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Process optimization in viticulture using functionalized biomimetic Hydroxyapatite (HAB) nanostructured particles, spectrographic analysis,and drone spraying systems

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Abstract. Today's agriculture must find increasingly innovative technological solutions with a perspective of conservation agriculture with systems that have less and less environmental impact by means of automatic control instruments for the distribution of products and the monitoring of site-specific ecological-environmental parameters. Since the symptoms of a disease attack vary depending on the nature of the pathogen and certain optical characteristics allow the development of imaging techniques for diseases detection, the plot monitoring allows to distribute the dose of product deemed suitable for the different areas into which it is divided: it is carried out by drones that, through multi-spectral analysis and specific artificial intelligence algorithms, make it possible to choose the appropriate doses of products to treat the disease at its onset or to prevent it. Processes can thus be optimised by spraying at variable rates in the quantities required at the time when pathologies are detected in order to intervene promptly for their treatment or containment. The use of these technologies allows a further reduction in Cu utilisation, compared to what was exposed at the 43° congress, thanks to applications with functionalised HAB: the timely and precise intervention suggested by the algorithms reduces the use of Cu to the bare minimum, the water consumption, the precision spraying with drones, the amount of product, its dispersion in the environment and the treatment time, safeguarding the health of the operator.

1 The problem – State of the art

In the last century, the exponential increase in world population has necessitated extensive land use, mainly due to intensive farming. The latter is one of the main causes of global environmental pollution due to the massive use of fertilisers and pesticides.

Soil depletion has caused the overuse of fertilisers and pesticides to ensure constant crop growth. As a result, the massive use of fertilisers and pesticides has become a major cause of soil pollution, further exacerbating the problem. In particular, many crops, especially viticulture, require the use of plant protection products to prevent or treat plant diseases caused by fungi, cryptogams or other pathogens.

Figure 1. Example of intensive farming.

Farmers have always endeavoured to interpret empirically observed interactions between soil conditions and weather events with crops, attempting to manageyield-dependent inputs.

Today's agriculture must therefore identify more and more innovative technological solutions with a view to conservative agriculture that adopts systems with less and less environmental impact with the use of automatically controlled instruments for the distribution of products and the monitoring of site-specific ecological-environmental parameters. The situation is aggravated by climatic variability, in particular the increase in temperatures, resulting in the destabilisation of plant-soil balances and the increasingly reduced permeability of the soil, which favours the phenomenon of erosion: this makes land management increasingly delicate. In recent years, developments in agricultural mechanisation have generated major engineering challenges towards sustainable approaches. The introduction of unmanned aerial systems (UAS) is growing in several agricultural operations, such as precision spraying applications of biostimulants and/or plant protection products (PPP). In

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particular, we consider it imperative to use a UAS with a dedicated spraying system, with the aim of reducing spray drift and improving the efficiency of vineyard operations.

Since the symptoms of a disease attack vary depending on the nature of the pathogen, and certain optical characteristics allow the development of imaging techniques for disease detection, plot monitoring allows the distribution of the dose of product deemed appropriate for the different areas into which it is divided: this is carried out by drones that, through multispectral analyses and specific artificial intelligence algorithms, make it possible to choose the appropriate doses of products to treat the disease as it occurs or to prevent it. Reflectance, the spectral imprint of vegetation, defined as the ratio of the intensity of reflected radiation to that of incident radiation, makes it possible to optically estimate the physiological state of plants based on variations in the incidence of light on their tissues: each constituent of the plant tissue absorbs incident radiation in specific spectral bands, modifying the spectrum of the reflected fraction according to the concentration with which it is present in the plant. Reflectance thus provides information on the nature and concentration of the constituents of the plant tissue, being linked to the chlorophyll content: rapid monitoring of leaf reflectance allows the calculation of vegetation indices that can be correlated with various aspects of the plant's phytosanitary state, such as nutritional stress, water stress and pathogen attack. Since pathological symptoms vary depending on the nature of the pathogen and its evolutionary state, optical disease detection systems can be developed. The variation in characteristics (reflectance, fluorescence and thermal radiation) allows the reactions of the leaf tissue to be detected in a timely manner in relation to pathogen attack. In this way, processes and interventions can be optimised, spraying at variable rates in the necessary quantities at the time when diseases are detected in order to intervene promptly for their treatment or containment. Without prejudice to this principle, copper and sulphur, at least for viticulture, still play a very important role as anti-cryptogamists. Although they are essential for crop growth, they can become toxic, harmful and irritating to humans. In fact, traditional methods of administration can cause uneven distribution of chemical species and generate areas of high concentration that cause side effects. In particular, traditional copper species tend to accumulate and become harmful to natural soil microfauna, plants and consequently the entire ecosystem(including humans).

Main advantages with the use of Cu e S: relatively high toxicity to plant pathogens, low cost, low toxicity of Cu compounds to mammals, their chemical stability and long-lasting residual effects.

Main disadvantages with the use of Cu e S: phytotoxicity, development of Cu-resistant bacterial strains, soil accumulation and negative effects on soilbiota and food quality parameters. It is important to emphasise bioaccumulation in soils: copper is neither metabolised nor degraded and tends to accumulate in the soil. It turns out that copper compounds formed in soils are transported by rainwater polluting groundwater. In addition, copper has shown toxicity towards microorganisms in the soil; this leads to demineralisation of soils (bacterial colonies are suppressed and thus cannotmineralise organic compounds and nitrogen fixation is limited). For all these reasons, the EU over the years is increasingly reducing the amounts of copper permissible in soils. At the end of 2018, the European Commission decided to set the maximum amount of copper at 4 kg perhectare. Nevertheless, even today, agriculture, and viticulture in particular, is heavily dependent on copper, and solutions must be found.

The development of an early detection system for the disease(s) would help to prevent its spread, limit productivity losses and assess the degree of phenolic ripeness of grapes.

This technology allows the acquisition of large quantities of images necessary for the refinement of artificial intelligence algorithms to automate and optimise activities in complex scenarios, with robust route planning and navigation control thanks to innovative modelling of the vineyard 3D point cloud. With index analysis, using drones with multispectral cameras, georeferenced maps can be created by index, the processed data of which allow process optimisation, and the identification of limited areas that need specific treatments, the detection of vineyard damage and the creation of maps of hydraulic stress, and diseases. High- resolution visual and multispectral imaging processes are also possible in order to identify the occurrence of plant diseases. For the purpose of effective monitoring, one could envisage the acquisition of a data set consisting of surveys carried out with adequate frequency on the same plot.

This data set can be used to train a neural network capable of recognising the onset of a disease, enabling a sudden and targeted intervention to avoid compromising the harvest and/or at least minimise losses.

The use of these technologies allows for a further reduction in Cu use, compared to what we presented at the 43rd Congreso Mundial held in Ensenada, thanks to applications with functionalised HABs: the timely and precise intervention suggested by the algorithms further reduces Cu use to the bare minimum, water consumption, precision spraying with drones, the quantity of products, their dispersion in the environment and treatment times, while also safeguarding the operator's health. This precision viticulture is based on the realisation that there are many environmental and non-environmental factors that determine significant physiological changes in the vine, with considerable repercussions on grape production in terms of yield and quality.

1.1 Precision farming

Precision farming is the application of technologies and principles to manage the spatial and temporal variability associated with all aspects of agricultural production in order to improve crop performance, environmental quality (Pierce&Nowak 1999) and enhance the sustainability of food production(Gebbers&Adamchuk 2010).

Spatial variation in crop performances can be caused by soil as well as diseases, weeds, pests and previous soil management, while variability over time results from previous years' crop management, as well as changing environmental conditions in the production year (Gebbers&Adamchuk 2010). In precision agriculture, it is important to study and develop methods to apply a given treatment in the right place at the right time. According to Pierce&Nowak (1999), the objectives of precision agriculture are:

- Optimise the use of available resources to increase the profitability and sustainability of agricultural operations.
- Reducing the negative environmental impact.

- Improving the quality of the working environment and the social aspects of agriculture, livestock farming and relatedprofessions.

The application of a treatment can be performed with:

- Variable dose distribution of the product by varying the flow rate of the distribution system according to specific needs at various points in the plot.
- Patch distribution or patch-sprying by spraying the product only where necessary.

Increasingly felt in the agricultural sector is the responsibility related to global population growth and increasing food production needs. In particular, the concept of Precision Agriculture (PA) is becoming increasingly important due to the fourth agricultural revolution and advances in technology. With regard to environmental protection, PA focuses on the reduced availability of natural resources and the causes ofchemical resistance. Especially with the increase in agricultural machinery, the level of pollution tends to increase, so optimising agricultural operations is crucial. At the same time, the technological evolution of agricultural machinery and communication systems makes it possible to increase the level of automation in complex environments with sustainable agriculture: unmanned aerial systems (UAS) are now combining with conventional machines, helicopters or human operators for certain automatic operations. Since the advent of agricultural spraying, a crucial challenge is the problem of drift (i.e. sprayed pesticides missing the target), which is becoming very important for risk assessment of spraying processes.

Leaf reflectance monitoring correlates with vegetation indices for the assessment of plant phytosanitary status, such as nutritional and water stress, and pathogen attacks. In particular, the concentration of N is closely related to the concentration of chlorophyll, which influences the reflectance of the canopy in the green (560 [nm]) and near-infrared (800÷810 [nm]) wavelengths according to an interaction between light and plant. These reflectance monitoring techniques can be conducted by multispectral or hyperspectral cameras installed on drones.

1.2 Vegetation indices NDVI

Plants in forest, agricultural and urban environments can be subjected to a wide range of stresses due to biotic (such as attacks by fungi, insects, nematodes, bacteria, viruses, phytoplasmas) or abiotic (such as drought, pollution, salinity, mechanical injuries, sunburn, frost) causes as well as their multiple synergies and interactions. The effects of an altered state of health can be found at the physiological level as well as at the morphological level; in both cases, the characteristic reflectivity of the healthy individual undergoes more or less marked changes. For example, a symptomatology involving a decrease in chlorophyll level, chloroplast disruption and yellowing of leaves will be evidenced in the spectral signature graph by a shift of the peak in the visible band, from green to red wavelengths, and a progressive shift towards lower wavelengths of the red edge. But before symptoms manifest themselves in the visible, they should show up in the near-infrared band with a decrease in reflectance, which will continue to decrease with the progressive worsening of symptoms. The NIR reflectance of leaves is in fact more susceptible to change than the VIS reflectance, being particularlysensitive to the water content of leaf tissue.

Figure 2. Multi-spectral analysis.

1) Atmospherically Resistant Vegetation Index

$$\frac{nir - red - y(red - blue)}{nir + red - y(red - blue)}$$

2) Atmospherically Resistant Vegetation Index 2

$$-0.18+1.17\frac{nir-red}{nir+red}$$

3) Canopy Chlorophill Content Index

$$\frac{\frac{NIR - rededge}{NIR + rededge}}{\frac{NIR - RED}{NIR + RED}}$$

4) CASI NDVI

$$\frac{((770{:}780) + (784{:}790)) - ((655{:}665) + (676{:}685))}{((770{:}780) + (784{:}790)) + ((655{:}665) + (676{:}685))}$$

5) CASI TM4/3

$$\frac{(770{:}780) + (784{:}790)}{(655{:}665) + (676{:}685)}$$

6) Cellulose Absorption Index

$$100(0.5(2031nm+2210nm)-2100nm)$$

7) Cellulose Absorption Index 2

$$0.5(2020nm+2220nm)-2100nm$$

8) Chlorophyll Absorption Ratio Index

$$\left(\frac{700nm}{670nm}\right)\frac{\sqrt{(a670+670nm+b)^2}}{(a^2+1)^{0.5}}$$

9) Chlorophyll Absorption Ratio Index 2

$$\left(\frac{|(a-[670]+[670]+b|}{(a^2+1)^{0.5}}\right)\left(\frac{|700|}{|670|}\right)$$

10) Chlorophyll Green

$$\left(\frac{[760:800]}{[540:560]}\right)^{-1}$$

11) Chlorophyll Index RedEdge 710

$$\frac{750nm}{710nm} - 1$$

12) Chlorophyll Red-Edge

$$\left(\frac{[760:800]}{[690:720]}\right)^{-1}$$

13) Chlorophyll Vegetation Index

$$\mathrm{NIR}\,\frac{RED}{GREEN^2}$$

14) Crop Water Stress Index

$$\frac{C-A}{B-A}$$

15) Green Leaf Index

$$\frac{2GREEN-RED-BLUE}{2GREEN+RED+BLUE}$$

16) Leaf Chlorophyll Index

$$\frac{[850]-[710]}{[850]+[680]}$$

17) MCARI/MTVI2

$$\left(1.5\,\frac{1.2(800nm-550nm)-2.5(670nm-550nm)}{\sqrt{(2800nm+1)-(6800nm-5\sqrt{670nm})-0.5}}\right)$$

18) Normalized Difference 800/680 Pigment Specific Normalized Difference A2, Lichtenthaler Indices 1, NDVIhyper

$$\frac{800nm-680nm}{800nm+680nm}$$

19) Normalized Difference NIR/Red Normalized Difference Vegetation Index, Calibrated NDVI – CDVI

$$\frac{NIR-RED}{NIR+RED}$$

20) Normalized Difference Nitrogen Index

$$\frac{log\left(\frac{1}{1510nm}\right)-log\left(\frac{1}{1680nm}\right)}{log\left(\frac{1}{1510nm}\right)+log\left(\frac{1}{1680nm}\right)}$$

21) Normalized Difference Vegetation Index 690-710

$$\frac{NIR-[690:710]}{NIR+[690:710]}$$

22) Ratio of WI and Normalized Difference 750/660

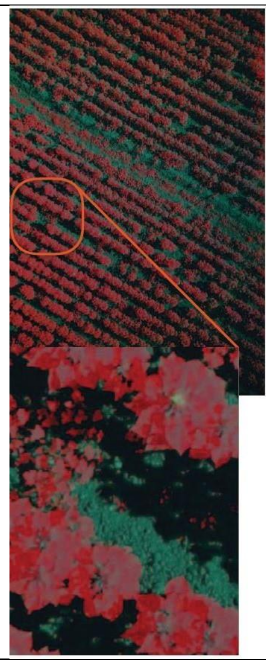
$$\frac{\frac{900nm}{970nm}}{\frac{750nm-705nm}{750nm+705nm}}$$

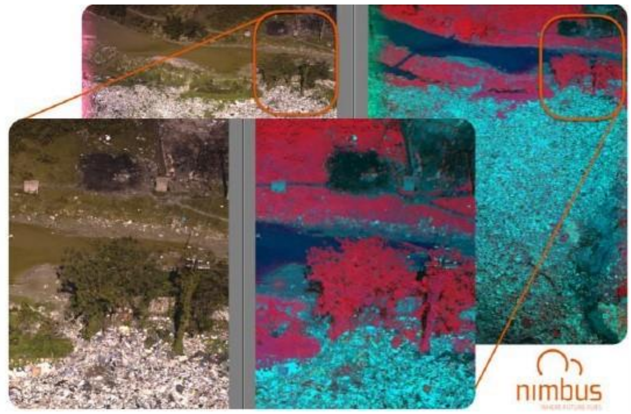
1.3 Multispectral camera and spectral indices

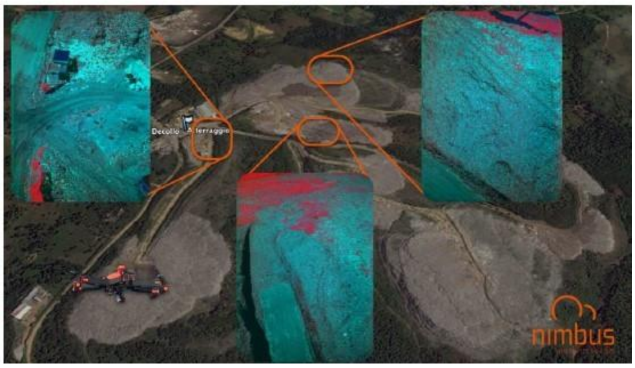
The sensor allows eight images to be obtained with one click, seven of them relating to spectral reflectances and one complete photo in the visible (RGB). Furthermore, it is possible to modify the centring of the various bands in order to obtain spectral data at different wavelengths from those indicated (always in the 300nm÷1000nm range), which are optimised for the evaluation of the vegetativity or vitality index known as

NDVI. By varying the centring of the bands it is possibleto calculate other types of indices.

Multi-spectral camera with spectral sensitivity from UV (≃300 [nm]) to IR (≃1000 [nm] NIR)		
1	350 [nm]	Spectral Reflectance UV
2	450 [nm]	Spectral Reflectance BLUE
3	550 [nm]	Spectral Reflectance GREEN
4	650 [nm]	Spectral Reflectance RED
5	750 [nm]	Spectral Reflectance NIR1
6	850 [nm]	Spectral Reflectance NIR2
7	950 [nm]	Spectral Reflectance NIR3
Radiometric accuracy > 95%		

Multi-spectral	NDVI
	





2 Research – Nanostructured particles in organic farming / Ude of active ingredients / Drone spraying and spectral analysis

In order to reduce the anthropogenic impact on the environment by reducing the amount of plant protection products and fertilisers, research today aims at the 'slow release' approach, which allows for a reduction in the amount of copper in the dosage. This approach involves the use of delivery systems able to release the fungicidal species slowly and only when necessary, always ensuring low concentrations and homogeneous distributions: todayit is possible to automatically identify plants affected by pathogen through a predictive model able to analyze images collected with footage taken by drones. This would allow early and targeted intervention on plants identified as diseased, using a quick and convenient means of taking pictures. In this way, excessive concentrations, typical of traditional products, which normally poison the soil, can be avoided. The intensification of our research, spurred on by the disorientation of organic wineries due to the continuous restrictions on the use of Cu, has allowed us to successfully experiment with the use of natural active ingredients in minimal quantities, such as essential oils of orange, grapefruit and others, using HAB, an edible material as a carrier, which greatly increases the efficiency. Another peculiarity of this technology is the long permanence of the active ingredient on the plant due to the non-washable carrier (HAB) which, due to its nanometric dimensions, can enter from the leaf stomata directly into the lymph fluids. Foliar spraying by means of drones must be able to rely on an extremely efficient active ingredient with immediate and prolonged action, as it happens with active ingredients having HAB as a carrier, whose dispersion in the air does not create ecological and environmental problems as it is a compound that is completely edible for humans and a calcium supplier for the soil.

In parallel to this research, a more efficient use of fertilisers could be investigated in order to improve crop performance, environmental quality and sustainable production: thanks to spectrometric techniques that allow the assessment of N status by means of spectral reflectance measurements of leaves, could introduce a dynamic fertiliser management for nutrient delivery.

For this purpose, the use of nanostructured particles was investigated. In 2008, the effect of nanostructured copper particles was tested; unfortunately, these also proved toxic. More recently, a particular formulation of hydroxyapatite (HA) and Cu (II) particles has been investigated. Hydroxyapatite is a mineral whose chemical composition is Ca10(PO4)6(OH)2, part of the apatite group, and its crystals have the shape of a very thin hexagonal prism. Hydroxyapatite is also produced and reabsorbed by organic tissues: in fact, it is one of the main components of bones.

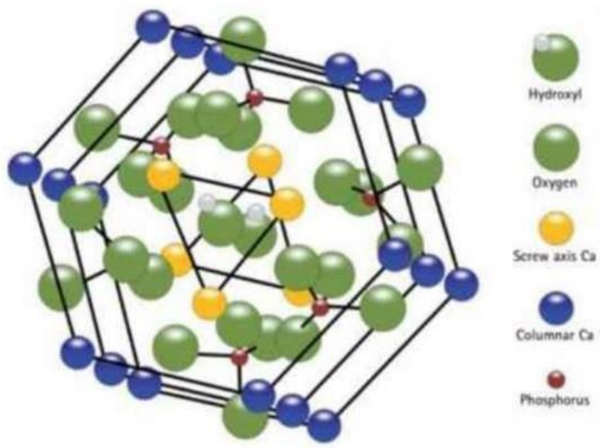


Figure 3. Example of Hydroxyapatite structure.

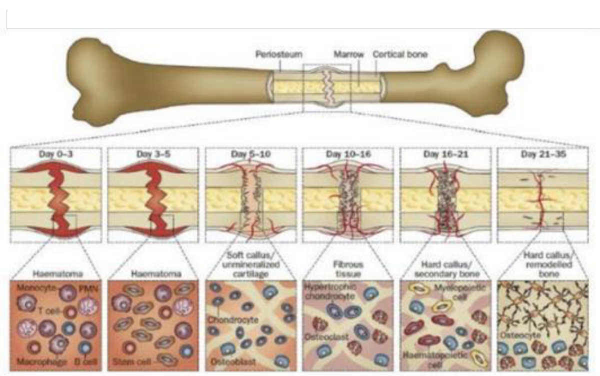


Figure 4. Hydroxyapatite in bones.

This is why it is a biocompatible and completely non-toxic material. The hydroxyapatite used in this study proved to be an excellent vehicle for treatment of crops.In fact, this material has drug delivery properties. This means that it is capable of carrying active ingredients within the circulatory systems of any living organism, primarily plants.

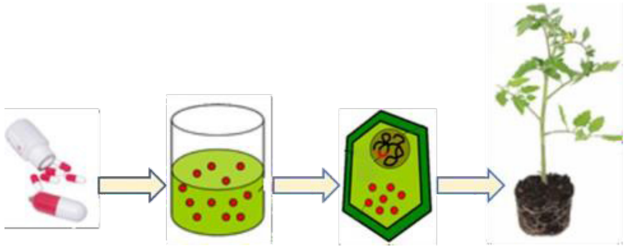


Figure 5. NPs *drug delivery* scheme.

To date, we have studied the use of nanostructured particles, in particular hydroxyapatite. In fact, this mineral has demonstrated excellent properties as a delivery system in agriculture, both for plant protection products and for the delivery of micro and macro elements necessary for plant growth. Moreover, biomimetic hydroxyapatite, as it simulates the structure of that found in living beings, is completely non-toxic and biocompatible. In this scenario, we present an innovative approach of delivering micro and macro elements using nanostructured biomimetic hydroxyapatite particles. These particles are functionalised with various micro and macro elements that support plant growth, prevent diseases and can treat pathogenic principles. Experiments have shown that this formulation allows the use of a lower dose of copper and sulphur than traditional products (up to 1/7). This, in turn, requires less water and thus reduces the environmental impact of vineyard treatments.

In this particular nanoparticle emulsion formulation, hydroxyapatite can be used as a nutrient and drug carrier. Conversely, foliar products on the market often contain high dosages; moreover, users are advised to use excess quantities, as these are water-soluble products that are easily washed away by rainfall, thus becoming ineffective for treatment purposes, but very dangerous for the environment. It is also known that some foliar products, while solving the plant's problems, cause a variation in the pH of the soil and the plant itself with consequent negative effects. One of the main problems associated with the use of these products for plants concerns water and soil pollution. A particularly important problem is their accumulation in the soil and groundwater. This problem has repercussions not only on the soil, but also on the food derived from it and thus on man.

2.1 Vine mycorrhization tests and effects on productivity and quality

Examination of the electromagnetic spectrum of the leaf is a fundamental method for assessing the bioactivity of plants, which is to be understood as vigour of the vegetative state, as a predictor of production or as an indicator of abiotic (water, heat) or biotic (infections, infestations) stresses. A spectral signature can be recognized using the NIR rays reflected by the leaves, each agronomic experiment having a "terrestrial" and a "celestial" leaf aspect: the EU is investing large sums to bring the satellite information to agronomic use, in particular those of Sentinel-2 that returns every 5 days a ghostly knitted image of 10 meters. Precision farming and 4.0 is based on servomechanised ground sensors and generally makes use of georeferenced satellite maps to advise - or materially guide - precision crop operations. A singular fact is the appearance of a strong difference between the years with a very pronounced upward trend: from Fig. 2.1.1 it can be seen that the 2018÷22 trend is well in line with the sunspot cycles that are proportional to the amount of UV radiation hitting the earth.

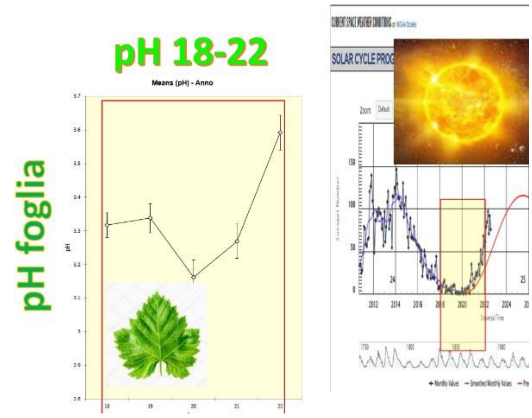


Figure 6. Increasing trend of foliar pH in vineyards from 2018 to 2022 in parallel with rising sunspot numbers of the 25th cycle.

Leaf pH also appears to be negatively related to polyphenolic maturity.

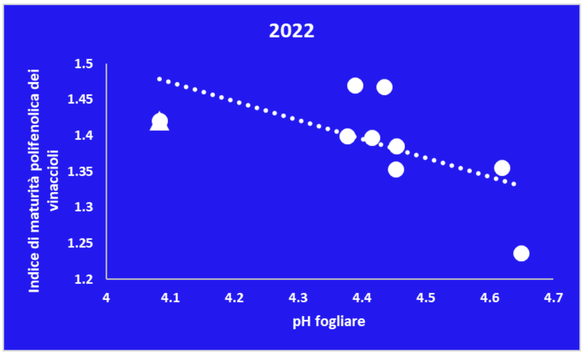


Figure 7. Trend in polyphenolic maturity index versus leaf pH of red grape varieties in 2022.

2.2 Quality of grapes

In order to choose the most propitious time to harvest, two components proportional to ripeness must be monitored:

i. **Technological Maturity [TM]**: it depends on berry pH and sugar levels, two components directly proportional to ripeness:

Technological Maturity index TM = pH^2*°Brix

ii. **Polyphenolic Maturity (PM)**: it depends on the amount and type of polyphenols present in the skin and in the pips whose most significant index is:

Polyphenolic Maturity index PM = [Non Extractable Polyphenols]/[Extractable Polyphenols]

Remarks:

- The PM Index takes into account the progressive polymerisation of the polyphenols present in the seed, a fundamental characteristic related to the woodiness and astringency of the seed, which is perceived during subsequent sensory evaluations in the vineyard. The rapid PM measurement is based on a spectral model from which rapid PM predictions are obtained from the NIR spectra of the grape seeds;

- With regard to Technological Maturity, there are no particular measurement problems that cannot be solved in the company;
- The NIR spectrum of leaves, being a mine of information on vine activity, also contains information on PM. Indeed, a development in rapid grape-seed analysis has correlated Nebbiolo leaf spectra to PM, apparently making it possible to use satellite data for simplified and direct prediction.

2.3 Vine mycorrhization with wool burial

The mycorrhization trial involved three red varieties, Bonarda (B), Freisa (F) and Malvasia (M) (Fig. 8) and two white varieties, Arneis (A) and Cabernet Sauvignon (C).

Figure 8. Localisation of the Mico test for the three red varieties. Treated 10 rows (60 plants) with 20 Mycosat + Wool and Control treatments.

The distribution of the preparation Mycosat F-Vine was carried out in one go in the period 5÷7 April 2022 ata dose of 20 [kg/ha] (material cost 600 [€/ha]). The operation turned out to be simple and expeditious having previously diluted the granular preparation to 5% in a mass of Compost.

For the inoculation treatment a CP electronically controlled Precision Fertiliser Machine in 4.0 technology was used.

A further soil treatment, performed by hand, buried 100 [g/m] greasy wool, previously sterilised with ozone, on half of the plants checked with litterbags and already inoculated with Mycosat (Mycosat + wool = ML). The treatment took place shortly after the passage of the precision fertiliser. Subsequently, the litterbags were buried for 60 days. In the course of the trial, leaves were collected for pH and NIRS analysis, in three replicates. Grape samples were collected in two steps to determine pH, BRIX (calculation of the technological index pH^2*BRIX), NIR- SCIO spectra of skins and seeds from samples of 10 berries repeated 3 times. Production was measured on samples of plants placed at the litterbags (N = 3 red grape varieties * 2 treatments * 6 = 36 plants).

2.3.1 Results - Leaves

Leaf pH is lowered by 1.7%, on average, in all vines following treatment (Table 1). This result confirms numerous results obtained on vines, other plants and trees:

Table 1. NIRS results and foliar pH in fine vines treated with Micosat.

Grapevine	1_Arneis	2_Cabernet Sauv	3_Bonard	4_Freisa	5_Malvasia	
N	56	64	292	224	170	806
1-VR	0.59	0.18	0.02	0.45	0.56	
P	<.00001	0.0005	0.015	<.00001	<.00001	
pH-Check	3.88	4.02	3.85	4.06	3.74	3.91
pH-Micosat	3.82	3.95	3.78	3.98	3.69	3.84
Diff%	-1.5	-1.7	-1.9	-1.9	-1.3	-1.7
P						0.021

1-VR=r-square coefficient in validation, indicates how different the normal control leaves are from those treated with Mycosat.

The NIR spectra of the leaves of treated plants differed from the Controls (Table 2), but to a limitedextent in Bonarda (1-VR=0.02) and Cabernet Sauvignon (0.18), while differences appeared very strong in the other tested vines. The degree of the differences can be seen in the % classification of the ten groups compared (Table 2) where values ranging from 13% for Cabernet Sauvignon-M to 64% for Malvasia-M can be seen, but with a non-random trend. In fact, the % of classification decreases significantly where the differences were low (Cabernet from 46% to 13% and Bonarda from 41% to 15%) while it increases where the differences were strong (Arneis from 21% to 70% and Malvasia from 51% to 64%). Figure 9 shows the connection between the two parameters.

Table 2. Percentage of recognition of NIR leaf spectra of the thesis Treated and Control in the five grape varieties of the Myco trial.

Grapevine	Treat.	N	% Correct	Ln (M/C)	P
1_Arneis	C	24	21%		
1_Arneis	M	47	70%	1.21	0.0021
2_Cab.Sauv.	C	24	46%		
2_Cab.Sauv.	M	48	13%	-1.30	0.0001
3_Bonarda	C	145	41%		
3_Bonarda	M	148	15%	-1.01	>0.0001
4_Freisa	C	126	55%		
4_Freisa	M	126	51%	-0.08	0.5255
5_Malvasia	C	102	51%		
5_Malvasia	M	97	64%	0.23	0.0645
TOTAL		**887**	**43%**		

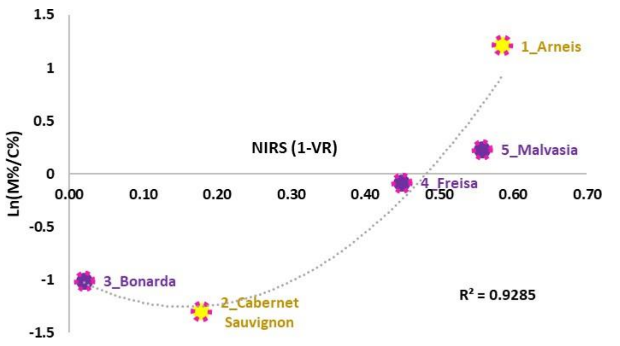


Figure 9. Variation in % classification between Mycosat and Control (ln(M%/C%) versus 1-VR coefficient in five grape varieties.

In summary, where treatment with Mycosat was able to strongly influence the plants to the point of changing the NIR spectrum of the leaves, which represents their chemical composition, it can be observed that the treated leaves are much more uniform and recognisable than the Control, which is more variable and less recognisable. In this sense, the treatment homogenised the leaves. Conversely, where the treatment had a weak effect (Bonarda and Cabernet) the opposite occurs, i.e. an increase in leaf variability is observed. In Freisa, where the 1-VR difference is zero the two classification percentages of C and M are not different.

So there is an acidification effect on the leaves in all grape varieties, but there are other treatment effects that change the chemical composition differently depending on the grape variety, with increased homogeneity (Arneis and Malvasia) or increased variability (Bonarda and Cabernet) or no change (Freisa).

2.4 Production

Following the fertiliser treatment, the number of grapes per bunch increased on average in Bonarda and Freisa (+3 to +6%), while it decreased by around 10% in Malvasia, resulting in an increase in the average bunch weight. Overall, the weight per plant increased significantly, albeit to a limited extent around +2÷+3% in Bonarda and Freisa, but not in Malvasia. The effect of wool does not appear in the production.

Grapevine Bonarda.

	Control	Micosat	Micosat+wool
No. grapes	21.63	23.03	22.77
	d	bcd	bcd
		+6%	+5%
Tot. weight [kg]	5.33	5.41	5.41
	c	b	b
		+2%	+2%
Av. weight [g]	246	235	238
	a	bc	abc
		-5%	-5%

Grapevine Freisa.

	Control	Micosat	Micosat+wool
No. grapes	22.19	23.02	22.83
	cd	bcd	bcd
		+4%	+3%
Tot. weight [kg]	5.32	5.45	5.47
	c	a	a
		+2%	+3%
Av. weight [g]	240	237	240
	ab	bc	abc
		-4%	-2%

Grapevine Malvasia.

	Control	Micosat	Micosat+wool
No. grapes	26.18	24.06	23.15
	a	b	bc
		-8%	-12%
Tot. weight [kg]	5.40	5.41	5.42
	b	b	b
		0%	0%
Av. weight [g]	206	225	234
	d	c	abc
		+11%	+16%

2.5 Quality

Treatment with Mycosat increased technological quality by 6% in Bonarda and 14% in Malvasia (Fig. 10).

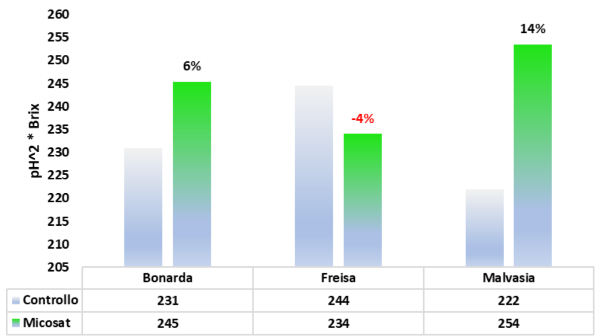


Figure 10. Trend in technological maturity (pH^2*BRIX) in the three red berry vines following treatment with Mycosat.

Treatment with Mycosat increased phenolic maturity measured at grape-seed level by 13% in Bonarda, 10% in Freisa and 4% in Malvasia (Fig. 11).

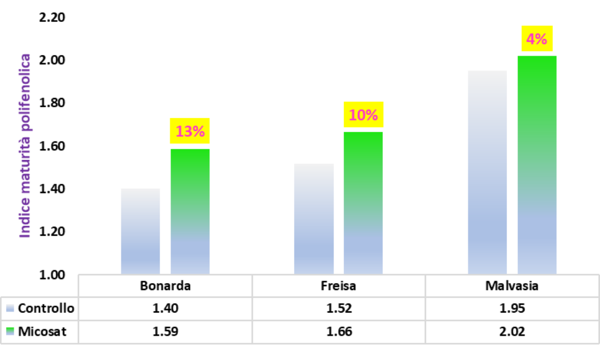


Figure 11. Trend in phenolic maturity (Non-Extractable Polyphenols / Grape-seed extractable polyphenols) in the three red berry vines following treatment with Mycosat.

2.6 Biodiversity

Finally, the same technique adopted above for measuring parameters with drones makes it possible to assess the microbial biodiversity of soils, a factor that conditions the quality of wine; it also makes it possible to detect and process with the drone the data provided by special sensors placed in the soil that measure sulphur and carbon enzyme activity: it is possible to intervene immediately with the spraying of HAB appropriately functionalised with enzymes. In fact, variation in crop performance can be caused by the soil as well as by diseases, pests, and previous soil management, while variability over time comes from previous years' crop management, as well as the changing environmental conditions of the production year. (Gebbers & Adamchuk).

3 Conclusions

The aggressive and rapid introduction into the market of aircraft commonly known as 'drones' usually based on cost-effective multi-rotor vehicles, has enabled the growth of affordable applications of UAVs and specifically UAVs in agriculture, especially in monitoring and precision intervention missions.

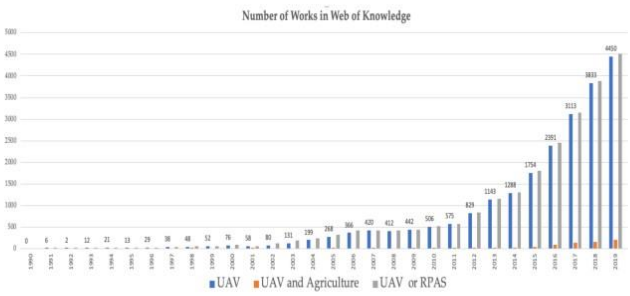


Figure 12. No. of papers on the WEB of drone and drone applications in agriculture.

So one can think of designing automatic solutions, as an alternative to the previous methodologies even if assisted by experienced people, with the help of trained algorithms and artificial intelligence techniques for sharing knowledge and expertise possibly on online platforms.

The use of spectrometers for the measurement of leaf reflectance at certain wavelengths allows an early relief of the nutritional stress of the plants thus allowing to intervene promptly and adequately with the use of minimum product quantities necessary: this results in a clear saving of both water and products.

The interaction between the vineyard and space technologies therefore makes the WineFood chain sustainable since the processing of data, such as the state of health of vegetation, soil moisture, the presence of pathogenic attacks, and multispectral analysis of the provided images allow to optimize the use of water and fertilizers, and the planning of interventions according to the conditions. To achieve this goal, the correlation between spatial resolution and temporal resolution is necessary, an approach necessary in agriculture for site-based managementcrop specification based on data acquisition and processing to regulate and translate field actions. The statistical approach applied to the processing of multispectral data allows to derive indicators of plant condition or to estimate biophysical parameters of crops. Today informations are available from multispectral images from satellites (e.g., Sentinel 2) with five-day frequency and resolution in the range 10 20 [m] which, if related to information processed by drones as described, allow you to make targeted choices to minimize the use of resources with the maximization of yield.

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