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Sunspots are Correlated with Foliar pH in Grapevines

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Abstract

Foliar pH is a specific multifaceted parameter that is sensitive to a deficit in soil water and to temperature variations. It also represents a tool that can be used to rapidly phenotype the symbiosis induced in several crops by bio-fertilizers containing Arbuscular Mycorrhizal Fungi. Yearly decreases in foliar pH, which dropped from 3.73 in 2015 to 3.15 in 2017 and then stabilized at around 3.13, have been observed in an experimental vineyard near Torino (Italy) in six grapevine cultivars. In this paper, these curious, original results have been paired with the average sunspots of the 24^{th} sun cycle, proximal to its endpoint. The paired values were highly correlated (r 0.95 P< 0.01), with close parabolic patterns. A lowering in foliar pH has been correlated with a modification of the leaf composition, as characterized by the higher hydration and reinforced wall. An increase in the circulating acidity of the plants has been hypothesized to interfere in a diminution in the general predisposition to block parasite attacks. From this perspective, the retrieval of several historic outbreaks and the long-term systematic monitoring of mud and *Erwinia amylovora* frequencies have suggested that the hypothesis that links the solar minima with dysfunctions of the plant-pest relationships cannot always be rejected. Cosmic influences pertaining to UV variations are poorly understood in plant physiopathology. Foliar pH appears to be a rapid and simple tool to unveil high-level mechanisms. It is this simple parameter that physiologists and geneticists, but also agronomists, are asked to consider.

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Introduction

The monthly average of the sunspot (S) numbers oscillates around a cycle, called the "solar cycle", which was decoded in 1843 by Heinrich Schwabe. Sunspots arise quickly and fall more slowly over an irregular cycle that lasts about 11 years. These cycles have been numbered since 1750. Currently, the 24^{th} cycle is unfolding, from the minimum (1 S) in December 2008, passing through the cyclic maximum, which occurred in February 2014 (146.1 S), towards the next minimum which will possibly occur around 2020, since a value of zero was measured in November 2019.

In 1801, Herschel [1] called attention to an apparent relationship between sunspot activity and the price of wheat, a parameter that was considered as a gold standard for economists. The theory was then invalidated after Love's [2] (2013) overall mathematical recalculation. However, Gorbanev [3] (2015) revisited evidence on the influence of solar activity on the economy, and examined whether economic recessions occurred more often in the years around and after solar maxima. Quite surprisingly, his results suggested that the hypothesis linking solar maxima and recessions was well founded, as a result of his data, and should not be rejected. From a purely agricultural viewpoint, the maxima have been correlated with yield benefits [4,5], while the minima have been correlated with lower productivity, and sporadically with highly detrimental events, which we consider hereafter.

Foliar pH is a new plant trait, which has been explored by Cornelissen's [6] team in 92 species. In a previous work [7], we observed a more acidic nature in 49 cultivated species and experimentally proved that the foliar pH depends on the water condition, on the temperature and on the symbiotic relationships with arbuscular mycorrhizal fungi. Moreover, foliar pH variations have been linked to different leaf compositions in *Sorghum* [8]. There are, to the best of our knowledge, no data on the influence of sunspot activity on soil or plant symbiotic microorganisms.

Experimental Procedure

Foliar pH was monitored over a five-year period to ascertain whether and how a significant trend could be detected in grapevines. When the results showed a diminutive parabolic pattern, we were astonished and searched for an explanation. We then paired our observations on the field with sunspots, and something began to become clear. Moreover, NIR-SCiO spectra, coupled with pH measurements, allowed us to decipher the correlated changes in the gross composition of the leaves. Finally, a retrospection of historic outbreaks, paired with the sunspots, corroborated by bibliographic results, began to open new scenarios.

Materials and Methods

The sunspot files were downloaded from the WDC-SILSO site of the Royal Observatory of Belgium, Brussels [9].

From 2015 to 2019, six adult vines, grown at the DISAFA experimental center (45°03'58.6"N 7° 35'23.8"E), were observed on a sunny day in the middle of July. Fifteen leaves were sampled from the same 15 plants. They were then transported to a laboratory for pH analysis and NIR-SCiO Tomoscopy. The foliar pH of these leaves was measured with a BORMAC "XS pH 70" pH meter, 0÷14 pH range, two decimals, provided with a Hamilton Peek Double-Pore F, / Knick combined plastic-glass electrode, dimensions (LxØ) mm 35×6, terminating with a very small and sensitive tip sensor; other types were found to be unstable and unreliable. The insertion of the tip into the petiole was facilitated using a small drill fitted with a 2 mm bit or, more simply, using a screw to slightly dent the rib in order to insert the electrode. A total of 470 leaves were examined for the raw pH in the petiole axis, on the basal side. The NIR spectra were used to predict the chemical composition, as previously described for pH [8, 10].

Using an SAS GLM procedure, we estimated the Least square means of the vines and the common parabolic regression of the pH on a year's sequence, including the vine * year interaction. Moreover, a within-vine parabolic regression was calculated. Finally, a Pearson correlation was computed between the average number of monthly sunspots and the LS means of the pH for the same five-year period.

Results

Years and pH Evolution

During the five years (Figure1), the average pH decreased almost regularly from 3.73 in 2015 to 3.15 in 2017, then appeared stable, according to the negative linear and the positive quadratic components (Table 1). However, the pattern was different for the six vines (significant interaction). A general common trend was verified in two vines (*Cabernet* and *Barbera*). A shift in height occurred in *Pinot* in 2018. After a minimum was reached in *Shiraz* and *Nebiolo* in 2017, the pH began to increase. The pH values in *Grenache* were lower in 2016 and 2019.

NIR Spectrum, pH Correlation, and Foliar Composition

The correlation of the foliar pH with the NIR reflectance spectra ranged from -0.34 to -0.59 (Figure 2) and the composition of the leaves varied accordingly (Table 2). In a condition of low pH, leaves tend to contain more water, and to raise the crop maturity index, NDF digestible, protein, ADF, cellulose, hemicellulose, lignin, energy and crude fiber. In a condition of high pH, leaves tend to lose the lipid, ash, NDF digestible, total digestibility and free sugar contents. In short, a lowering of the pH, in response to a few sunspots, induces the plant to privilege the wall at the expense of the vacuole and the cytoplasm. Moreover, a higher maturity level tends to favor a rapid and amplified reproduction phase.

Sunspot Correlation with Foliar pH

Two parallel parabolic traces described a conjoint descent of the sunspots and the foliar pH over the years (Figure 3) A Pearson correlation of 0.95 (P 0.01) linked the two parameters. This is a new finding, but it does not seem to be based merely on statistics, for the reason discussed thereafter.

Sunspots are Statistically Related to Outbreaks

We here present a data mapping of the outbreaks that were reviewed by plant pathologists (Table 3), from which it appears that several outbreaks (Figure 4) took place during some periods of low sunspot occurrences. Considering a 50% possibility of falling below the sunspot average of the involved solar cycle, twenty-two of the twenty-five referenced cases of outbreaks were below the average (P 0.0001) and often at minimal values, as can be seen from the average 49% decrease.

As far as insect pests are concerned, after assessing some of the *Phylloxera vastatrix* outbreak statistics in the grapevines, the relationships appeared positive (Table 4): only eight out of thirteen historic cases (61%) were below the mean value of the cycle and the sunspots were significantly correlated (r 0.78; P 0.001).

However, a clear confirmation of the pattern shown in Figure 3 was derived from long-term experiments and scientific studies on the forest moth pest species. Selas *et al.* [15], from 1970 to 2004, observed a clear inverse correlation that opposed the presence of sunspots to the outbreaks: r -0.92 in the autumnal moth (*Epirrita autumnata*) in *Betula* and r -0.78 on *Eilema lurideola* from a lowland mixed forest.

A further confirmation of a possible, non-random cyclical correlation between sunspots and epidemiology can be derived from the accurate monitoring of the fire blight pest in Trentino [16]. In Figure 5, it is possible to observe that the frequencies were relatively stable and the sunspots were unrelated in the middle of two full solar cycles, in the 1999-2011 interval. However, in the interval 1999-2003 and after the maximum outbreak occurred in 2011, problaby due to extraordinary temperatures and heavy rainfall, the two lines show strong opposite trends (r -0.88; P 0.049 and -0.80; P 0.0172, respectively).

Discussion

Foliar pH Functionality and Sunspot Mechanisms

The only multispecies study concerning the functionality of foliar pH [6] hypothesized that the tissue pH itself is closely controlled by a given species, because of its direct or indirect functions in the plant. For instance, a low pH has been found to correspond to poor digestibility, and may therefore act as an anti-herbivore defence in subarctic flora.

In a previous paper [8], we outlined the pivotal role of foliar pH in changing the composition of the leaves in conventional or mycorrhizal *Sorghum*. The results of the present work have confirmed the positive co-variation of pH with the dry matter, sugars and NDF as well as the negative co-variation of the ADF, hemicellulose, lignin, gross energy and crude fiber. Some constituents now appear different, namely the lipids (now positive) and the cellulose (now negative). However, the general pattern of leaf acidification manifested by high hydration and reiforcement of the wall compartment shown in the *Sorghum* study [8] has

Table 1. LS Means of the foliar pH of the six cultivars over the five years and the regression coefficients

Vines		*Cabernet*	*Barbera*	*Pinot*	*Shiraz*	*Nebbiolo*	*Grenache*	Mean
Years	2015	4.17	3.57	3.65	3.81	3.77	3.39	3.73
(Y)	2016	3.42	3.41	3.46	3.33	3.23	3.16	3.33
	2017	3.18	3.11	3.02	3.04	3.14	3.38	3.15
	2018	3.16	2.99	3.34	3.21	3.12	3.21	3.17
	2019	3.30	3.15	2.72	3.35	2.86	3.37	3.13
	Mean	3.45	3.25	3.24	3.35	3.23	3.30	3.30
Regression	b(Y)	-1.0617	-0.4640	0.1664	-0.8378	-0.5046	-0.1667	-0.5486
	P	<.0001	0.0012	0.9379	<.0001	0.0025	0.1419	<.0001
	b(Y^2)	0.1420	0.0587	-0.0078	0.1216	0.0494	0.0269	0.0671
	P	<.0001	0.0023	0.6908	<.0001	0.007	0.147	<.0001
Model	R^2	0.80	0.43	0.64	0.46	0.67	0.28	0.43
	P. Interaction Vine * Year							<.0001

Table 2. Correlation of the foliar pH with the constituents, estimated from the NIR-SCiO spectra (r(X,pH), and comparison with the previous Sorghum work [8] (r (Y, pH)) [a].

Constituent (X)	r(X,pH)	r(Y,pH)
Dry matter	**0.57**	**0.40**
Lipids	0.48	-0.52
Ash	0.38	-0.02
Total digestibility	0.37	-0.04
Sugars	**0.24**	**0.23**
Neutral Detergent Fiber (NDF)	**0.10**	**0.20**
NDF digestibility	0.06	-0.08
NDF non digestible	**0.01**	**0.03**
Crop Maturity Index	**-0.19**	**-0.20**
NDF digestible	**-0.21**	**-0.41**
Crude protein	-0.24	0.04
Acid Detergent Fiber (ADF)	**-0.26**	**-0.36**
Cellulose	-0.32	0.58
Hemicellulose	**-0.33**	**-0.16**
Lignin (ADL)	**-0.38**	**-0.22**
Gross Energy	**-0.46**	**-0.18**
Crude fiber	**-0.51**	**-0.28**

[a]The concordant coefficients are in bold

Table 3. The twenty-five referenced cases of pandemic outbreaks paired with the yearly and 11-year moving average of the sunspots.

#Cases	Outbreaks	Country	Year	Sunspots	11 years	Reference
1	Potato Leaf Roll Virus	N.Am. and W.Eu.	1784	17	120	[11]
2	Potato Leaf Roll Virus	N.Am. and W.Eu..	1812	8	22	[11]
3	*Pyricularia oryzae* Rice	Italy	1824	11	37	[12]
4	*Pyricularia oryzae* Rice	Italy	1825	28	44	[12]
5	*Pyricularia oryzae* Rice	Italy	1826	59	65	[12]
6	*Phytophthora infestans* on Potato	Ireland	1845	66	97	[13]
7	Potato Leaf Roll Virus	N.Am. and W.Eu.	1846	102	97	[11]
8	*Oidium* on Vine	France	1854	39	81	[13]
9	*Doryphora* on Potato	USA	1874	75	96	[13]
10	Potato Leaf Roll Virus	N.Am. and W.Eu..	1878	5	51	[11]
11	*Plasmopara* on vine	Italy	1884	105	68	[13]
12	*Plasmopara* on vine	Italy	1889	10	61	
13	*Plasmopara* on vine	Italy	1890	11	61	
14	*Plasmopara* on vine	Italy	1910	31	51	
15	*Plasmopara* on vine	France	1910	31	51	
16	Potato Leaf Roll Virus	N.Am. and W.Eu.	1912	6	50	[11]
17	*Plasmopara* on vine	France	1915	79	65	[13]
18	*Pyricularia oryzae* Rice	Italy	1921	43.5	75.04	[12]
19	*Pyricularia oryzae* Rice	Italy	1922	23.7	76.19	[12]
20	*Pyricularia oryzae* Rice	Italy	1923	9.7	70.3	[12]
21	*Pyricularia oryzae* Rice	Italy	1924	27.9	69.81	[12]
22	*Plasmopara* on vine	Italy	1934	14	81	[13]
23	Potato Leaf Roll Virus	N.Am. and W.Eu..	1944	16	101	[11]
24	Potato Leaf Roll Virus	N.Am. and W.Eu..	1976	18	94	[11]
25	*Xylella* on Olive	Italy-Puglia	2004	65	90	[14]
	Average			36.0	71.0	
	Sunspot decrease			-49%		

Table 4. *Phylloxera vastatrix* outbreaks on grapes throughout the world [13] paired with the yearly and the approaching 11-years moving average .

#	Country	Outbreak	Sunspots	11-Years
1	France	1863	83	100
2	Italy	1870	232	105
3	Portugal	1871	185	103
4	USA (California)	1873	110	102
5	Switzerland	1874	75	96
6	Germany	1875	28	85
7	Australia	1877	20	58
8	Spain	1878	5	51
9	New Zealand	1885	86	62
10	South Africa	1885	86	62
11	Peru	1888	11	58
12	Greece	1898	44	58
13	Spain	1901	4.6	42
		Means	74.6	75.5
	Correlation; r (P)		+0.76 (P 0.001)	

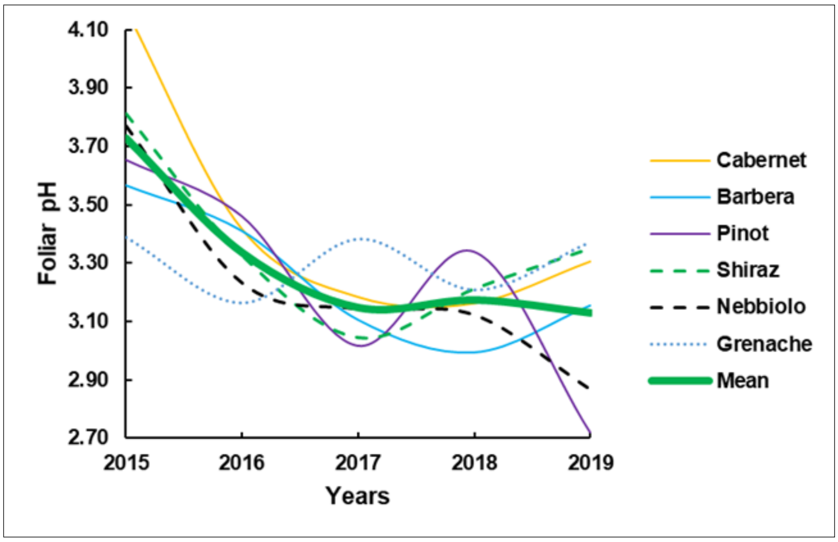

Figure 1. Plot of the foliar pH for the six grapevine cultivars over the five years.

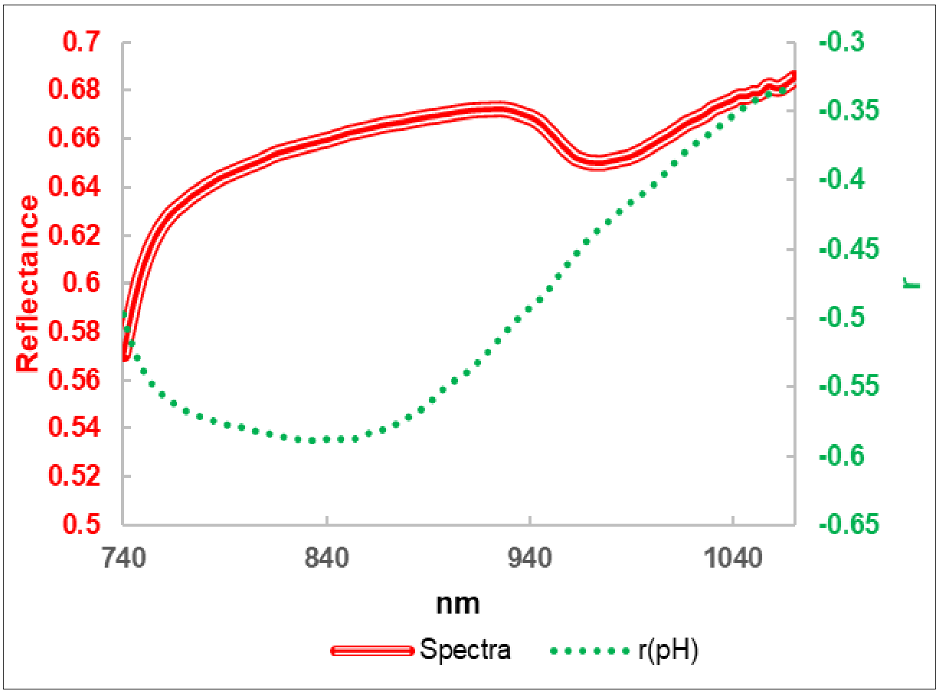

Figure 2. Average reflectance spectra of the leaves and correlation with the pH.

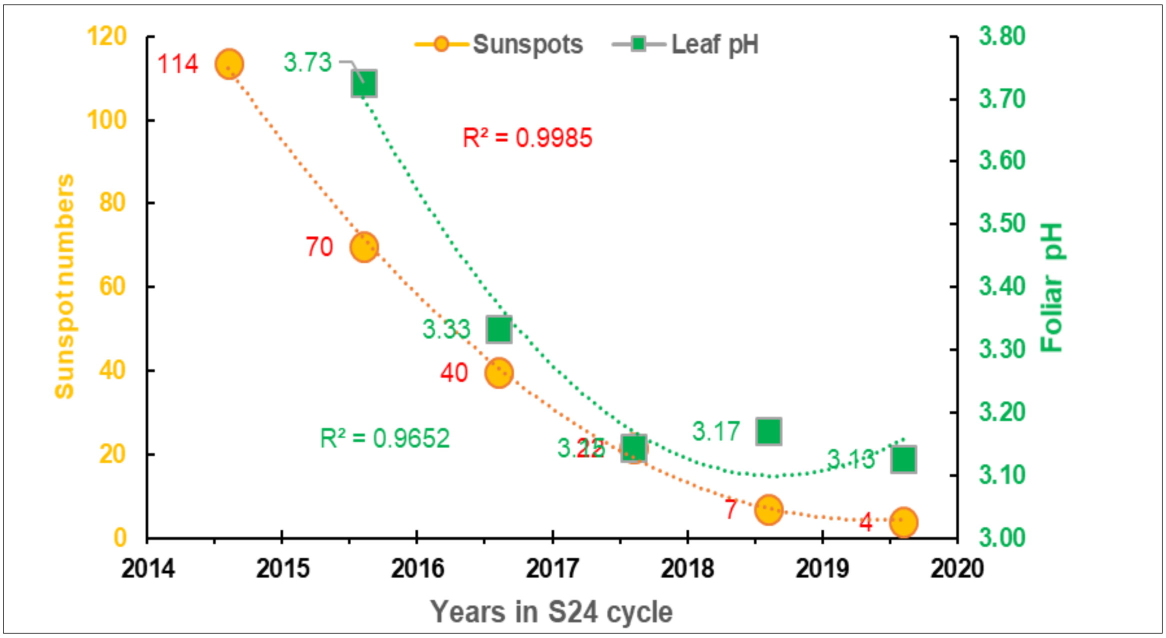

Figure 3. Plot of the sunspots [9] and the average foliar pH of the six grapevines over the five years of the 24th solar cycle (S24) and the parabolic fittings (r pearson 0.95; P 0.01).

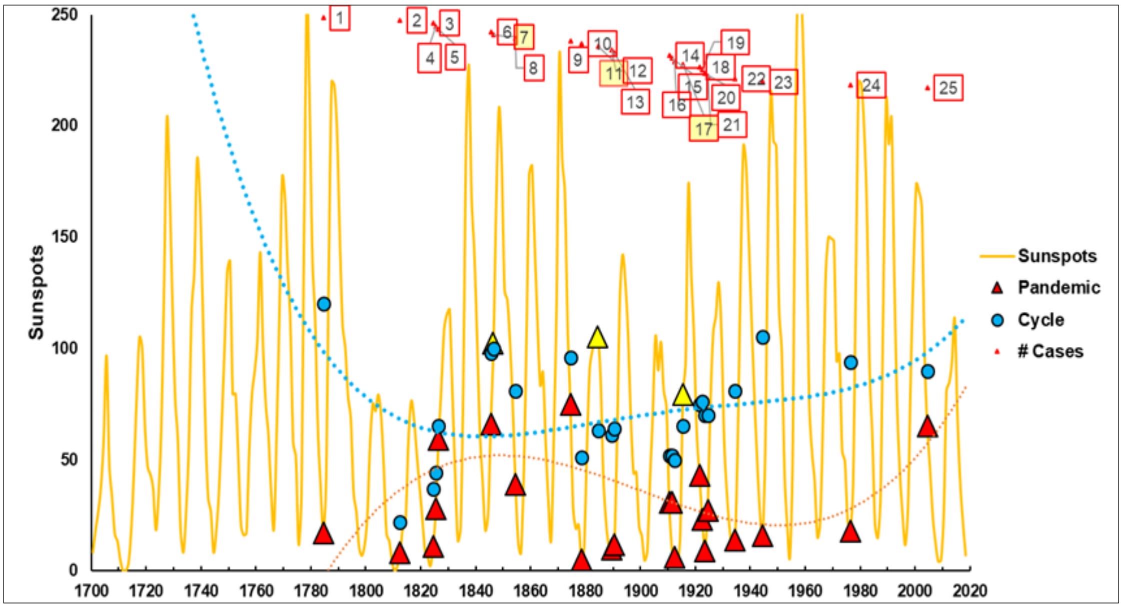

Figure 4. The monthly sunspot frequencies in the 1700-2019 interval with the yearly sunspots for twenty-five pandemic outbreaks (r 0.40) and for the approaching 11-year cycle. The numbers in the upper boxes indicate the cases reported in Table 2.

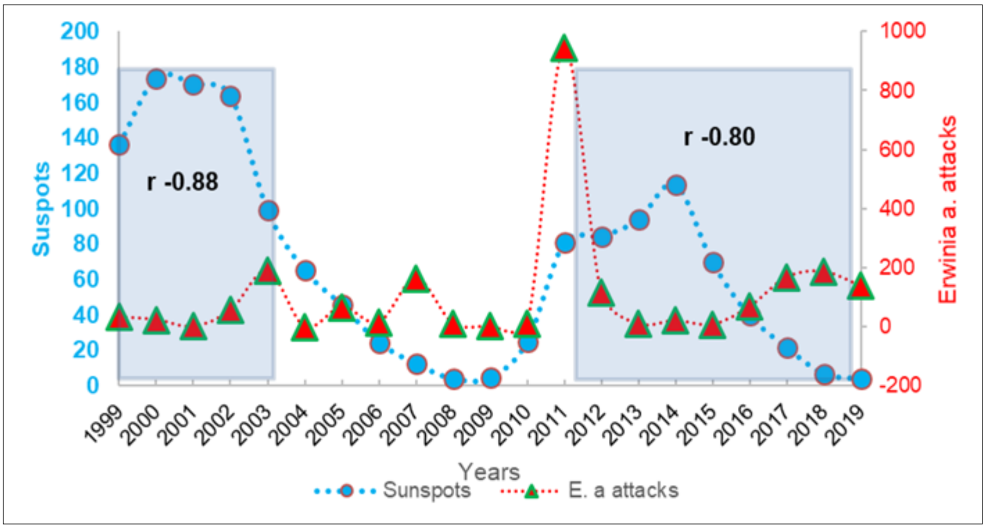

Figure 5. *Erwinia amylovora* frequencies in Trentino plotted angainst sunspots for the 1999-2019 interval.

here been confirmed for grapevines. In general, although more resistant walls are favorable, a greater turgidity of leaves is negative for the defense against parasites.

As far as the negative correlation of the sunspots with mud insect development is concerned [15], this unexplained fact was deemed to be due to a differential UV-B irradiation in a high sunspot phase which, in turn, led the plants to lower their chemical protectants. A low sunspot activity leads to a thinner ozone layer and thus a higher surface ultraviolet (UV)-B radiation. As winter moth larvae prefer leaves subjected to enhanced UV-B radiation, the Authors argued that the statistical relationship between sunspots and moths could be substantiated by the metabolic costs of producing UV-B-protective pigments during periods of low sunspot activity, which reduce tree resistance to herbivores, and thus increase the survival of moth larvae. The sun emits light, heat and UV radiation. The UV region covers the 100–400 nm wavelength range and is divided into three bands: UV-A (315–400 nm) UV-B (280–315 nm) UV-C (100–280 nm). As sunlight passes through the atmosphere, all the UV-C, and approximately 90% of UV-B radiation, are absorbed by ozone, water vapor, oxygen and carbon dioxide. UV-A radiation is less affected by the atmosphere. Therefore, the UV radiation that reaches the Earth's surface is mostly composed of UV-A with a small UV-B component. The global solar UV Index (UVI), graded from 1 to 11^+, is a measure of the intensity of UV radiation on the Earth's surface and it is relevant because of its effects on human skin [17]. WHO *who.int/uv* has developed reliable predictions of the consequences on human health and on the environment due to changes in UV exposure as a result of stratospheric ozone depletion. Maps of the daily UV irradiation at the soil level depend to a great extent on the season and latitudes. Nordic countries (Norway, Sweden and Finland) tend to receive higher levels of UV irradiation than Germany or France in late spring and early summer.

Sunspots are Statistically or Functionally Related to Outbreaks

According to the examined outbreak cases, a statistic hypothesis of an association with sunspots cannot always be rejected. However, only a few serious long-term studies are available to corroborate a general theory on such an argument. Taking inspiration from the mud-insect studies, a solar influence could be envisaged on the quantity of the UV-B reaching the plants, and the ozone layer is involved to a great extent. In short, if the sunspot/pH relationship that has emerged for the first time in the present work could be back-projected correctly, the plants would be induced to be in a acidic status, when and where the parasites could have manifested their maxima attacks, in true historical events not mitigated by pesticides. An increase in the circulating acidity of the plants has here been hypothesized to play a role in diminishing the general tendency to block parasite attacks. According to the present pH model hypothesis, the evolution of the plants might have been driven *in primis* by some of the photo-energetic assets and *in secundis* by the parasitisms being overdominated by the fungi, which are well adapted to growing in the acidic environment of plants. Cornelissen *et al.* [18] showed a variety of acidic levels that characterize the green foliar world, and this foliar pH is totally independent of the soil pH. In a previous study [7], we confirmed the *cornucopia* of acidic substances that determine a low pH in plants, and highlighted an inverse correlation between the number of fungicide treatments and the foliar pH (R^2 0.9). Moreover, the foliar pH was inversely correlated to water stressed conditions, and with the temperature, which is, overall, the main abiotic factor in agriculture.

Volpato *et al.*[19], using a pH mycorrhizal model, outlined that some maize varieties did not respond by lowering their foliar pH after inoculation, i.e. were not responsive to symbiosis, as they were oriented toward a commensalism or to parasitism. Thus, the change in the energetic status is the key to understanding the critical sustainability of plants over the short horizon of a sunspot cycle, where critical points (<7 sunspots) are observed in 1 out of 5.66 years, i.e. in 18% of the cases or two per cycle [9]. The preceding discussion was focussed on the foliar pH responses to the diminishing sunspots in this 24th cycle. This is a physioclimatic response to a reduction in sunspots. But what the "trojan horses" that threaten plants are could remain unknown.

Conclusion

The solar cycle is still debated in the

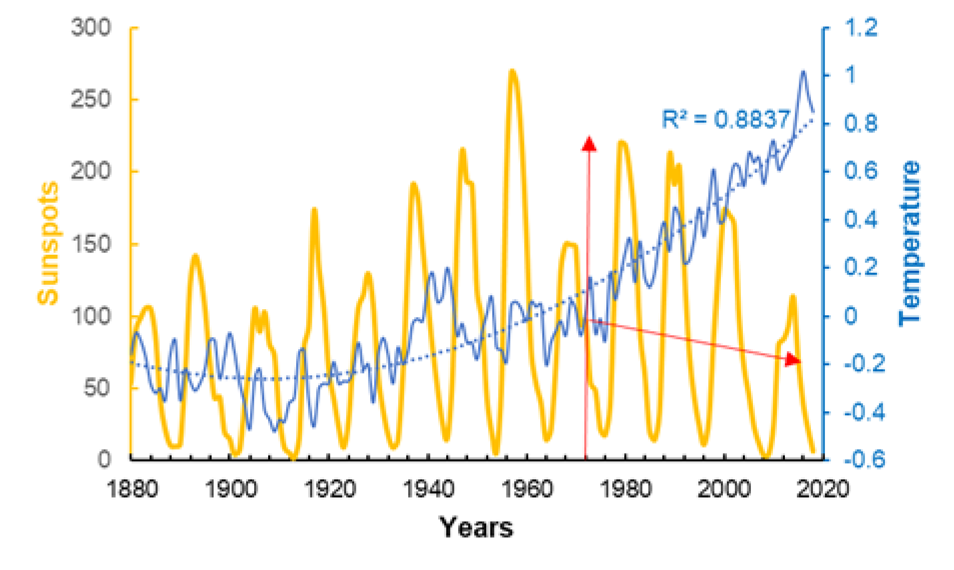

Figure 6. Yearly trend of the sunspots and global world temperature (NASA https://climate.nasa.gov/vital-signs/global-temperature). The two red arrows indicate a bifurcation of the temperature and sunspot trends.

framework of climate change. There is a general consensus toward an independence of sunspots from the phenomenon of accelerated deglaciation and localized warming in the northern hemisphere. Since the conclusion of the 21th cycle (1976), other anthropogenic components have been implicated more to spread the trends (Figure 6) .

Since the dawn of time, plants have lived in maternal symbiosis with the sun, fighting with parasites, while adapting their relationships to periodical sunspot oscillations. We have shown that a lowering of foliar pH depends on the sunspots in a solar cycle. Furthermore, we have hypothesized that a probable change in energy status may be correlated with acute parasitism events. Moreover, a new, more serious threat is derived from the increase in the temperature, as it determines a lowering of foliar pH. It is this simple parameter that physiologists and geneticists, but also agronomists, are asked to consider, especially in the perspective of sustainable bio-fertilizer management.

In short, for the first time in the present work it has emerged the sunspot/pH relationship. If it could be back-projected correctly, the plants would have been induced to an acidic status, when and where the parasites could manifest their maxima attacks. This happened in true historical events not mitigated by pesticides. An increase in the circulating acidity of the plants has here been conjectured to play a role in diminishing the general tendency to block parasite attacks.

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