Wind damage study and control on citric fruits

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ABSTRACT

A huge proportion of the citric production is discarded from exportation quality with large economic losses. The principal reason is the damage associated to the wind named "rameado". Young fruit with less than 1cm dimension can be stressed by the leaves movement. The leaves produce small injuries on the fruit peel, which increase when the fruit increase. From particular observation, it is common find a damaged fruit below a leaf.
Field measurements were made with ultrasonic anemometer YOUNG model 81000, with a frequency sampling of 10Hz. The anemometers were installed in a tower with a tree height.
Measurements in the orchard shows very low wind velocities with 10 minutes mean values lower than 2.2m/s in the greater part of the time. Threshold values between 5m/s and 6m/s are quoted. Then the damage must be linked to the turbulence structure of the flow inside the orchard.
Turbulence longitudinal integral scales, as large as 10m are obtained, then greater than the tree. Small scale parameter as high as 1615 was estimated.

INTRODUCTION

In Uruguay a huge proportion of the citric production is discarder as exportation because don't satisfy quality appearance requirements producing big economic losses. The appearance of the fruit in modified due peel damage associated to the wind. This kind of damage is named "rameado" (damage produced by the branches movement). Usually, farmers use live fences, composed by tall trees arranged in lines. Associated to different reasons, these kinds of fences don't operate in good way and the fruit usually present damage. Alternatively, some citric producers use screens as wind fences. Usually, these screens are plastics with a very small mesh size, 2mm to 3mm, and they produce changes in the flow similar a solid wall.

The Fluid Mechanics and Environmental Engineering from School of Engineering and the Vegetal Production Department from the Scholl of Agronomy, both at the University of the Republic, beginning a research program aimed to analyze the damage produced by the wind over the citric fruit in Uruguay. The objectives of this program are to know the harmful wind characteristics to the fruit assess the wind fences behavior and develop wind damage criteria. Particularly, we want characterize the wind-tree interaction, as well as the damage that occur over the fruit. Along this program, it was observed that is very significance the damage occurred in the peel of young fruit, because it growth with the time. That initial damage could be associated to very low velocity wind events. Usually, when a leaf is in contact with a young fruit, if the leaf is lifted, it is possible observe an incipient damage on the peel fruit down to the leaf edge.

In the frame of this program, also it was studied artificial wind fences built with screen of different dimensions and size mesh, located inside or on the border of the orchard with the aim of reduce the wind velocity, reduce the turbulence and specially adjust the energy content in the turbulence small scales. As part of the activities two tests were set up, one in AGRISUR, firm located in San José Department and the other in COSTA DE ORO, firm located in Paysandú department, both in Uruguay. The tests include the partial protection of the orchard and the measurement of wind velocity.

DAMAGE DESCRIPTION

The citric production is concentrated in two regions of Uruguay. The first one is the NORTHWEST and the other one the SOUTHWEST. In the fist zone the mean wind velocity is lower that in the second one. Correlated with this difference a smaller damage in the first one if found, but is very high in both.

A minimum of 10% discarded by wind in all citric evaluated but reaching 40% in more sensible species as Washington Navel and lemon are reported. Martínez, 1995 report a damage proportion of lemon between 25% and 33%, and the Washington Navel between 10% and 70%. The firm AGRISUR from its package unit report damage by wind of 45% to 71% for specie NOVA, 30% to 57% for lemon, 45% to 72% for Washington Navel orange and 50% to70% 'Ortanique' tangor.

The aforementioned "rameado" refers to the damage produced by the hits and rubbing of the branches and leaves when they move under the action f the wind during the phenological cycle. Such movements present different scales. The young fruits, with dimensions lower than 1cm, present surfaces with irregularities over which the neighbor leaves rub. As consequence of the abrasion the peel of the fruit is damaged, the oil is secreted and new tissue is produced with a texture similar to cork. Initially, this tissue presents a coarse texture but usually wear taking a fine texture yellow as figure 1 shows.

Figure 1: Damaged fruit images

Some report for California, USA, conditions refers 24km/h as a threshold to produce damage on fruit. Green, 1968 present similar values for South Africa conditions. Generally, these references describe the damage of adult fruit. In this case the damaged is not produced by leaf, the damage is produced by branches movements, which hit the fruit.

It is worthwhile that the harmful movements present different scales during the live of the fruit. In the first stage the movement of the leaf produces the damage, due to the rub, while the movement of the branches is harmful due the hit on the fruit.

WIND CLIMATE ANALYSIS AND ITS LINK WITH THE DAMAGE OCCURENCE

At national level weather information is obtain from National Weather Directorate as one hour mean velocity and mean direction. The measurement is taken 10m high and its aim is local climate characterization. Although these data are not good estimators of event characterized by wind velocity, turbulence or turbulence scale, that could produce damage, it is possible visualize climatic patterns of macro and meso scale. From such data, figure 2 shows ESE and NNE as more probable wind directions.

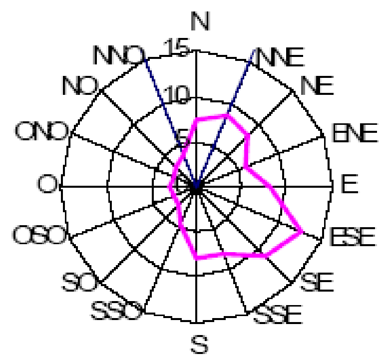


Figure 2: Mean value wind rose

Mean wind velocity at 10m high, in SOUTHWEST zone is about 5m/s, while in the NORTHWEST region would be 3.5m/s.

The extreme wind climate is qualitatively different. Figure 3 shows the wind rose for wind event with velocity greater than 32km/h

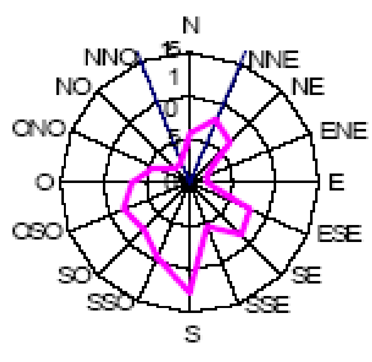


Figure 3: Extreme value wind rose

But, it would be not sufficient the mean values of the velocity to analyze the damage of the wind on the fruit. Also, it would be necessary to know the turbulent kinetic energy and the scales of the turbulence inside of the orchard.

The guess of the scales could be made from the power spectra, particularly from the longitudinal power spectra S_u. A first method uses the limit of the spectra when the frequency tend to zero ($S_u(0)$), then the longitudinal integral length scale could be estimated as follow

$$L = \frac{\overline{U}.S_u(0)}{4.\sigma_u^2} \tag{1}$$

where

$$\sigma_u^2 = 2.\int_0^\infty S_u(f)df \tag{2}$$

and $\overline{U}$ is he mean velocity value.

If the spectra are dimensionless as $\frac{S(f).f}{\sigma_u^2}$, the resulting curves present a peak for a frequency f_p, and then the longitudinal integral length scale could be estimated as follow

$$L = \frac{\overline{U}}{2\pi.f_p} \tag{3}$$

This scale usually is greater than the tree height. Then when a vortex, with this scale, flow over the orchard stress all tree parts in the same way and then, after the vortex evolve the different part of the tree will oscillate at its own frequency. As consequence each part of the tree will have a relative movement to other parts and some hit over the fruit could be occurring.

If we want to know about the movement of the leaf, then it would be necessary to know the energy content at scales near to the leave size (about 10cm). These vortices will move the leaf and it will rub the younger fruit. The energy of such small vortices is characterized using the small scale turbulence parameter, which after Melbourne is as follow

$$\mathrm{S} = \frac{f_{ss}.S_u(f_{ss})}{\sigma_u^2}.I_u^2 x10^6 = \frac{Energía(\lambda_{ss})}{Energía(flujo\ medio)} \tag{4}$$

where $I_u = \frac{\sigma_u}{\overline{U}}$ is the turbulence intensity and f_{ss} is the characteristic frequency of the small scale of the turbulence guessed from

$$f_{ss} = \frac{\overline{U}}{\lambda_{ss}} \qquad (5)$$

The scale λ_{SS} would characteristic of the vortices that give maximum energy to the vortices of scale ℓ that stress the leaf. If the vortices of scale λ_{SS} energy increase, then greater stress will act over the leaf and they will present greater deformation. As consequence, the leave could rub the fruit.

FIELD EXPERIMENT

As it was mentioned, farmers use screens a usual practice to protect cultivate areas. The screen used in this kind of application present a high porosity (free area passage relative to total area) but with very small mesh size. As part of this program, in a previous test it was used one of such screen and velocity measurement was made inside of the orchard. Although, a mean velocity decrease was verified, also it was identified spectral components that correspond to vortices with a scale similar to the height and length of the screen. Some reduction in the proportion of damaged fruit was found in an area with a width similar to the height of the screen. Therefore, the screen operates as a solid wall. Some results of this test were referred in Cataldo and Durañona, 2007 and in Gravina et al., 2008.

A new experiment was designed. Two orchards were selected. The first one property of AGRISUR firm located in Kiyú place, department of San José located in the region SOUTHWEST of Uruguay. The second one is located in the NORTHWEST of Uruguay, department of Paysandú, near Quebracho village and it is property of COSTA DEL ORO firm.

In both cases, an orchard was selected and a partial protection was designed. The position of the screens was selected using results similar as presented in figure 2.

The mesh size was selected analyzing the required energy content at small scale turbulence. Then a typical leave size of 10cm was supposed. Then, the small scale of turbulence was defined as 6cm following results as Tenekes and Lumley, 1981 or Cataldo and Farell, 2001. Also, it must be taken into account that the scale of the screen turbulence produced increase with the distance downstream of the screen. Then a screen with a mesh size 5cm times 10cm. Figure 4 shows the screen installed in AGRISUR.

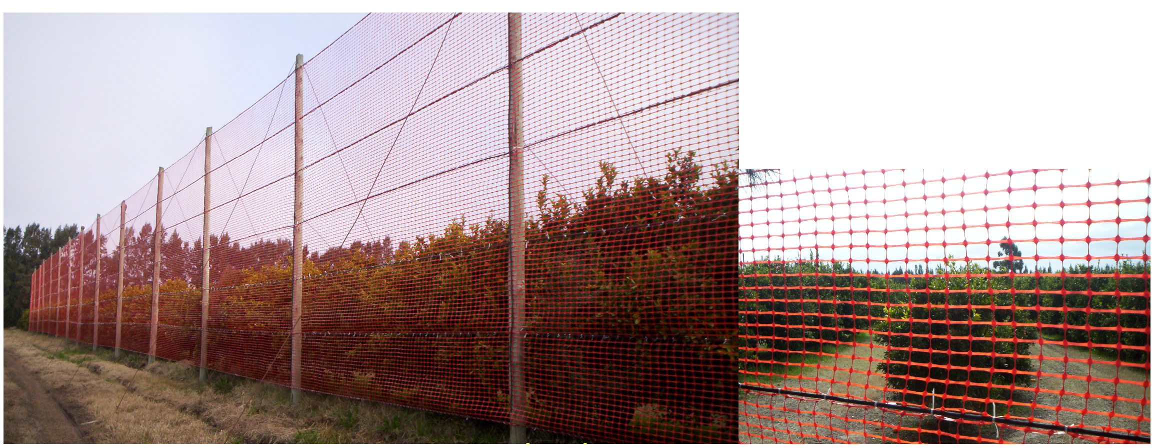


Figure 4 - Kiyú screen images

In both orchards were installed ultrasonic anemometers brand YOUNG, model 81000 that solve the three velocity component. The anemometers were installed over a mast 3m high and the sampling frequency was 10Hz. An acquisition program was designed specifically and it was installed in a dedicated laptop. The system was complete with an energy back-up composed by batteries and UPS unit.

The acquisition system stores the three components each 0.1 second.

RESULTS

It was observed a relatively low velocity inside the orchard in almost any time. Figure 5 shows the evolution of the 10 minutes mean horizontal component velocity along one day.

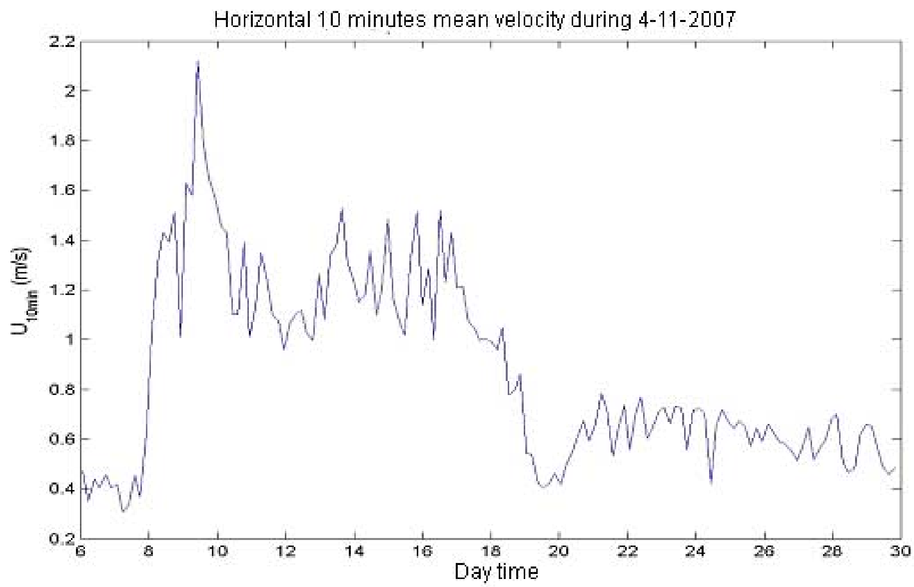


Figure 5 – Evolution of the wind during one day

The analysis was made in time intervals where the mean velocity could be considered steady and greater than 1m/s to obtain relatively large Reynolds number. As an example, in the day 4-11-2007 (figure 5), was selected the period from 13 to 17.

Figure 6 shows the spectra of the longitudinal turbulent component $S_u(f)$ for the studied period of time. To obtain a better description of the spectra, a three frequency intervals analysis was made. A first frequency interval was 0.000075Hz to 0.0011Hz, a second frequency interval was 0.0012Hz to 0.0691Hz and a third interval from 0.07Hz to 5Hz. In any case different time interval was considered. In the first case one period of 4 hour was considered, while in the second interval four intervals 1 hour long and in the third case twenty four intervals of 10 minutes.

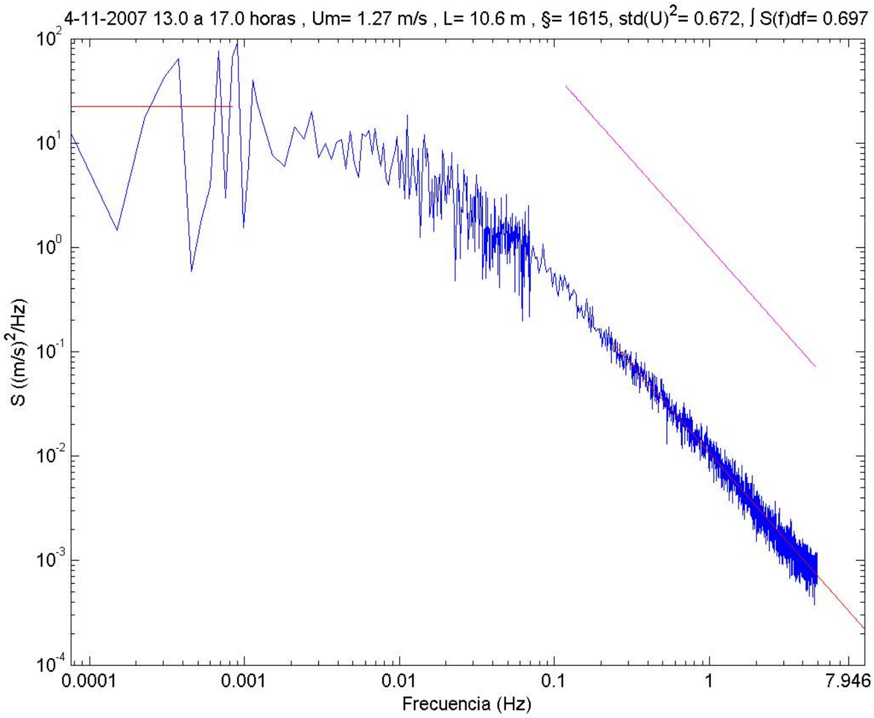


Figure 6 – Power spectra of the fluctuation component

In this example a value of $S_u(0)$ of 21(m/s)^2/Hz was obtained and a longitudinal integral length scale of 10.6m was deduced. The frequency of the turbulence small scale was 7.94Hz and the small scale parameter was 1615.

Figure 7 presents the dimensionless power spectra. The peak spectrum was obtained at a frequency of 0.224Hz and the longitudinal integral length scale was 9m.

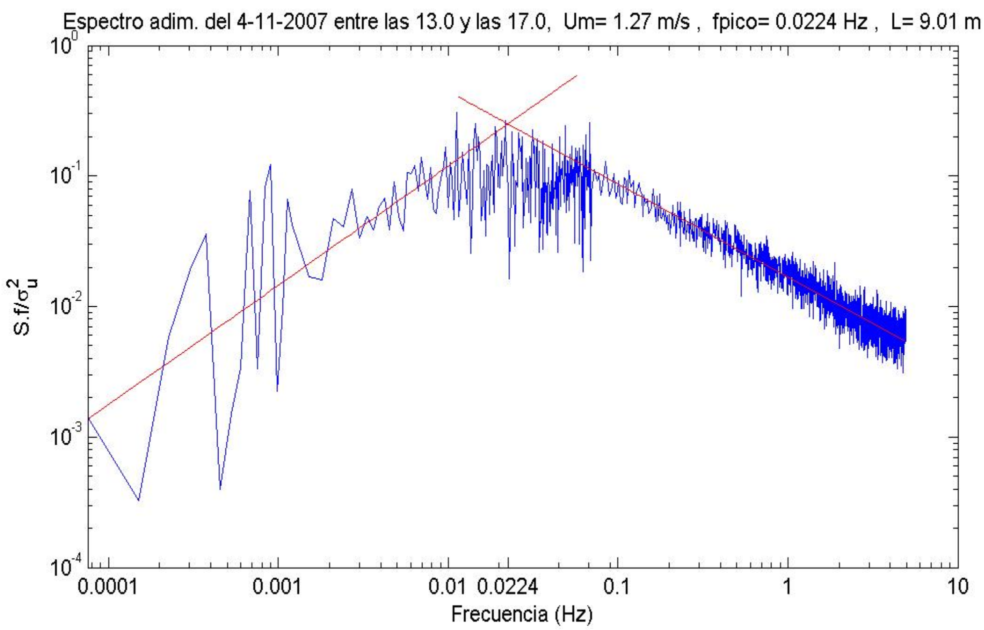


Figure 7 – Dimensionless power spectra of the fluctuation component

This analysis was mead for the three components u (longitudinal), v (lateral) and w(vertical). The horizontal mean direction was defined to the mean lateral wind be zero. Figure 8 shows the evolution of the wind a different days as it was presented in figure 5.

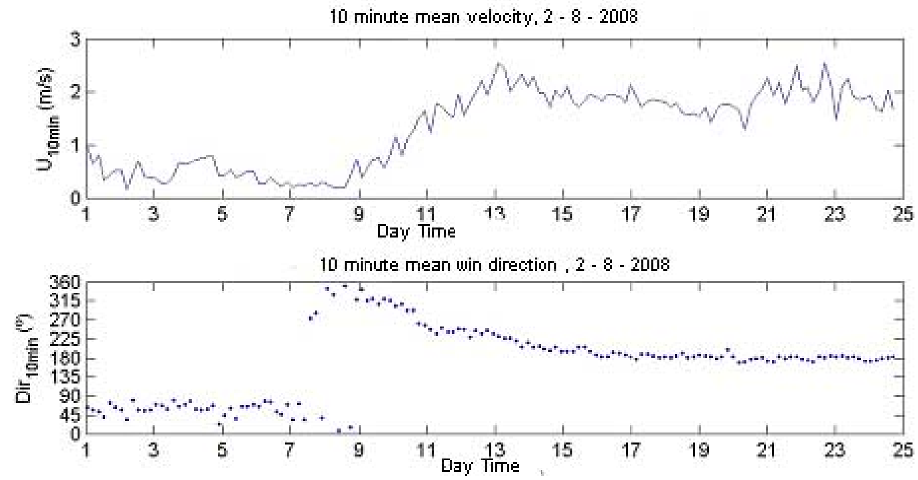


Figure 8 – Wind evolution the day 2 – 8 - 2008

In this case, a statistic analysis allows verify if the flow was steady. Figure 9 shows the histogram of 10 minutes longitudinal mean velocity and 10 minute direction velocity.

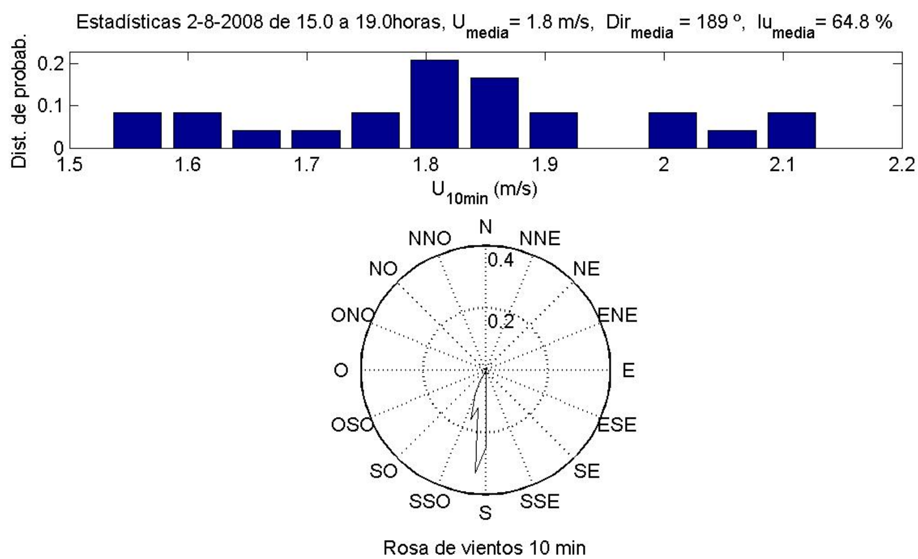
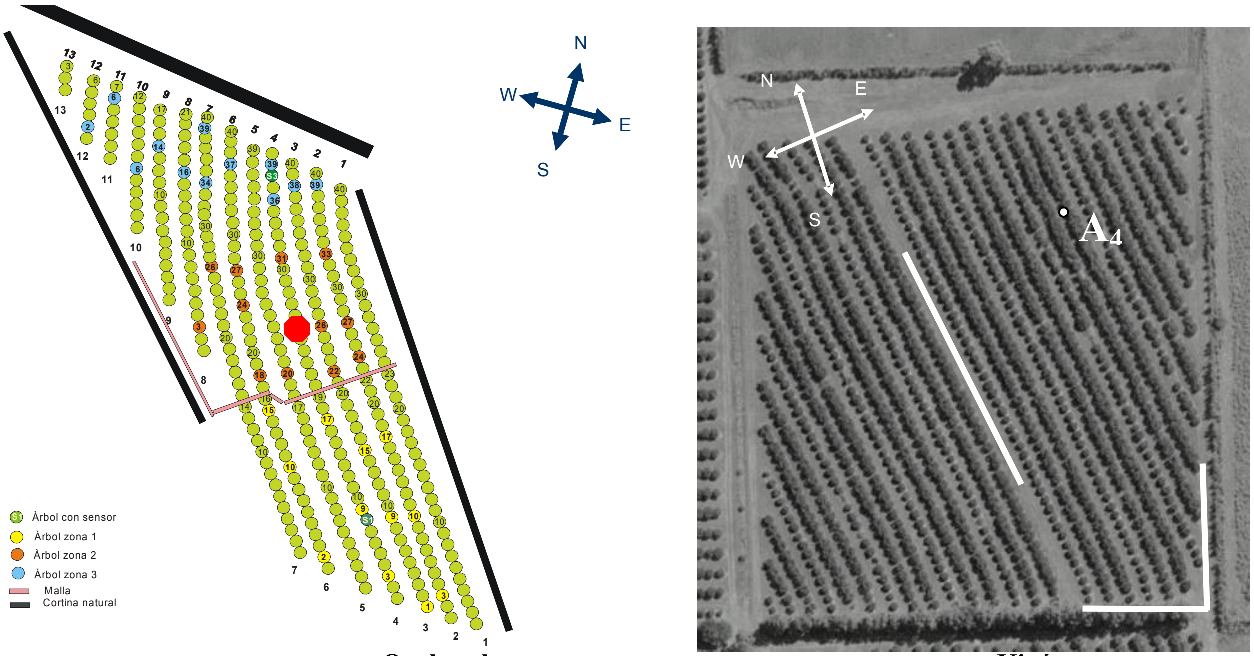


Figure 9 – Mean histogram and wind rose for the day 2 – 8 - 2008

ANALYSIS

This analysis was made in the case when the anemometers were installed as show figure 10 in both orchards.



Quebracho **Kiyú**

Figure 10 – Anemometer location

Tables 1 and 2 show the result obtained in any site.

Table 2 – Characteristic parameters in Kiyú

Direction	u_m (m/s)	σ_u^2 ((m/s)^2)	σ_v^2 ((m/s)^2)	σ_w^2 ((m/s)^2)	§	I_u (%)	L_u (m)
NE	0.78	0.21	0.17	0.06	1406	61	3.2
S	1.43	1.46	1.19	0.39	3543	85	3.0
ONO	1.83	1.08	0.79	0.27	1093	57	10.2
O	1.53	1.04	0.65	0.25	1213	67	5.6
S	1.07	0.91	0.78	0.25	4284	90	3.3
SSE	1.03	0.92	0.74	0.24	4076	93	3.9
ONO	1.67	1.14	0.96	0.28	1432	65	9.2
SSO	1.27	1.24	1.22	0.36	5152	87	4.4
S	1.12	1.03	1.01	0.30	4718	91	2.9
ENE	1.05	0.21	0.15	0.06	919	45	13.8
ENE	1.62	0.56	0.34	0.12	865	46	7.6
ENE	1.21	0.2	0.13	0.05	708	37	9.1
ONO	2.85	2.84	1.92	0.71	1299	59	9.9
ENE	1.22	0.59	0.37	0.12	1149	64	13.6
ENE	1.91	0.69	0.43	0.17	761	44	3.4
NE	1.28	0.64	0.43	0.15	1381	64	6.0

Table 3 – Characteristic parameters in Quebracho Table

Direction	u_m *(m/s)*	σ_u^2 *((m/s)²)*	σ_v^2 *((m/s)²)*	σ_w^2 *((m/s)²)*	*§*	I_u *(%)*	L_u *(m)*
N	1.17	0.9	0.71	0.29	2375	82	4.4
N	0.93	0.77	0.66	0.25	3957	98	3.47
NO	1.08	1.02	1.00	0.34	3820	94	4.37
ENE	0.92	0.41	0.49	0.12	1677	71	3.01
SE	0.79	0.75	0.61	0.20	4641	115	3.93
O	0.67	0.77	0.88	0.25	9040	145	4.73
E	0.83	0.27	0.34	0.09	1422	64	3.55

We obtain similar turbulent energy for lateral and longitudinal components and both greater than the vertical one.

In both case, when the wind blown from the screens, let say WEST in Kiyú and SOUTH in Quebracho, a higher small scale turbulence parameter is obtained. Also, when the wind blown from direction without screens, but with line of trees used usually as protection, the small scale turbulence parameter is minimum.

Also, it was verified a strong correlation between a high integral longitudinal length scale and a low small scale turbulence parameter, we guess related to the distribution of turbulent energy

When the energy content at small scale is high, then the energy of the vortex produced around the leaf could be drained and decrease the leaf fluctuation.

Preliminary results obtained about damage proportion, shows a strong decrease of the discarded fruit, correlating with the velocity measurement results.

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