Sustainable Viticulture Method

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The goal of sustainable viticulture is to determine appropriate varieties and suitable cultivation modes for different ecological types to achieve optimal land and scientific management. The quality and yield of plants should be selected to ensure the sustainable use of ecological resources and the life of vine plants. Sustainable viticulture should aim to produce high-quality vines and wine, respect people and the environment, and ensure long-term economic benefits of vines and wine.

Keywords: Vitis vinifera L. ; cold climate zone ; abiotic stress ; sustainable viticulture practice ; vineyard management

1. Introduction

Most of the world's grape and wine producing areas are dominated by Mediterranean or oceanic climates, with hot and dry summers and cool and rainy winters [1]. However, with the development of climate change, many researchers have focused on high-quality production areas in cold climatic zones [2][3][4][5], such as the central and northern states of the United States, Central Europe and Northern Europe, Eastern Europe (Russia and Ukraine), Canada, and the northwestern regions of China. Vines are affected by various unfavorable environmental factors during winter, such as low temperature, dry damage, and sudden temperature changes, and face severe frost and draining risks. The Chinese viticulture area can be divided into 12 types based on the climatic zoning, with more than 90% ofVitis viniferadistributed in areas where the vines must be buried under a layer of soil during winter (vine burial)

In order to choose suitable overwintering protection measures, scholars around the world have carried out a lot of research, including interspecific hybrid breeding, rootstock grafting, wind dispersing cold air, adjusting plant load, soil or material covering for cold protection, delaying pruning, etc. [6][7][8][9][10]. Soil burial increases farming management costs and labor intensity, restricts mechanized production, and destroys the ecological environment. In order to realize the mechanization, simplification, and ecologicalization of grape production, improvements must be made from the aspects of racking, growing season management, overwintering measures, and ecological protection.

For traditional viticulture in winter soil-burial zones, methods such as multiple cordons fan training (MCF), "V" shape, "U" shape, and cordon training (CT) are performed after the spring unearthing. The branches need to be fixed on iron wires and the new shoots can grow in any direction, which can cause canopy closure, poor ventilation, poor light transmission, variation in fruiting, and poor fruit quality. In the growing season, new shoots must be manually tied and shaped multiple times, and trimming must be done manually, increasing labor intensity. With the cold winter, the traditional cultivation mode requires vines to be removed from wires before winter dormancy and reattached to the wires in the spring.

To mechanize vine production for high quality, stable, and long-term production, as well as to create vineyards with improved appearance [11], after more than 20 years of practical research, researchers designed a viticulture mode for the sustainable development of burial zones called crawled cordon mode (CCM). CCM includes crawled cordon training (CCT), physical methods of flower and fruit thinning, winter suspension of shoots, the use of a biodegradable liquid film, and the covering of grass and branches. Together, these measures allow simplified management of vineyards. This article summarizes the recent research on CCM, a vineyard management model suitable for Northwest China, and aims to provide inspiration for the study of sustainable and eco-friendly cultivation measures for vineyards in other cold climate zones.

2. The Foundation of CCM—Crawled Cordon Training (CCT)

Vine shape plays a key role in allowing mechanized operations during the grape harvest and soil burying processes, and it also determines the quality and efficiency of these operations [12]. Pruning is required for viticulture to control the elongation of shoots, maintain the desired tree shape, slow aging, allow the plants to grow in the predetermined space, and control the number of shoots to balance plant yield and growth [13]. However, mechanical damage caused by inappropriate pruning may promote the formation of tylose in the branches [14], affect the flow and transport of sap, and accelerate the aging of the tree. The results showed the induction of tylose by pruning, with development from axial parenchyma cells and ray parenchyma cells entering the duct lumen (**Figure 1**).

Tylose generation will block the xylem ducts of the tree and reduce or eliminate the water transport function of the functional catheter, hinder liquid flow in the new tip, and can reduce the liquid flow rate. Moreover, many small vessels were cross-linked and swirled together around the node area. Some of the cells remained in the differentiation stage, resulting in the development of a thick protoplasm with an irregular cell orientation [15][16]. Twisted vessel molecules and parenchyma cells reduced the flow rate during water transportation and limited distribution between the nodes.

Due to the potential risk of pruning, the theoretical basis of CCT—the theory of minimum pruning—is proposed [17]. Additionally, the branches of bearing shoots (one-year-old branches) should be positioned as close to the trunk as possible to reduce transport distance, reduce sap flow resistance, and increase the ability of plants to regulate the distribution of matter between the source (the tissues or organs that are synthesized and transported to other parts of the plant) and the sink (the net importers of photosynthetic products in the form of sugar or related substances) and prevent plant senescence. In actual production, annual branches are fixed flat on the first wire (bearing wire), 30–40 cm away from the ground or the ditch (**Figure 2**). In CCT, the annual branches or the main cordons are then connected end-to-end, like a long dragon crawling on the ground, in the same planting ditch after winter pruning [18].

The CCT shaping method minimizes the height of the trunk, the length of the perennial part, and the number of cuts, so should reduce the formation of intrusions, shorten the distance of water transport, and facilitate flow in plants. The vines managed by CCT have fewer incisions and fewer tyloses produced, resulting in better vine vigour, health, and yield. Additionally, with lower bearing sites, grapes matured 5–8 days earlier than grapes on vines managed by MVF or CT (cordon training) [19].

Another important function of pruning is to maintain the balance between the reproductive growth and vegetative growth of the vines by adjusting the leaf structure of the vineyard [20]. A divided canopy profile in a vineyard resulting from shoot-positioned training systems could help stimulate the light microclimate of the foliage and clusters in the cluster zone. This change could affect the physiological and ecological characteristics of grape plants, including photosynthetic characteristics, distribution characteristics of the carbon, and the maturation of shoots, leaves, fruits, and aroma accumulation in grapes [21][22][23][24][25].

The results of Nan et al. showed that CCT’s (crawled cordon training) photosynthesis accumulation is better than ILSP (independent long-system pruning), and in all cases, the photosynthesis of each point of CCT is relatively uniform compared with ILSP, because their leaves are vertically exposed to the sun and a wide area of effective light is received, and, due to the inclined configuration, the leaves used for ILSP are blocked by sunlight. Therefore, CCT created a steadier ecological environment, which made for absonant vegetative growth caused by leaf maturation and season; the CCT should be a system with traits for optimization of light capture. Due to the difference in photosynthetic characteristics, the distribution characteristics of organic carbon (TOC) in the two shapes were also different. TOC content of most shoots and leaves in CCT were less than the corresponding value in ILSP, and the maturation of each lamina was earlier in CCT than in ILSP; CCT leaves would be given greater priority over the shift of most TOCs to root through the shoot or stored in the shoot, which resulted in less residual TOC in CCT blade.

Acceleration of berry maturity was influenced by the increase of fruit exposure and effective leaf area [26]. Therefore, the effect of trellises on the grape composition and wine quality attributed to the role of the trunk height and/or a large number of perennial xylems to the fruit exposure, canopy microclimate, and production [27]. The appropriate trellises could also build comfortable microclimate environments, such as water stress, sunlight, and air temperature, without destructive technical measures, such as the leaves thinning or clusters thinning, to promote berries maturation. CCT can promote the early accumulation of aroma compounds, and is suitable for regions or varieties that need to be harvested as soon as possible [24].

Compared with traditional training methods [21][17], CCT eliminates the need for unmounting in winter and mounting in spring, so reduces mechanical damage, thus prolonging vine life span by 8–10 years. Under ILSP, minor shoots (e.g., sub laterals) must be removed during winter pruning, and irregular shoots need to be unmounted from the wires to facilitate vine burial. Labor input from winter pruning to spring unearthing under CCT was reduced by 23.0% compared to that under ILSP [28]. Compared with ILSP, CCT reduces the need for high labor input and high labor intensity when it is urgent to prepare for winter.

As shown in**Table 1**, the yields under CCT were lower than those under multiple main vine fan-training (MVF) and cordon training (CT). Additionally, the stable production coefficient A values of CCT and CT were smaller, indicating higher stable production capacity [29], so the three trimming modes in order of stable production ability were CCT > CT > MVF. Factors such as wind and humidity affect the incidence of disease, ripeness, and grape size. The increased gaps in the canopy under CCT increase the use of sunlight for photosynthesis, but increased shade with ILSP delayed fruit ripening and reduced wine quality [17].

3. Vineyard Management during the Growing Season

The study of conservation tillage techniques has identified strategies to reduce sediment loss, conserve water and counter drought, increase soil water use efficiency, improve crop yield and quality, increase resource utilization efficiency, and promote sustainable agricultural development. Complete grass cover is recommended to limit excessive vegetative growth and improve grape quality, especially phenolic content [30]. Use of a complete grass mixture and natural covering negatively inhibit vine mealybug activity, thus reducing pest impact [31][32][33]. The sustainability of the vine and wine industry in China would benefit from the use of conservation tillage measures in the management of vineyard soils, such as the traditional clean tillage method (**Figure 3**a) and the grass cover method (**Figure 3**b) [34].

Compared with clear tillage, grass covering reduces the soil water content of vineyards and the relative water content of grape leaves, reduces the photosynthetic rate, stomatal conductance, and transpiration rate of grapes, and advances the peak of stomatal conductance and photosynthetic rate [35]. The use of a cover crop system resulted in high non-anthocyanin phenolics content and total phenolic compounds content, with the most obvious effect from tall fescue treatment, followed by white clover and alfalfa. Compared with soil tillage, there was low total nitrogen content in grapes and juices of plants grown with the three cover crops, higher total nitrogen content in wines, and higher total content of free amino acids in berries and wines, except for a lower amount of amino acids in white grapes for clover treatment. Although the total N of the grapes was decreased under cover crop treatments, there were no differences in the duration of alcohol fermentation between treatments because of increasing amino acid content [36].

In natural grass growing, grass species are selected that are suitable for local natural conditions, such as one that is already growing in the vineyard [37]. Compared with clean tillage, the use of grass cover significantly increased the soil microbial activity and organic matter content and improved overall soil structure [34][38]. From the research results of Xi [39], compared with clean tillage, white clover, alfalfa, and tall fescue treatments improved soil microorganism quantity, soil enzyme activity, and soil nutrients, with bigger effects observed for white clover and alfalfa than those for tall fescue. With alfalfa as a cover crop (CA), soil physical characteristics were improved, with 8.5–9.8% decreased soil bulk density and 11.5–13.9% increased soil porosity at 0–60 cm depth compared with soil clean tillage treatment (ST).

Disease is one of the important factors restricting grape quality and yield. It has been reported that mechanical stimuli induce a reduction of plant susceptibility to pathogen and pest attacks by developing plant immunity for different plant species [40]. To reduce disease sources and incidence rates, and reduce chemical use for grape and wine protection, a sprayer fan is used to blow off unfruited flowers and inferior fruits. After flowering, this treatment is performed three times before sealing [41].

The removal of unfruited flowers and inferior fruits effectively reduced the incidence ofBotrytis cinerea, and also reduced grape downy mildew and grape powdery mildew. Under natural conditions, the incidence rate ofBotrytis cinereais 21.7%, which was reduced to 5.6% when unfertilized flowers and inferior fruits were blown off by the fan of the sprayer [41].

4. Sustainable Development Prospects of Grape and Wine Industry in Arid and Semi-Arid Regions under Continental Monsoon Climate

The challenges of the environment and the depletion of natural resources, coupled with the growing appreciation of these problems have led to a goal of more sustainable development. Sustainable development is a multi-dimensional approach that combines economic growth, social issues, and environmental protection [42] to ensure that the next generation can also obtain the necessary resources. The concept of sustainability requires reducing the consumption of resources, improving the ecological environment, and improving the quality of life.

The goal of sustainable viticulture is to determine appropriate varieties and suitable cultivation modes for different ecological types to achieve optimal land and scientific management. The quality and yield of plants should be selected to ensure the sustainable use of ecological resources and the life of vine plants. Sustainable viticulture should aim to produce high-quality vines and wine, respect people and the environment, and ensure long-term economic benefits of vines and wine. The ecological conditions required by vines dictate the necessary cultivation strategies, including the layout and the reasonable pruning strategy to ensure sufficient quality of the vines, grapes, and wines.

In arid and semi-arid regions under the continental monsoon climate, sustainable development requires viticulture practices that are convenient and economical for winter survival of vines. Practices should be simple, fast, labor-saving, easily mechanized, allow the improvement and reconstruction of ecological conditions, able to be adjusted to improve the quality of the vines and stabilize yields, ensure the biodiversity of vineyards, and should maximize the longevity of vine plants and the landscape of the vineyards [18]. Thus, the goal of sustainable viticulture can be defined as high quality, stable, and long-term production with vineyards that are pleasing in appearance [11].

Stable yield is required to maximize economic benefit for the vine and wine industries. Measures such as balancing reproductive and vegetative growth, reasonable water and fertilizer management, and scientific plant protection can prolong the life of grape plants, increase land utilization rate, and ensure long-term benefits for the vine and wine industries. CCM proposes a strategy of minimizing pruning on the basis of China's wine grape climate zoning, which is of great significance for extending plant life, stabilizing yield, balancing reproduction and vegetative growth, and ensuring the long-term benefits of the grape and wine industry. More importantly, these measures can also improve product quality and form a unique style of grapes and wine with characteristics of origin for increased overall value.

The wine industry integrates secondary and tertiary industries, since tourism and entertainment services are important parts of the output value. A beautiful vineyard landscape can promote the vine and wine industry, increase income from tourism and entertainment services, promote the rational use of land and resources, increase land appreciation, and increase income for farmers [11]. The improvement of the vineyard landscape will also have many benefits for giving play to the tourism service function of the wine industry and increasing the income of viticulture. Moreover, the simple, fast, labor-saving, and easy-to-mechanize characteristics of CCM also prove that it is actually suitable for sustainable cultivation in a continental monsoon climate and arid and semi-arid regions.

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