, 10^o, 15^o tilt angle. It reveals that the relative wind velocity of windbreak net with different tilt angle does not have significant difference each other. It means that the tilt angle does not influence the wind reduction effect of windbreak net within 4h horizontal distance behind the windbreak net. At 6h and 8h horizontal distance, the relative wind velocity of windbreak net with 0^o and 15^otilt angle has significant difference each other, and the windbreak net with 15^o tilt angle has lower relative wind velocity. But behind 10h horizontal distance, the relative wind velocity of windbreak net with different tilt angle does not have significant difference each other. It means that at 10h horizontal distance behind the windbreak net, the tilt angle of windbreak net does not influence the wind reduction effect.

Table 2 The relative wind velocity of windbreak net with 20% porosity and different tilt angle at different horizontal distance and 1h vertical distance

The relative wind velocity (U_Z/U_{ref})		Tilt angle (°)			
		0	5	10	15
Horizontal distance measurement (h) [1]	2 h	0.38±0.010 [a]	0.37±0.015 [a]	0.37±0.020 [a]	0.37±0.021 [a]
	4 h	0.38±0.005 [a]	0.39±0.020 [a]	0.40±0.015 [a]	0.38±0.010 [a]
	6 h	0.51±0.011 [a]	0.49±0.015 [ab]	0.44±0.020 [c]	0.45±0.011 [bc]
	8 h	0.52±0.005 [a]	0.51±0.005 [ab]	0.49±0.011 [bc]	0.48±0.010 [c]
	10 h	0.54±0.010 [ab]	0.55±0.015 [a]	0.51±0.010 [b]	0.52±0.005 [ab]
	12 h	0.54±0.000 [a]	0.54±0.011 [a]	0.55±0.028 [a]	0.56±0.010 [a]
	16 h	0.59±0.020 [a]	0.58±0.015 [a]	0.62±0.023 [a]	0.60±0.010 [a]
	20 h	0.67±0.020 [a]	0.64±0.005 [a]	0.66±0.032 [a]	0.62±0.011 [a]

[1] Mean±Std. with different superscripts in the same row are significantly different($P<0.05$),using the Scheffe test.

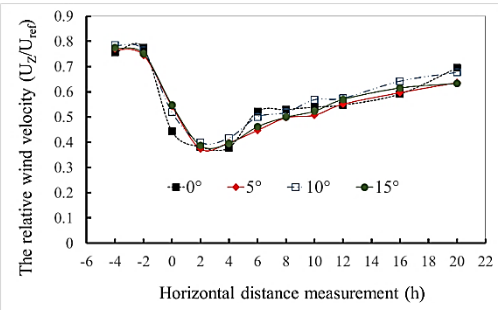


Fig. 8 The relative wind velocity of windbreak net with 20% porosity and different tilt angle at different horizontal distance and 1h vertical distance

Fig. 8 illustrates the relative wind velocity of windbreak net with 20% porosity and different tilt angle at different horizontal distance and 1h vertical distance. The windbreak net has lower relative wind velocity at the interval of 2h to 4h horizontal distance. However, the change of relative wind velocity is very small with the increase of tilt angle of windbreak net. It means that the influence of tilt angle of windbreak net on relative wind velocity is very low, namely the increase of tilt angle of windbreak net does not have much influence on the wind reduction effect.

4. Conclusions

Erecting the windbreak net in front of the simple greenhouse can reduce the wind velocity. It can suitably protect the simple greenhouse and fruits and vegetables and reduce the damage of the crops from strong wind. The following results can be obtained by carrying on the wind tunnel simulation test of the windbreak net. For the windbreak net with 0^{o} tilt angle, at 1h vertical distance and 2h horizontal distance, the relative wind velocity of windbreak net with 20% porosity does not have significant difference with respect to that of 30% and 40%, but have significant difference with respect to that of 50%. The relative wind velocity of the windbreak net with 20%, 30%, 40% and 50% porosity is 0.38, 0.39, 0.41 and 0.48 respectively, and the corresponding wind reduction effect is 62%, 61%, 59% and 52% respectively. At 1h vertical distance and 6h horizontal distance, the relative wind velocity of the windbreak net with 20%, 30%, 40% and 50% porosity is 0.52, 0.51, 0.55 and 0.62 respectively, and the corresponding wind reduction effect is 48%, 49%, 45% and 38% respectively. At 1h vertical distance and 10h horizontal distance, the relative wind velocity of the windbreak net with 20%, 30%, 40% and 50% porosity is 0.54, 0.55, 0.60 and 0.68 respectively, and the corresponding wind reduction effect is 46%, 45%, 40% and 32% respectively. The increase of tilt angle of windbreak net does not have much influence on the wind reduction effect.

Conflicts of Interest

The authors declare no conflict of interest.

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