EXTENDED ABSTRACT

Soil incorporation of new superabsorbent hydrogels to improve vine tolerance to summer stress: physiological validation and vineyard applications

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Keywords: water stress, superabsorbent polymers, soil hydrology, vineyard establishment, water potential, photosynthesis

INTRODUCTION

Water scarcity is one of the main factors affecting yield and fruit composition. High evaporative demand in concomitance with reduced soil water availability affects grapevine physiology and thus the development of vegetative and reproductive organs (Stevens et al., 1995; Tomás et al., 2012). Impacts of such occurrence are even worsened in the case of young vines having a still limited root system with quite poor soil colonization capacity (Olmstead et al., 2012) organic production can be challenging, and weed management is a critical issue during the establishment of an organic vineyard. In 2009, the effectiveness of five cover crop treatments and cultivation regimes was evaluated for two years for weed control in a newly established organic vineyard of 'Pinot noir précoce' and 'Madeleine angevine' grape cultivars in northwestern Washington State. Alleyway management treatments were cultivation in alleyways with hand weeding in the vine row (control. In both rainfed or irrigated vineyards, abiotic stresses might reduce shoot growth, impair or delay permanent structures formation and training, and postpone cropping by years, turning into significant economic losses (Tomás et al., 2012).

Superabsorbent hydrogels are materials capable of absorbing and retaining significant amounts of water or solutions, compared to their relative mass. They are constituted by a network of polymeric chains rich in hydrophilic groups (Guilherme et al., 2015). According to their biochemical configuration they can absorb water by 9 to 400 times their specific weight (i.e. up to 400 mL water per g). Even though they have been industrially available for decades, in agriculture their use has been limited by cost and environmental concerns about the release of polyacrylamide in the environment (Crous, 2017)especially after transplanting as this water will enable the growth of new roots to facilitate nutrient and water uptake. Water absorbed by a hydrogel (superabsorbent polymer. This scenario has recently changed thanks to the realization of new acrylamide-free polymeric hydrogels, some of them entirely obtained by organic raw materials (ligno-cellulosic or starch-based byproducts), having also reduced manufacturing costs. At the same time, climate change pressures are increasing the interest of growers and technicians towards hydrogels functions (Piccoli et al., 2024). However, scientific literature about the effects of hydrogels on plants is currently very limited, especially concerning tree crops. Several reviews highlight the capability of hydrogels in changing soil water retaining properties and increasing plant survival under reduced or absent water supply. On the other hand, other authors point out concerns about the magnitude of the water absorbed in relation to plant evapotranspiration needs, especially those of tree crops, and argue if hydrogels make water available to plants, or if they compete with root systems for it (Crous, 2017)especially after transplanting as this water will enable the growth of new roots to facilitate nutrient and water uptake. Water absorbed by a hydrogel (superabsorbent polymer. Studies on olive and orange trees showed that hydrogels could help maintaining a less negative midday stem water potential and improve tree physiological performances. Data available agree on the soil application at transplanting as the most feasible implementation of hydrogels, considering daily evapotranspiration and root systems development of young and mature trees (Arbona et al., 2005; Chehab et al., 2017). Available literature provides no clues about efficacy of hydrogels at improving grapevine water status, physiological performance, and vegetative or reproductive development. The only work on the topic evaluated the interactions with different doses of applied fertilizers (Ali et al., 2023).

RESEARCH OBJECTIVES

The objective of this study was to evaluate the effects of two different superabsorbent hydrogels on soil hydrology and on grapevine physiological performances, when applied at transplanting. Our general hypothesis was that localized changes in soil hydrology could improve vine water status and vegetative performances, facilitating space filling on support wires hence shortening the duration of vineyard unproductive stages. Under a multidisciplinary approach, we combined tests on soil physical properties and studies on grapevine physiology under semi-controlled conditions and then in the field.

MATERIAL AND METHODS

Treatments layout

In this study, the three following treatments were compared: an untreated control (C); incorporation to the soil of a potassium polyacrylate based hydrogel (SH1); incorporation to the soil of a ligno-cellulosic hydrogel admitted under organic agriculture (SH2).

Soil hydrology

Samples of 5 g of a loamy sandy clay soil (three replicates per treatment) were prepared by adding hydrogels (2.5mg/g for SH1 and 23mg/g for SH2) and achieving full hydration status. Then, soil samples were weighed and immediately subjected to water potential (Ψ) measurement with a WP4C Dew Point PotentiaMeter (Decagon Devices, Pullman WA, USA). Operation was repeated multiple times after keeping samples at 30°C and 45% RH for 10 min, until full dehydration was achieved. Correlations between SH absorbed water and SH Ψ during the process were evaluated accordingly. For each sample, field capacity was calculated as the water concentration after drainage, permanent wilting point as the water concentration at Ψ =-1.5MPa, and maximum available water as the difference between field capacity and wilting point.

Potted vines experiment

The experiment on potted vines was carried out in 2023 and 2024 in Piacenza, Italy. Fifteen one-year-old vines (*Vitis vinifera* L.) cv. Sangiovese clone VCR5/SO4 were planted in 55 L pots and assigned to the three treatments on 23/3/2023. Superabsorbent hydrogels were applied at 30g/vine for SH1 and 100g/vine for SH2. Vines were standardized retaining the two best shoots developing on each plant and removing the others. In the subsequent winter, vines were pruned retaining 10 buds on one of the two canes. In spring 2024, canopies were standardized retaining the 8 distal shoots on each vine, thinning the others.

Daily vine evapotranspiration (ET) was gravimetrically measured every week by weighting the pots at 24hour intervals. In both seasons, a progressive water deficit was imposed by reducing irrigation to 50% ET and then fully suspending the water supply until full stomatal closure was achieved on all vines. Then, full irrigation was resumed until the end of the season. Pre-dawn and midday stem Ψ were monitored during water deficit imposition in both years, leaf gas exchange parameters were concomitantly measured with an ADC LCi-SD (ADC bioscientific). After Ψ measurement, leaves were sampled for proline and hydrogen peroxide quantification.

In 2024, when grapes total soluble solids (TSS) reached an average of 20°Brix, all vines were harvested, yield was measured, and crop components were determined. Three clusters per vine were brought to the laboratory for determination of TSS, pH, titratable acidity (TA), organic acids, anthocyanins and phenolics determinations.

At the end of the second year, total leaf area was determined separately for main and lateral shoots, then biomass allocated above-ground and below-ground was quantified measuring fresh and dry weight of roots, trunk, two-year-old wood and one-year-old wood (separating main and lateral shoots) on each vine. Samples of each of the above-mentioned organs were collected for soluble sugars and starch analyses.

Field experiment

Sauvignon blanc grapevines grafted onto 1103Paulssen rootstock were planted on 12/4/2023 in a field parcel located at Prato Ottesola, Lugagnano Val d'Arda (PC), Italy and a section of the vineyard of 120 plants (5 rows of 24 plants each) was used. At transplanting, vines were assigned to the three treatments according to a RCBD layout, and SH1 and SH2 were added to the portion of soil comprised between 5 and 35 cm below the root systems, at doses of 30g/plant and 100g/plant respectively. In spring 2023, vines were standardized retaining the two best shoots developing on each plant and removing the others. In the subsequent winter, considering the low average canes diameter, all vines were pruned retaining 2 buds on one of the two canes. In spring 2024, plants were again standardized retaining the 2 best shoots.

In both years, main shoots growth was measured at varying intervals on each vine during the season. In specific hot days during the summer, leaf gas exchange parameters were monitored on 15 vines per treatment, and pre-dawn and midday stem Ψ were measured with a Scholander pressure chamber. After Ψ measurement, leaves were sampled for metabolites quantification.

In both years, at the end of the season, the number of dead vines per treatment was counted, then vine leaf area was determined on each vine separately for main and lateral shoots. Before pruning, 3rd internode diameter was measured on each vine, then the internode was sampled for soluble sugars and starch analysis. Pruning weight was determined on each vine separately for main and lateral shoots.

RESULTS

Changes in soil hydrology

The two tested SH affected soil hydrology, increasing field capacity and wilting point. However, in both SH1 and SH2, the increase in field capacity was proportionally higher than that of the wilting point and, consequently, maximum plant available water was significantly increased in SH1 and SH2 as compared to the C soil. Moreover, both SH1 and SH2 changed the correlation between instantaneous soil water concentration and soil Ψ, with a significantly higher amount of water made available for soil Ψ < -1.5MPa.

Potted vines experiment

Under full irrigation, midday stem Ψ remained comparable between treatments in both years (Fig.1A and 1B). In 2023, after the reduction of irrigation to 50%ET, stem Ψ decreased in C vines passing from -0.43MPa to -0.64 MPa (Fig. 1A), while in SH1 and SH2 it remained significantly higher (-0.31MPa on DOY212 and -0.49MPa on DOY214, pooling SH treatments). When irrigation was fully suspended, in all treatments stem Ψ dramatically decreased, but in SH1 and SH2 stem Ψ was again higher than in C vines (-1.25MPa pooling SH1 and SH2, *vs* -1.5 MPa in C). In 2024, stem Ψ decreased significantly as irrigation was reduced to 50%ET, due to the larger canopy size and increased vine transpiration losses (Fig. 1B). However, the difference between treatments was similar, with SH1 and SH2 displaying higher stem Ψ than C vines (+0.27 and +0.20MPa, respectively, on DOY182). Leaf photosynthetic rates tracked vine water status in both seasons, with SH1 and SH2 showing consistently higher leaf A than C under reduced or null irrigation, and a better resumption of leaf gas exchange parameters at rewatering. Interestingly, while in 2023 (Fig. 1C) at the end of the experiment SH1 was showing the highest leaf A (+9μmolm^{-2}s^{-1} than C), in 2024 (Fig. 1D) SH2 had higher post-rewatering photosynthetic rates than SH1 (+8μmolm^{-2}s^{-1} than C). Overall, the improved leaf physiology after rewatering is likely an effect of the higher leaf F_v/F_m ratio found in SH treatments in both years. SH1 and SH2 showed higher leaf WUE than C for stem Ψ ranging between -0.8MPa and -1.2MPa (Fig. 1E and 1F).

In 2024, SH1 and SH2 vines had higher vine leaf area at harvest due to a more abundant emission of lateral shoots. SH1 and SH2 had significantly higher vine yield than C (+55% and +59%, respectively), due to higher shoot fruitfulness (+2clusters/vine), cluster weight (+29% in SH1 and +31% in SH2), and berry mass (+0.3g/berry) (Table 1). Leaf area-to-fruit ratio was significantly lower in SH1 and SH2 vines, since the increase in yield was proportionally higher than the increase in lateral shoots leaf area. Consequently, SH1 and SH2 showed lower TSS at harvest than C (-2.0 and -2.2°Brix respectively).

Field experiment

No differences between treatments in terms of shoot growth were observed in 2023. SH1 and SH2 had a slightly higher pre-dawn Ψ (-0.20 and -0.21MPa respectively) than C (-0.27MPa), while no difference was found in midday leaf Ψ. At the end of the season, the vine leaf area was higher in SH1 (0.62m^2/vine) and SH2 (0.63m^2/vine) vines than in C vines (0.52m^2/vine), again due to more lateral shoots. SH1 had also higher pruning weight (131g/vine). In 2024, shoot growth rate between DOY184 and 214 was significantly higher in SH1 and SH2 vines (2.38 and 2.76cm/d), than in C vines (1.81cm/d). In November 2024, 4 dead vines were counted in C, one dead vine in SH1, and no dead vines were found in SH2.

CONCLUSIONS

In a near future, the soil application of hydrogels could represent a game-changing tool in the adaptation of agriculture to climate change. Our work demonstrates that new hydrogels can be used to locally control soil hydrology and improve vine tolerance to water deficit after transplanting, thus reducing vine mortality and accelerating the transition towards full crop production. Although studies in relation to different soils and pedoclimatic conditions are needed, this work paves the way for the implementation of the technique in vineyards.

ACKNOWLEDGEMENTS

This work was funded by the EIP-AGRI IN+VITE ‘New technologies for reducing vineyard inputs and for improving the sustainability of viticulture’ project, PSR Emilia-Romagna Meas. 16.1 FA4B, call 2022, proposal n. 5517720.

REFERENCES

Ali, M. A., Farag, S. G., Sillanpää, M., Al-Farraj, S., and El-Sayed, M. E. A. (2023). Efficiency of Using Superabsorbent Polymers in Reducing Mineral Fertilizer Rates Applied in Autumn Royal Vineyards. Horticulturae 9. doi: 10.3390/HORTICULTURAE9040451

Arbona, V., Iglesias, D. J., Jacas, J., Primo-Millo, E., Talon, M., and Gómez-Cadenas, A. (2005). Hydrogel substrate amendment alleviates drought effects on young citrus plants. Plant Soil 270, 73–82. doi: 10.1007/S11104-004-1160-0/METRICS

Chehab, H., Tekaya, M., Mechri, B., Jemai, A., Guiaa, M., Mahjoub, Z., et al. (2017). Effect of the Super Absorbent Polymer Stockosorb® on leaf turgor pressure, tree performance and oil quality of olive trees cv. Chemlali grown under field conditions in an arid region of Tunisia. Agric. Water Manag. 192, 221–231. doi: 10.1016/J.AGWAT.2017.07.013

Crous, J. W. (2017). Use of hydrogels in the planting of industrial wood plantations. South. For. a J. For. Sci. 79, 197–213. doi: 10.2989/20702620.2016.1221698

Guilherme, M. R., Aouada, F. A., Fajardo, A. R., Martins, A. F., Paulino, A. T., Davi, M. F. T., et al. (2015). Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review. Eur. Polym. J. 72, 365–385. doi: 10.1016/J.EURPOLYMJ.2015.04.017

Olmstead, M., Miller, T. W., Bolton, C. S., and Miles, C. A. (2012). Weed Control in a Newly Established Organic Vineyard. Horttechnology 22, 757–765. doi: 10.21273/HORTTECH.22.6.757

Piccoli, I., Camarotto, C., Squartini, A., Longo, M., Gross, S., Maggini, M., et al. (2024). Hydrogels for agronomical application: from soil characteristics to crop growth: a review. Agron. Sustain. Dev. 2024 442 44, 1–23. doi: 10.1007/S13593-024-00958-4

Stevens, R. M., Harvey, G., and Aspinall, D. (1995). Grapevine growth of shoots and fruit linearly correlate with water stress indices based on root-weighted soil matric potential. Aust. J. Grape Wine Res. 1, 58–66. doi: 10.1111/J.1755-0238.1995.TB00079.X

Tomás, M., Medrano, H., Pou, A., Escalona, J. M., Martorell, S., Ribas-Carbó, M., et al. (2012). Water-use efficiency in grapevine cultivars grown under controlled conditions: effects of water stress at the leaf and whole-plant level. Aust. J. Grape Wine Res. 18, 164–172. doi: 10.1111/J.1755-0238.2012.00184.X

TABLES AND FIGURES

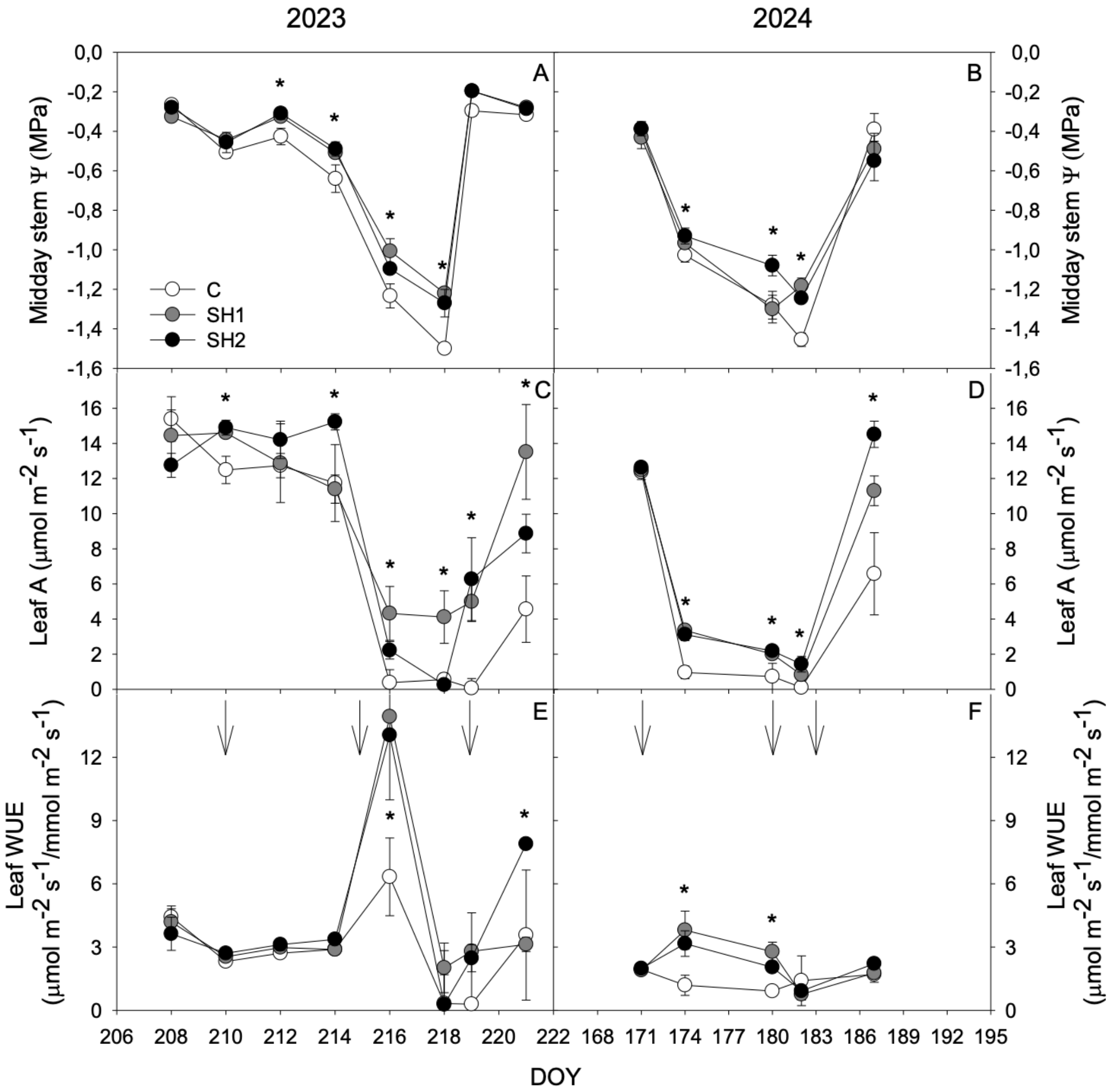

Figure 1. Seasonal trend of midday stem water potential Ψ (panels A and B), leaf photosynthesis (A) (panels C and D) and leaf water use efficiency (WUE) (panels E and F) in vines cv. Sangiovese according to pre-planting soil application of Superabsorbent Hydrogels. C: Untreated control; SH1: soil incorporation of a potassium polyacrylate hydrogel 30 g/plant; SH2: soil incorporation of a lignin sulfonate hydrogel 100 g/plant. Asterisks indicate significant difference between treatments per P<0.05. From left to right, arrows in panels E and F indicate the day of reduction of irrigation to 50%ET, the day water supply was fully suspended, and the day of rewatering, in 2023 and 2024.

Table 1. Yield and fruit composition in 2024 in vines cv. Sangiovese according to pre-planting soil application of Superabsorbent Hydrogels. C: Untreated control; SH1: soil incorporation of a potassium polyacrylate hydrogel 30 g/plant; SH2: soil incorporation of a lignin sulfonate hydrogel 100 g/plant.

Treatment	Yield (kg/vine)	Cluster weight	Berry weight	TSS	pH	TA
C	2.2 b	216 b	2.1 b	20.9 a	3.30	6.2
SH1	3.4 a	283 a	2.4 a	18.9 b	3.30	6.5
SH2	3.5 a	279 a	2.4 a	18.7 b	3.29	6.5
t	***	***	**	***	ns	ns

TSS= Total Soluble solids; TA= Titratable Acidity.
****,** and *** indicate significant difference per P<0.05, 0.01 and 0.005, respectively. ns= no difference.***
Different letters within columns indicate significant differences between treatments per P<0.05 (SNK test).