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Impact of different mulching practices on grapevine (*Vitis vinifera* L.) growth and soil properties

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Abstract

Taking sustainable viticulture measures is critical to successfully cope with the impact of ameliorating population and global climate change. Low rainfall and increasing temperature insist grapevine plants demand more water use. The ongoing drilling of underground consequences in the deep-water table. In this scenario, there are requirements for logical techniques to preserve soil water management and save water opportunities from depletion. Therefore, mulching practices become highly impactful techniques in the different areas for grapevine growth which include organic mulch for instance dry leaves, manure, compost, straw, sawdust, living grass, fabric, hairy vetch, and ryegrass, while inorganic much include gravels, crushed stones, carpets, scree, pebble, and plastics. High requirements of yield performance and competition in the market pushed horticulturalists to produce more grapevine plant quality. Because of global climate change rain design has been altered and water shortage. Additionally, mulching practices in grapevine crops can be applied as a soil preservation technique, regulate soil microbial biodiversity, soil characteristics, soil temperature (which changes in cold and summer seasons and leads to damage to grape cells), pest management, disease resistance, weed control, soil organic matter improve and performance of soil ecological functions. Furthermore, mulch acts as a biocontrol agent against grapevine fungal and bacterial pathogens. Despite, its promising application, challenges such as variability in mulch practices and their interactions with soil microbial carbon and crop systems need further study. This review consolidates the recent advancements in mulch research highlighting its practices, applications mechanism of action, disease resistance, and limitations while proposing future directions to optimize mulch for grapevine management. The insights presented aim to support the development of sustainable viticultural practices that enhance soil improvement, disease management, crop yield, development, and environmental resilience.

Keywords: Grapevine; Mulching Practices; Soil Properties; Soil Organic Matter; Disease Resistance; Nutrients

1. Introduction

Elevated competition for soil fertility, water and other possibilities like demand for grapevine yield, production, cultivation, and food security is rising due to the increasing population in the world [1]. Half of the global tillage is below arid and semi-arid areas and plays a role in overcoming the world grapevine food security-related problems. Almost 65-75% of the global yield is cultivated from non-irrigated areas [2]. The irregular climate change scenario and global warming are responsible for the scarcity of water resources that inhibit sustainable viticulture in arid and semi-arid areas. Therefore, it is important to ameliorate grapevine growth, development, yield, quality, production, cultivation, and stable farmer incomes by different horticultural management practices to increase food quality processing [3].

Incorporating different viticultural practices not only enhances the water use efficiency but also improves plant soil ecology and development and limits weed growth, water filtration, soil erosion, and preserves soil humidity,

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temperature, moisture, and management [4]. For sustainable agriculture, it is essential to adopt orchard management practices not only for high crop yield but also ecofriendly environment. Different horticultural practices such as mulching, tillage, and a combination of both are essential for vineyard management practices in the different ecological regions. Additionally, mulching is the technique of covering the soil profile with different materials such as grasses, foliage, pinnules, lawn, resins, bark, tree skin, rind, outer layer, and polymeric materials. Mulch indicates soft decay which focuses on advantageous grapevine growth, fertilizer leaching minimized as well as weed infestation is hampered [5, 6]. Mulch includes both natural and artificial processes that are used in viticulture as a weed control strategy, limiting soil erosion, soil temperature, and water conservation, and play an essential role in the development of soil control. Soil development control refers to elevating plant health, soil profile, ion homeostasis, water retention, increasing soil organic carbon, organic residue, improving humus, decomposed matter, and organic debris, and ameliorating the activity of beneficial microorganisms with the soil profile. As shown in (**Fig. 1**) mulching practices improve the quality of fruits, soil fertility, conservation of soil matter, control soil temperature, prevent erosion, soil and water conservation, control weeds, and regulate plant species. In this mini-review, we summarize the recent studies on the growth and development of grapevine crops under different mulching practices and the responses of mulching to climate change, disease resistance providing references for future studies on grapevine varieties responses to mulching techniques.

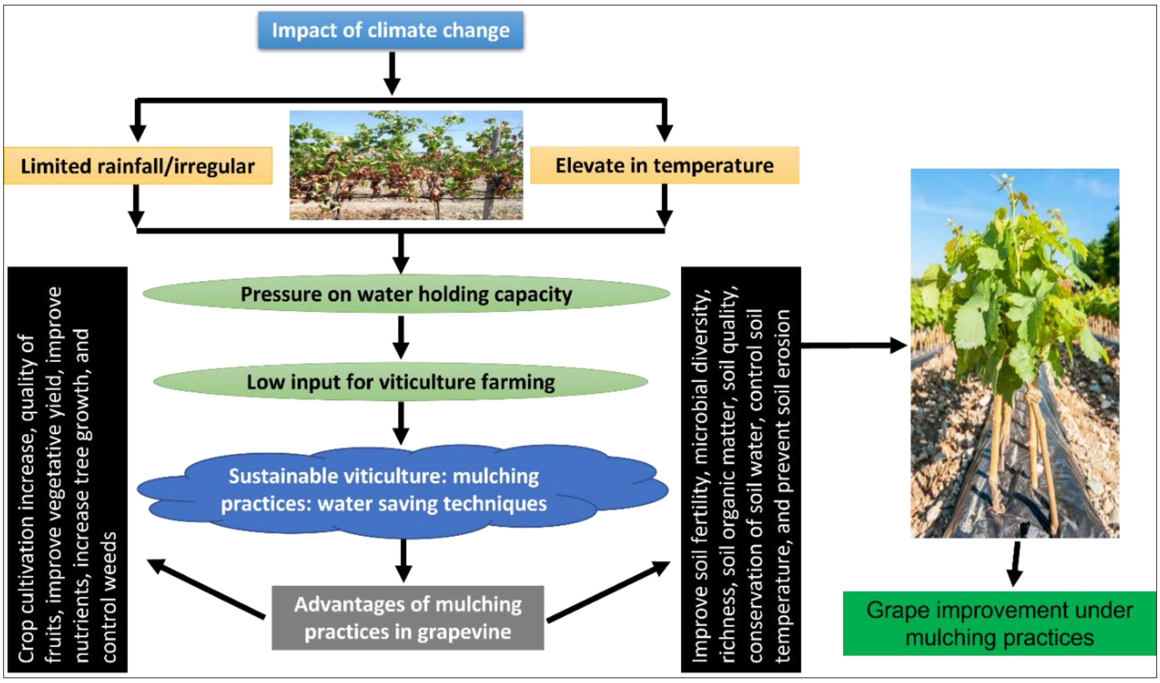

Figure 1 Interaction of conservation viticulture with climate change and mulching practices improve plant growth and development

1.1. Types of mulch practices on grapevine growth and its usefulness

There are two different types of mulch (1) organic mulch, and (2) inorganic mulch, which are categorized as follows.

1.2. Organic mulch

Organic mulch (OM) is that plant-based material which found inherently and can be effortlessly disintegrated by microbes. The OM is plant wastes, fallen leaves, leaf mold, grape dry bushes, grass clipping, wood debris, tree skin, manure, organic fertilizer, dust particles, hay, dung, dried grass, plastic bags, and pasture mulch are used. OM is more socioeconomically in improving soil profiles, furnishing organic matter, retaining water holding capacity, insect control, improving soil health, promoting soil organic substance, preventing soil compactness, controlling soil erosion, nitrate leaching, regulating nitrogen & sodium balance, and ameliorating grapevine growth performance within the soil properties [7].

1.3. Dry leaves

Dry leaves (DLs) are smoothly accessible and they provide shelter, prevent soil erosion, retain moisture, improve soil structure, and nutrients to soil profile (**Fig. 2a**). However, DLs are not smoothly accessible during the spring season.

Plant leaves are lighter, simpler, thin, and delicate as compared to other leaves. These characteristics allow better photosynthesis, which is essential for photosynthesis. Grapevine crop leaves can be used effectively in the research field for weed control, soil temperature regulation, moisture retention, disease control, and pests [8]. In addition, the thickness of this mulching should be 5-6 inches, but it varies for how long we kept.

1.4. Manure

Manure is the best mulch and soil improver (**Fig. 2b**). Manure strengthens soil physiochemical properties, soil structure, density, water holding capacity, soil salinity, soil nutrient content, soil cation exchange capacity, microbial activity, enzyme activity, soil organic matter, and nitrogen in the soil [9]. Other than advantages, it has some disadvantages also such as nutrient-poor vineyard soils and weed seed [10]. Their thickness varies from 4-6 inches.

1.5. Compost

Compost is the best mulch and improves soil quality **(Fig. 2c)**. It improves species growth, nutrient status, balanced soil pH, water conservation, reduces chemical fertilizer, and promotes sustainable vineyard management and practices [11]. By applying compost applications, we can promote an eco-friendly environment, a healthier ecosystem, and a more sustainable garden. Its thickness varies from 3-4 inches.

1.6. Straw

Straw mulch application reduces the vulnerability of grapevine, maintains ion contents, and soil organic matter, reduces evaporation, suppresses weed growth, and moisture retention. Straw materials as shown in (**Fig. 2d**) such as grape and berry straw are commonly applied. The application of straw is simple, reasonable, easy, and reflects sunlight that sustains soil temperature, humidity, and environment for grapevine plant cultivation. Preliminary mineral contents are very low in straw but along with the passage of time, variable season, and climate change decomposition ameliorate soil minerals. Soil characteristics and hydrological response, grapevine crop yield, and availability of nitrogen, potassium, and chlorine are elevated with straw mulch [12]. Straw mulching is highly inflammable so it cannot be used near the roads, buildings, and factories.

1.7. Sawdust

Sawdust is a better material, which is easily available to improve crop growth and yield. Sawdust is obtained as a by-product or waste material during the woodworking process. Sawdust might be applied in basic soil containing a pH greater than 7 because it is acidic. Though, its nutrient value is less but has enough moisture for a long time and post-harvest quality of grapes [13] (**Fig. 2e**).

2. Living grass and fabric mulches

Living grass and fabric mulches are an essential practice for regulating temperature, humidity, water, and nutrient loss in vineyards [10]. Living grass and fabric mulches contain selecting proper grass species for artificial sowing in the complete vineyard or between fruit crop rows or eliminating unsuitable bushes from the domestic weeds and retaining some for natural grass production. These mulches are an influential soil practice technique and may enhance soil physio-chemical properties and vegetative composition **(Figs. 2f and g)** [14]. These are now being progressively applied in vineyards in China. It elevates the soil water retention, nutrient availability, evapotranspiration, ecological function of soil microbes, soil bacterial function, and electrical conductivity, and decreases the degree of mineralization of soil organic matter in the vineyard [10]. Natural grass is more conducive to accomplishing a balanced supply of mineral composition and enhancing fruit yield and species quality. In addition, various investigations have shown that these applications in different regions significantly enhance the vineyard environment and total soluble solids [15]. These also enhance single fruit weight, anthocyanin, fruit color, and increase fruit quality. However, living grass and fabric mulches positively decrease tree growth and vigor and thickening of grapevine trees [16].

2.1. Hairy vetch and ryegrass

Hairy vetch and ryegrass mulch practices are essential for controlling crop disease resistance, pest pressure, soil temperature, stress tolerance, microclimate, environmental fluctuation, and reduced weed control and herbicides [17]. Both management are better and easily available to ameliorate grapevine photosynthesis, stomatal conductance, net photosynthetic rate, transpiration rate, gaseous exchange, maximum efficiency of photosystem II, and anatomical structures [18]. It was postulated that these practices improve soluble solids, titratable acids, single fruit weight, fruit appearance, post-harvest quality, promotion of plant growth, nutrient availability, organic matter content, soil moisture composition, formation of new soil microbes, and significantly reduce the proliferation of soil pathogenic bacteria and thickness of grapevine crop species performance [19]. In addition, soil enzyme activity, soil microbial diversity, agronomic features of crops, nutrient refinement and uptake, ecological functions, fruit yield, environment, and biochemical activity of microbes were also improved **(Figs. 2h and i)** [18].

Figure 2 Different mulching ways to improve grapevine growth and development

3. Inorganic mulch

Inorganic mulching (IM) is nonliving substances such as carpets, gravels, crushed stones, scree, pebbles, clay, and plastics, which are employed for soil preservation as erosion, disintegration, thermal level, low temperature, heat, and weed control soil water deduction and are generally employed for grapevine crop management practices [20]. For instance, grapevine cultivation IM is employed mostly involving plastic film mulch (PFM) technique. Studies reported that polyethylene, polyvinyl, polyethylene glycol, polyethylene films, and nanocellulose can be used as PFM techniques in commercial grapevine cultivation, planting, harvesting, and farming production [21]. Globally the main plastic film consumer for grapevine orchard management practices in China is used for insect pest control management, drip irrigation, and eliminating flooding, and waterlogging or thermal and cold stress conditions [22, 23].

Throughout the 1960s, a variety of PFM based on different types of polymers were examined for mulching purposes. The technical distinctions between flexible polyvinylchloride (PVC), high-density polyethylene (HDPE), low-density polyethylene (LDPE), Styrofoam (STF) are minimal [24]. Because it is more cost effective to use, linear low-density polyethylene (LLDPE) makes up the overwhelming majority of PM today. Black PM film technique is growing in popularity and it has produced outstanding results, especially in arid, semi-arid, and vast grassland regions. Black polyethylene mulch attained a greater grapevine crop yield and development which elevated the socioeconomic value for farmers. It reduced soil evaporation, modified the microbial community, and increased soil moisture levels, crop soil management, soil microbial biomass, agricultural management practice, and natural agroecosystem [10].

Grapevine trees were progressively being produced through a practice called as "plastic culture", which contains using plastic as mulch in viticultural practices farming [22]. Over one million tons of PFM had been used each year in all parts of the world [25]. In particular, PFM was applied in more than 600, 000 ha of greenhouse in Spain in 2012, which increase 5.7% (Market research), respectively. According to estimates, China uses 0.7 million tons of PFM annually, or above 40% of the global total in order to improve sustainable agriculture [26]. Previous study suggested that China, Japan, South Korea, Germany, France, Australia, Canada, and Italy are currently the main countries that use PFM the most globally (80%) [27, 28]. It has increased the production of grapevine by about 29.3% in China [22].

4. Mulching effect on grapevine growth and crop production

In grapevine crop growth transpiration architecture elevates due to evapotranspiration is declining because of mulch film that efficiently berry sugar, ion homeostasis, water use efficiency, osmotic potential, yield performance, and quality of fruit increases [22]. Plant residue management practices on farms ameliorate berry composition, water relation, and yield of grapevine crops by improving water conservation, soil temperature, soil moisture quality, nutrient status, and vegetative growth [29]. Annual precipitation, water availability, temperature, and moisture elevates which increases phenolic compounds, decrease flavonoids and ultimately increases grapevine species growth and production [30]. In China, plastic film mulching increases grapevine yield up to 80% [31]. These effects play a role in increasing grapevine growth, development, and crop yield.

4.1. Mulching effect on soil properties

In this section we discuss; (1) soil moisture conservation (SMC), (2) soil organic matter (SOM), (3) soil microorganism (SM), and (4) soil temperature maintenance (STM).

4.2. SMC

In growing regions, SMC and increased water relation, water effectiveness, irrigation system, soil respiration, soil temperature, and soil health are leading factors in grapevine cultivation [32]. The study revealed that with little rain straw mulching ameliorates soil microorganisms, soil physiological properties, soil fertility, soil enzyme activity, adjusts soil moisture, and hinders evapotranspiration, and strengthens moisture conditions at the depth of 0-50 cm than those with tillage practices or traditional techniques [33].

4.3. SOM

In soil of low fertility, proper plant mulching and water irrigation successfully enhance grapevine growth and development [14]. The organic mulch adds organic material to the soil delivers minerals refines soil composition, soil management, soil temperature, soil moisture, and chemical properties, and maintains soil loose and soft root architecture penetration easily take place [19]. When more soil organic mulch is used more will be the SOM, thereby improving soil physiological properties. Plot mulched with sun hemp waste cover (0.71%) organic carbon content, silkworm bed waste (0.68%), paddy straw (0.66%), and non-mulched plot (0.48%) organic carbon content [34].

4.4. SM

Soil microbial diversity plays an essential role in soil characteristics and bacterial diversity in native grapevine microbiome preharvest [35]. A rich source of carbon is organic mulching that is directly acquired by plant root microbes for their suitable cultivation and multiplication when their development is higher they perform their process quickly, integrate more organic material, and lead essential grapevine crop nutrients [36]. In addition, sufficient moisture in response to mulched soil microbial community composition has an important role in soil enzyme activity and water use efficiency by vineyard crops that manage signal transduction with biological nitrogen fixation [37].

4.5. STM

In grapevine, soil temperature refers temperature of the soil in the root system of a plant that is indirectly or directly associated with root morphology, growth, and germination [38]. During the time of winter season when the soil temperature is very low or under freezing point water within the grapevine crop cells expands which ultimately causes damage within cells and also causes rapture of cells. On the other hand, during the summer season when the soil temperature is high mostly water evaporates creating waterlogging conditions for grapevine species and causing wilt, redness, and stunt growth. Mulching delimits the upper soil temperature in grapevine and agriculture [39].

5. Mulching effect on vinery weed control strategy

Covering the soil surface with biological control enhances grapevine crop germination, and photosynthesis, and improves soil structure, soil temperature, humidity, soil fertility, and the emergence of weeds the important purpose of the soil covering is to inhibit the light of weeds, which controls its viticulture sustainability, growth, yield and emergence. All inorganic, organic, fabric, spent mushroom compost, straw, herbicide application, and living mulching grass are essential barriers to weed. Mulching of loose material such as bark, compost bark, dry leaves, and vinery green material are successful practice of biological weed management [10, 14].

5.1. Impact of Mulch Practices Application

Mulch positively affects grapevine crop development, including biotic and abiotic stress levels. The advantages of mulch are relevant and far more diverse than mere profits concerning promoting grapevine health, offering ecological profits that bear soil conditions and global environmental balance. Mulch has been proven to elevate the fertility of soil characteristics and therefore it plays an essential role in water retention, ambient temperature fluctuations, microbial communities, soil microorganisms, and curbing global warming. The key characteristics of mulch include mineral sequestration that ameliorates plant photosynthetic performance but slows down the rate of degradation of chlorophyll products and thus carbon dioxide in the climate change adaptation [10].

Mulch production impacts the carbon & nitrogen cycle and thus positively decreases atmospheric greenhouse gas concentration. Applying mulch positively enhances soil microbial diversity, soil's physio-biochemical properties, dynamic life system of soil and soil architecture exactly the way fertile soils improve their potential to stimulate grapevine plant development and adsorb pollutants in particular locations [40]. For these reasons, mulch practice is given three major roles: sustainable soil management practices, prevention of contamination, and recycling of wastewater. It has been reviewed that mulch has a strong potential to adsorb a wide variety of catastrophic substances, such as pesticides, fungicides, anthropogenic activities, heavy metals, antibiotics, and environmental pollutants. In addition, these factors are dangerous and will contaminate soil, animal, plant, and human health. Thus, regarding the rapid economic profits and ecological advantages, mulch practice is assumed to be a great option for ecological contamination biological control. Mulch loaded with activated nitrogen has proven to be an organic material of an equivalent potential to adsorb and possibly eliminate environmental pollutants such as pesticides and heavy metals [41]. Moreover, no standard application rate for mulch practice exists, field trials have displayed a remarkably wide range of application rates in previous literature [42]. Although the scope for bespoke uses further helps to accommodate the disparate requirements of control soil temperature and weed control, bringing out the versatility and practicality of mulch in vineyard establishment, soil properties, environmental management, and promotion of crop growth and development.

6. Mulch application for disease resistance in grapevine crop

The roots of the concept of using mulch for disease tolerance are in studies carried out over a century ago, which suggested that certain soil pathogens cause damping-off disease in grapevine garden construction and that adding charcoal to the nursery potting mix can stop it [43] (**Fig. 3**). The mulch's antifungal, antibacterial and qualities are generally knowns. It has been reviewed that mulch shields plants from a variety of diseases, for instance, viruses, bacteria, nematodes, powdery mildew, and even red blotch [14, 44]. Mulch has been illustrated to enhance anticipatory defense responses in grapevine crops due to its profitable quality. Namely, this pertains to the so-called systematic acquired resistance, where such pathogenesis-related (PR) proteins are biologically activated by a burst of salicylic acid.

Such responses can also be caused by host crop response to chemical or biological elicitors [45] (**Fig. 3**). Taken together, two main mechanisms could be acknowledged: two essential forms of systematic acquired resistance (SAR), and induced systematic resistance (ISR). Salicylic acid-mediated SAR generally comprises then relative expression of PR proteins and is usually related to an ameliorated hypersensitive adaptation towards pathogens, respectively. Instead, ISR is the consequence of colonization with profitable grapevine crop-linked bacteria for instance plant growth-promoting rhizobacteria (PGPR) is mediated through various signaling pathways [46].

Previous studies also conducted by [47], and [48] indicate that mulch that has its origins in many raw material sources improves grapevine crop health as well as disease tolerance by enhancing yield production and cultivation. Moreover, some of the most essential functions of mulch include the sorption of different toxic compounds, for instance, water-soluble cell wall-degrading enzymes like cellulase, pectin, and pectin lyases produced by pathogens of a soil profile. These so-called cell wall degrading enzymes (CWDE), together with other mycotoxins secreted by fungi, contribute to the survival of the majority of plant pathogens required for digestion and infection. Mulch grapevine can protect crops against attacks by sorbing and sequestering these dis-advantageous substances in soils [10]. Furthermore, mulch technique is considered an essential tool for modern sustainable viticulture, promoting the activation of crop defenses along with the neutralization of toxic compounds (**Fig. 3**).

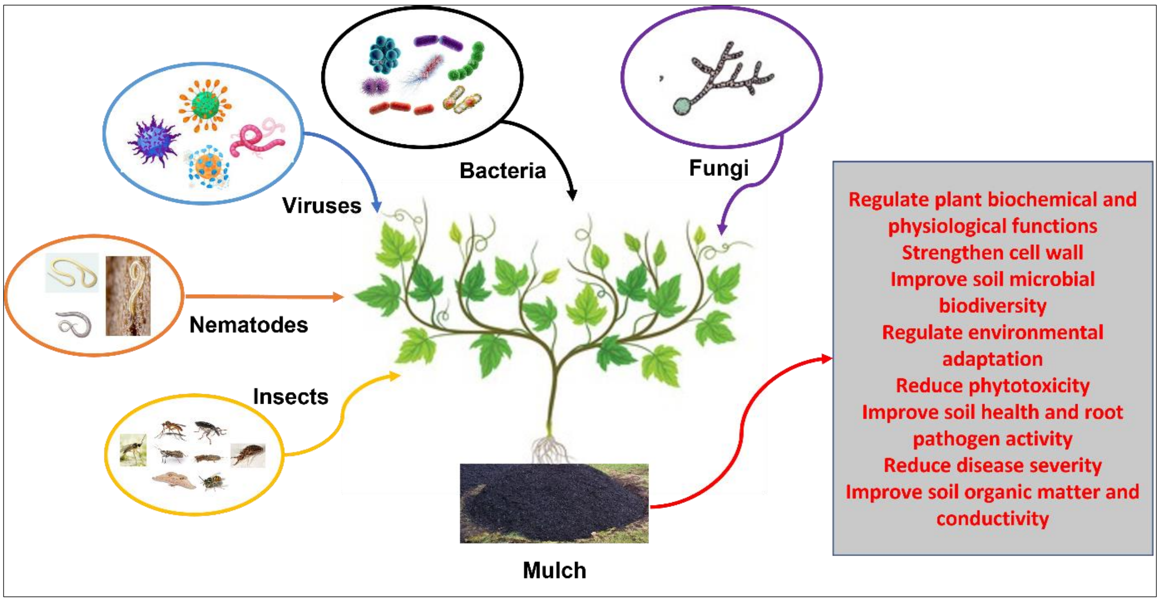

Figure 3 Effects of mulch appliction to grapevine crop fortification against insects, nematodes, viruses, bacteria, and fungi and enhance crop immunity by triggering defense mechanism

7. Resistance against fungal disease

Mulch application has been reviewed to beneficially influence bacterial diversity and richness [49] who suggested the suppressive action of grape husk mulch in the treatment of fungal pathogens, such as *Botrytis cinerea*, *Aspergillus carbonarius,* and *Penicillium expansum*. The application of 3% wood waste mulch to potting soil decreased infections by *Fusarium oxysporum* and *Botrytis cinerea* in grapevine, which was associated with elevated beneficial microorganisms that may act directly in response to fungi or elicit SAR in grapevine crops [50]. The recent literature review connects mulch as one of the beneficial approaches to managing soil-borne necrotrophic fungi and grapevine plant diseases affected by fungal pathogens. According to [51] reviewed that 1% grapevine leaves mulch and noticed that it decreased vinery diseases which were caused by *Colletotrichum gloeosporioides*. Another study [52] reported that organic mulch (1-3%) could suppress *botrytis bunch rot* in grapevines and utilized to decrease disease transmission, and improve beneficial root-zone microbes. Mulch application decreases powdery mildew (*Erysiphe necator Schwein*) in the Sultanina grapevine variety, most probably enhancing the availability of soil resources, disease severity, environmental health, stronger vegetative development, yield production and biomass [53].

7.1. Resistance against bacterial diseases

Mulch improves tolerance to bacterial diseases, including bacterial blight (*Xylophilus ampelinus*), Pierce's disease (*Xylella fastidiosa*), and crown gall (*Agrobacterium vitis*), the main bacterial pathogen causing wilt in grapevine [44]. Grapevine straw mulch (2%), herbicide application, and living mulch significantly reduce vinery diseases, and weed competition and improve sustainable weed management strategies that maintain grapevine productivity, fruit quality, and soil physiological properties [54]. The crushed glass mulch, grain mulch, and creeping red fescue further reduce soil temperature, surface reflectance, vineyard weed management, and soil fertility in grapevine wilt [55]. Mulch from grapevine shells, and dried leaves elevates the number of beneficial bacteria while reducing the number of plant pathogens [43]. Applying vintage husk mulch at 40 t/ha in grapevine also decreased wilt incidence by enhancing profitable bacteria counts and reduced specific bacterial populations (**Fig. 3**), respectively. The above findings suggest that grapevine crops perceive different approaches through mulching practices and that precise information is transmitted to all grapevine crop tissues by delivering organic mulch.

7.2. Suggestions for future studies

It is an undeniable fact that high or less tillage and mulching practices play a significant role in grapevine cultivation, especially in arid and semi-arid areas, respectively. These mainly include increasing soil properties, and soil physiological properties, enhancing soil water temperature, reducing surface water evaporation, altering soil microbial structure, promoting soil enzyme activity, and inhibiting weed control. Moreover, crop mulching practices increase the collection and utilization of water use efficiency, which is conducive to the prevention and control of soil degradation vs erosion. At the current stage, the problem of global warming is becoming more and more severe, resulting in environmental change, which directly impacts viticultural growth and development. In addition, the aim of grapevine success is sustainable production, conserving climate as much as possible while regulating grapevine yield and fruit quality, particularly in rain-fed horticulture in arid and semi-arid areas. In this current scenario, there are a large number of topics to be studied in the future, but the important tasks viticulturalists and horticulturalists are currently facing are mentioned. Such as (a) selecting a combination of viticultural practices, (b) exploring the role of micro and macro-nutrients, (c) application of grapevine crop physiology in horticulture, (d) reduced fertilizer leaching, (e) disease resistance and pest management, and (f) risk of soil pollution, etc.

8. Conclusion

This literature concludes that the impact of mulching on grapevine production has great potential by viewing its advantageous impression on crop growth and yield performance. Mulching with different materials organic and inorganic becomes modern field production in viticulture for plant development and fruit quality. Mulching not only conserves soil physio-chemical properties but also soil temperature regulation, reduces weed control, and disease resistance, protects soil from fluctuation, microorganisms, and fertilizer leaching, adds soil organic matter and mineral ions in the soil, and elevates grapevine production and yield performance. Selection of mulching material based on climatic environment, durability, seasonal changes, growing practices, availability of labor, and cost. Moreover, mulch application is equally essential for managing disease resistance including fungal and bacterial pathogens. In addition, it can be supposed that water scarcity becomes a reasonable problem in the near future worldwide so by application of mulching practices we gain more grapevine crop yield in rain-fed and play a role in changing the sustainability of the environment, soil condition, food security, and promote crop production.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Authors' contributions

Abdul Hakeem: Played a leading role in conceptualizing the literature review, and compilation of research work. **Li Shaonan**: Contributing to sections data curation. **Lingfei Shangguan**: Handled the review paper investigations, and review editing. **Jinggui Fang**: Worked as a corresponding author, conceptualizing, funding acquisition, steering the review process, and correspondence with the journal.

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