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Review

A Sustainable Viticulture Method Adapted to the Cold Climate Zone in China

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Abstract: Due to the particularity of the continental monsoon climate in China, more than 90% of the wine grape cultivation areas require vines to be buried in winter for a burial period that can extend to half a year. Additionally, traditional vine cultivation practices can expose the surface of the soil during winter, easily leading to soil erosion. To meet the restrictive factors for viticulture in the Chinese cold climate zone, a new sustainable viticulture strategy called crawled cordon mode (CCM) has been developed. 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 covering of grass and branches for simplified management of vineyards. This article summarizes the specific implementation methods of the main measures of CCM and their significant effects on the quality of grapes and wine, ecological environment, and costs, and aims to provide inspiration for the study of sustainable and eco-friendly cultivation measures for vineyards in other cold climate zones.

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

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1. Introduction

Climate change has aroused wide concern in recent years, and may have a major impact on the distribution and production of crops in temperate and tropical regions [1]. As a perennial plant, grapevines have a strict regional distribution, they are in a higher-risk climate niche, and are sensitive to both short-term and long-term climate changes [2]. 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 [3]. However, with the development of climate change, many researchers have focused on high-quality production areas in cold climatic zones [4–7], 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. Most of these producing areas have a continental monsoon climate, which is characterized by hot and rainy summers and cold and dry winters [8]. 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. In addition, as the main cultivated wine grape varieties, the quality of *Vitis vinifera* is higher than that of *Vitis labrusca* and various wild species. At the same time, the cold resistance is completely opposite. When the extreme low temperature in winter is lower than −15 °C, the vines need to be protected to withstand the severe cold, prevent draining, and ensure its safe overwintering [8]. The Chinese viticulture area can be divided into 12 types based on the climatic zoning, with more than 90% of *Vitis vinifera* distributed in areas where the vines must be buried under a layer of soil during winter (vine burial) [9–11]. In general, vines are buried in the winter and unearthed in the spring, requiring increased labor intensity and costs, potentially causing damage and diseases to branches, restricting mechanized production, and destroying the ecological environment [12–15].

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. [15–19]. However, the current focus is on the impact of a single measure, and there are few systematic reports on the annual management strategy of the vineyard. 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.

With the particularity of the continental monsoon climate in China, more than 90% of the viticulture areas require the burial of vines in winter. 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. This also requires high labor intensity and can easily cause mechanical damage, reducing plant lifespan. With increased area devoted to grape planting, it is urgent to explore a simpler cultivation method that is suitable for cold regions and that can be mechanized [20].

To mechanize vine production for high quality, stable, and long-term production, as well as to create vineyards with improved appearance [21], 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 [22]. 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 [23]. However, mechanical damage caused by inappropriate pruning may promote the formation of tylose in the branches [24], affect the flow and transport of sap, and accelerate the aging of the tree. Zhao et al. conducted a systematic study on the tylose formation process and influencing factors [25]. 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. Cells in node areas or between nodes are inhomogeneous. 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 [26,27]. Twisted vessel molecules and parenchyma cells reduced the flow rate during water transportation and limited distribution between the nodes. With increased age of pruned branches, the longer the perennial part of the grape, the greater the number of cuts caused by pruning, and the greater the possibility of tylose intrusions, reducing the transportation capacity of vessels and sieve tubes, and eventually leading to cracking of the perennial parts of plants [25]. In addition to hindering the transportation of water and nutrients, different pruning methods can change the photosynthetic characteristics and the distribution of organic carbon between the new shoots and leaves of the grape plant, as well as the flow of phloem sap, thereby affecting the overall quality of the grapes and the grape vines [28].

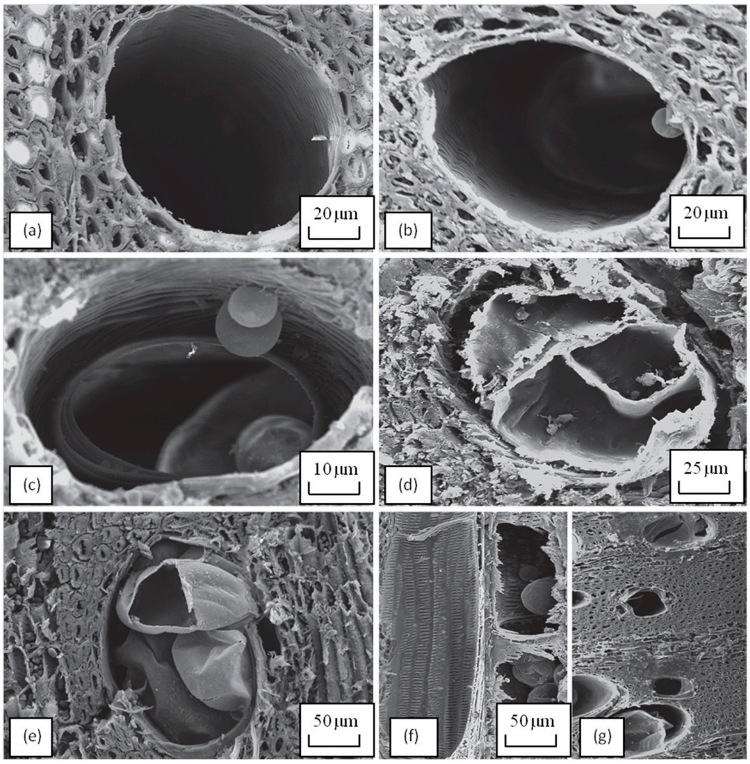

Figure 1. SEM micrographs of tylosis development in vessels of current year shoots after pruning (**a**–**f**). (**a**) No tylose in the vessel lumen of an unwounded control; (**b**) a small tylosis formed in the vessel lumen; (**c**) several small tyloses developed in the vessel lumen (arrows); (**d**) tyloses divided in the vessel lumen; (**e**) tyloses completely occluding the vessel; (**f**) a longitudinal section of two adjacent vessels with and without tyloses; (**g**) a vessel with gels (arrows) [29].

Due to the potential risk of pruning, the theoretical basis of CCT—the theory of minimum pruning—is proposed [29]. The goal of minimal pruning is to minimize the height of the main trunk, remove as much of the perennial part as possible to prevent its elongation, and minimize the number of cuts. 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 [20].

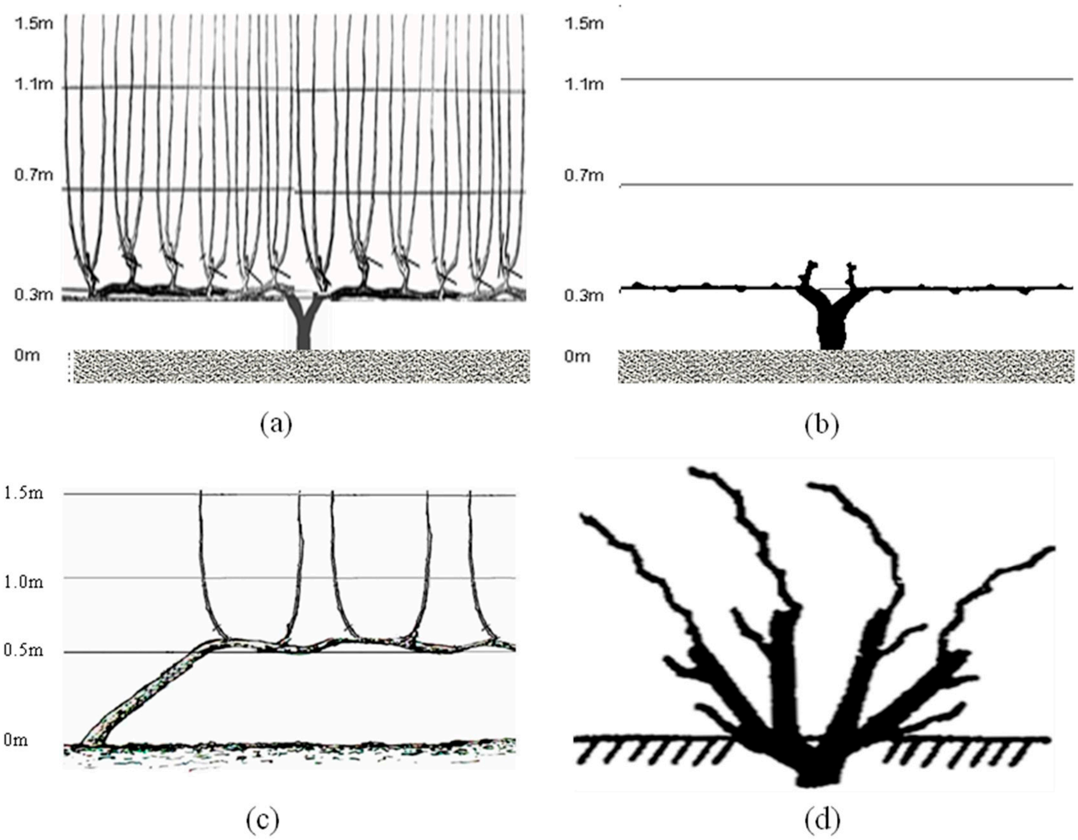

Figure 2. Diagram of vines under the "crawled cordon training" (CCT) training system before pruning in winter (**a**) and after pruning in winter (**b**); diagram of independent long-system pruning (ILSP) (**c**) [28]; diagram of multiple cordons fan-training (MVF) (**d**).

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) [30].

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 [31]. 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 [28,32–35].

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. In addition, the vine in CCT showed a high Pn as for the total gain compared with ILSP; the diurnal changes of the photosynthetic light response curves were also smoother in CCT than in ILSP at the second growing period other than at the riping stage. 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. Thus, the lignification rate of CCT shoots was faster than that of ILSP ones. The transformation of the trellis also changed the physiological structure of the plant, and the structure of the phloem further.

Acceleration of berry maturity was influenced by the increase of fruit exposure and effective leaf area [36]. 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 [37]. 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 [34].

Compared with traditional training methods [28,29], 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. Wang et al. [38] evaluated the labor costs for CCT and compared it to a traditional training system of independent long-stem pruning (ILSP) at Rongchen Chateau in China during the years 2011, 2012, and 2013. 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. However, under CCT, an easier pruning strategy is used without sublateral removal and with regular positioning of shoots. CCT does not require unmounting before burial, allowing some work to be performed the following spring when less effort is required. Labor input from winter pruning to spring unearthing under CCT was reduced by 23.0% compared to that under ILSP [38]. Compared with ILSP, CCT reduces the need for high labor input and high labor intensity when it is urgent to prepare for winter. The time required for harvest under CCT was reduced by 37.5% compared with that under ILSP. Using CCT, shape management in summer is simple. New branches are collectively managed to form a hedgerow, with canopy a height of 1.5 m and canopy width of 0.5 m. The canopy that extends beyond this height and width is mechanically removed. Branches cover rows and grass cover is used between rows [20]. Although, initially, the CCT vines had lower yields, which reduced labor, CCT better positioned the vines so that the fruiting/renewal zones became much more uniform [29]. In contrast to ILSP, for CCT cultivation, harvesting was performed at a single height, so workers did not have to spend time searching for more widely distributed fruit.

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 [39], 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 [29].

Table 1. Yield (kg/666.7 m^2) and A values of different shaping methods measured for five years (2005–2009) [28].

Treatment	2005	2006	2007	2008	2009	A Value
MVF	810.42	869.88	750.72	812.26	429.63	0.2180A
CT	782.72	930.22	993.94	780.87	420.02	0.1070B
CCT	692.08	721.78	781.88	746.46	595.16	0.0837B

Note: Different letters (A and B) indicate the LSD test reached the level of significant difference ($p < 0.05$), and the same letters indicate no significant difference.

3. Vineyard Management during the Growing Season

3.1. Covering of Grass and Branches

The Chinese winter soil-burial zone includes arid and semi-arid areas, which are areas with the most serious water and soil erosion in China because the ecological environment is extremely fragile [40,41]. 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 [42]. Use of a complete grass mixture and natural covering negatively inhibit vine mealybug activity, thus reducing pest impact [43–45]. Pruned branches left on the wires in winter can fall to the ground between rows, which can prevent the growth of long grasses and allows the branches to decay naturally. 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 3a) and the grass cover method (Figure 3b) [46].

Grass covering is an excellent soil management method, which is generally considered to increase the total phenol content of grapes and wine, thereby improving the quality of grapes and wine [47,48]. Xi et al. systematically studied the effects of grass covering on the photosynthetic characteristics of the vine and the main mono-phenol content, main mono-anthocyanins, and aroma compounds of grapes and wine, and compared the effects of different mulching grasses (tall fescue, white clover, alfalfa, and soil tillage) on the quality of grapes and wine [49]. 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 [50]. 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. The total anthocyanin content increased in the following order: alfalfa, tall fescue, white clover, and soil tillage [49,51]. The permanent cover crops increased the total content of wine aroma compounds compared to those in plants grown in the bare soil. Alfalfa sward had the biggest effect, followed by tall fescue treatment. Wines made from grapes with different cover crops had more aroma compounds, which can improve the wine quality [52]. 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. Proline was the most abundant amino acid in grapes and wine with all treatments, accounting for 46–57% and 90–92% of the total amino acids in grapes and wine, respectively. 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 [51]. The color density, aroma, and taste of wine from plants grown with covering were significantly improved compared with those cultivated with clean tillage. Overall, green cover improved the quality of the grapes and wine [49].

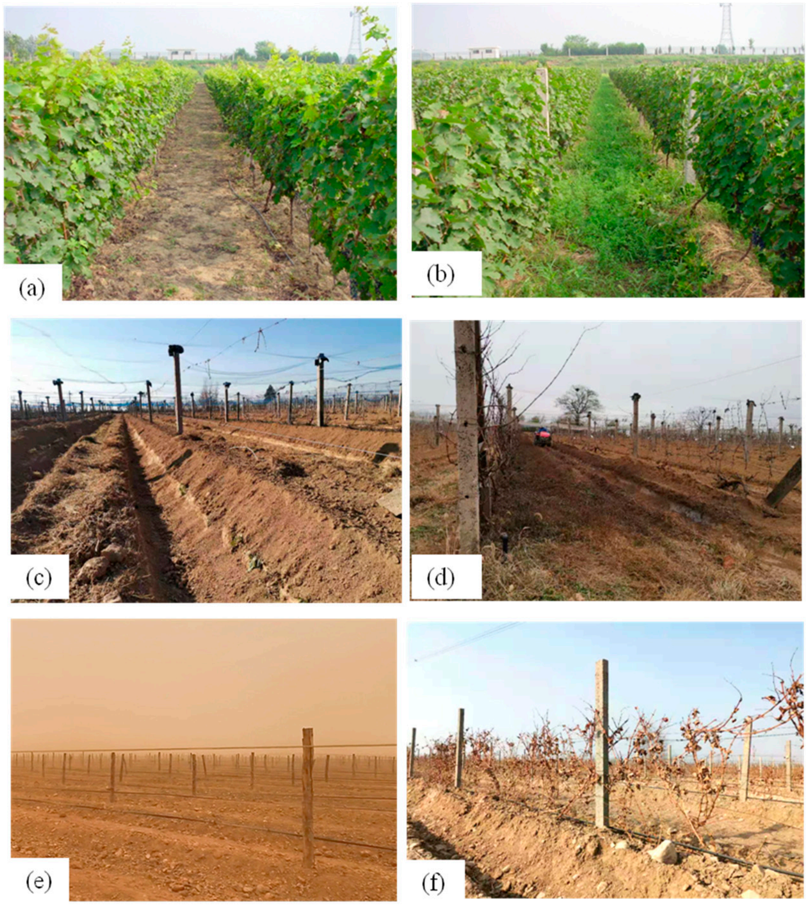

Figure 3. (**a**) The traditional clean tillage vineyard. (**b**) The grass covered vineyard. (**c**) Vineyard soil burial overwintering. (**d**) Vineyard sprayed with BLF overwintering. (**e**) No shoots vineyard after extreme wind erosion. (**f**) Shoots windbreak in vineyard.

Artificial or natural grass planting can be used in vineyards. 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 [53]. The selection of natural species is time-saving and labor-saving for producing grass cover [23]. Compared with clean tillage, the use of grass cover significantly increased the soil microbial activity and organic matter content and improved overall soil structure [46,54]. From the research results of Xi [49], 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. Tall fescue resulted in bigger increases in available P and amylase activity. Cover cropping helps to regulate soil water and improve the soil water utilization ratio (Table 2). However, it should be noted that grass covering in vineyards reduced the average annual soil water content to a certain extent, especially in years with insufficient water storage in winter and drought in spring. Areas with severe water shortage during the growing season should be cautious in using a grass covering strategy [46]. 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). The results show that, in the Chinese winter soil-burial zone, the use of grass cover in vineyards improves the microclimate environment of the vineyard and improves the soil environment.

Table 2. Comparison of average microbial amount, enzymatic activity, nutrient content, soil bulk density, and porosity (average values for four seasons). The data has been modified based on the study of Xi et al. [49].

Treatment		CA	ST (CK)
microbial amount (0–20 cm)	Bacteria ($\times 10^4$/g)	31,572.23a	14,549.43b
	Fungi ($\times 10^4$/g)	8.45a	4.84b
	Actinomyces ($\times 10^4$/g)	375.60a	305.81a
	Azotobacter ($\times 10^4$/g)	282.76a	71.42b
	Cellulose-decomposing microorganisms ($\times 10^4$/g)	5.31a	2.76b
enzymatic activity (0–40 cm)	Urease (NH_3-N mg/g)	1.70 ± 0.83a	1.18 ± 0.53b
	Phosphatase (P_2O_5 mg/100g)	7.41 ± 1.04a	4.68 ± 0.50b
	Amylase (Maltose mg/g)	0.78 ± 0.09a	0.94 ± 0.43a
	Sucrase (Glucose mg/g)	15.08 ± 2.46a	10.31 ± 3.87b
	Cellulase (Glucose mg/10g)	6.37 ± 0.85a	4.91 ± 0.64a
	Catalase (0.05 mol/L $KMnO_4$ mL/g)	7.69 ± 0.85a	7.20 ± 0.58a
nutrient content (0–40 cm)	Hydrolyzable N (mg/kg)	40.75 ± 4.28a	35.30 ± 2.09b
	Available P(mg/kg)	5.54 ± 1.05b	10.77 ± 0.65a
	Available K (mg/kg)	122.63 ± 6.97a	109.13 ± 5.59b
	Total N (g/kg)	0.74 ± 0.02a	0.66 ± 0.05b
	Total P (g/kg)	0.67 ± 0.04a	0.75 ± 0.05a
	Total K (g/kg)	20.10 ± 0.39a	19.88 ± 0.31a
	Organic matter (g/kg)	11.31 ± 0.51a	9.90 ± 0.37b
physical properties (0–60 cm)	Soil bulk density(g/cm^3)	1.38b	1.53a
	Soil porosity (%)	48.06a	42.20b

Note: 0–20 cm: 0–20 cm soil depth; 0–40 cm: 0–40 cm soil depth; 0–60 cm: 0–60 cm soil depth. CA: alfalfa as cover crop; ST: soil clean tillage, CK. Different letters (a and b) indicate the LSD test reached the level of significant difference ($p < 0.05$), and the same letters indicate no significant difference.

3.2. *Physical Methods of Flower and Fruit Thinning*

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 [55]. 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 [56].

The removal of unfruited flowers and inferior fruits effectively reduced the incidence of *Botrytis cinerea*, and also reduced grape downy mildew and grape powdery mildew. Under natural conditions, the incidence rate of *Botrytis cinerea* is 21.7%, which was reduced to 5.6% when unfertilized flowers and inferior fruits were blown off by the fan of the sprayer [56].

4. Vineyard Management during Dormant Season

4.1. *Biodegradable Liquid Film (BLF)*

In recent years, Xue et al. identified a biodegradable liquid film (BLF) (Figure 3d) suitable for vine application as a protective strategy against winter chill to replace vine burial (Figure 3c). This film can be used on the branches and the soil of the planting furrow after winter pruning.

The developed BLF is brown and creamy and forms a thin, brown, multimolecular chemical protection film that wraps the branch surface into a closed body. The BLF gradually degrades within approximately 70–90 days, protecting the branches in cold winters. The addition of film to the soil protects the volatile soil water and significantly reduces soil wind erosion, but still allows the full infiltration of pesticides and nutritive material into the soil [12,13]. The use of BLF instead of vine burial was developed for use in vine cultivation areas with a minimum temperature below −15 °C in winter. Currently, BLF is widely used for winter protection of vines in the soil burial area in China, either as the sole treatment for areas with a minimum temperature of −15 °C in winter or as part of a combination treatment with other physical measures for use in colder areas. There is a risk of plant death in areas with too cold a climate, and the mortality rate of the pillar is closely related to the variety [12], so the selection of the variety and region to be used is also crucial. There are ongoing efforts to further improve BLF to accommodate colder vine growing areas.

Xue et al. compared BLF spraying on vines after training in winter (BLF spraying treatment) to vine burial (VB) for germination date, yields, grape quality, and cost from the winter of 2015 to the spring of 2017 at Heyang Station of Viticulture, NWAFU, in China [12]. The results showed that the BLF application protected some cultivars of Vitis vinifera Merlot, Ecolly, Sauvignon Blanc, and Italian Riesling from the winter chill in Heyang and delayed bud germination date in cold years. A significant decrease in the content of reducing sugars was observed for BLF treatment compared to VB treatment for Cabernet Sauvignon, but a significant increase was observed for Italian Riesling. Interestingly, the opposite trend was observed for acidity content. BLF treatment increased tannins, flavonoids, and total phenol content in grape skins, increased tannins, flavanols, and flavonoids in the grape seeds of Cabernet Sauvignon, and increased flavanols, flavonoids, and total phenols in the grape skins of Italian Riesling. The composition of BLF could be further improved, and further studies are warranted to better characterize its ability to protect vines against the winter chill and explore related indexes. Burial treatment requires advance winter pruning to remove most of the annual branches, because it will overwhelm the plants and bury them underground, but the winter pruning time can be postponed to only one week before the next spring bleeding period under BLF treatment. The freezing damage of perennial fruit crops may occur in multiple stages, including autumn before dormancy, during dormancy, and spring after germination [57]. Delaying pruning of winter spurs will delay bud germination, which can reduce the susceptibility of grapevines to spring frost damage [58]. Additionally, later pruning contributes to higher yields and delays vine phenology, may slow fruit ripening, and alters the chemical composition of grapes at harvest [12,59].

Xue et al. evaluated the influence of BLF spraying on vines after training in winter and analyzed the overall vineyard operation costs for spraying treatment or soil burial treatment without spraying from winter of 2015 to spring of 2017 at Heyang Station of Viticulture, NWAFU, in China [12]. For BLF, the costs included the removal of branches, the cost of BLF, mechanical equipment, and labor costs. For soil burial treatment, the costs included winter unmounting (removal of the trunk), winter vine burial, removing the trimmed branches from the wires, spring unearthing, spring mounting (tie the trunk back to the wire), mechanical equipment, and labor costs. The results showed 48.04% lower costs for winter vineyard operations with BLF treatment compared to the cost for operations including soil burial treatment.

4.2. Winter Suspension of Shoots

In traditional viticulture, the soil surface is exposed when vines are soil buried (Figure 3e), and dry windy spring conditions can expose the soil of large mounding areas. This results in an increased risk of wind erosion in viticulture regions, which can alter the natural landscape of the vineyard.

The vines of CCT are near the ground, so the vines can form a leaf-like curtain with a height of 1.5 m and a width of 0.5 m in the vine-growing season. Another difference of CCT from the traditional cultivation mode is that the shoots of vines hang on the wires after winter pruning to form a kind of windbreak (Figure 3f). This windbreak can play a protective function, improving the ornamental nature of the vineyard while protecting the surface by reducing wind erosion and the degree of desertification. After unearthing the following spring, pruned branches left on the wires in winter can be cut off. These pruned branches fall to cover the ground in the vine rows, which prevents the growth of grass during the year and allows the organic matter in the branches to return to the soil and promote the carbon cycle in the vineyard.

The winter suspension of shoots has a certain impact on the microclimate of the vineyard, thereby affecting the growth and physiological characteristics of the plants. In the vineyard where shoots are used as a windbreak, the water content of shoots remaining on the trunk is higher than that of shoots in the wilderness, but it is not significant. Shoots as windbreak also did not significantly influence vine germination rates. Traditional viticulture management cleans the pruned shoots out of the vineyard in winter to remove the sporangia, mycelium, and eggs of pathogenic bacteria to reduce pests and diseases. Using shoots as a windbreak means that the risk of pests and diseases in the coming year may increase. For this reason, Wang conducted a comparative test on the two vineyards and found that the shoots windbreak had no significant effect on the morbidity of leafhopper and vine erinose, but decreased by 1.11% and 0.24%, respectively [14]. The impact on other pests and diseases needs to be further studied.

The use of a windbreak of vine shoots helped protect against winds. Wang et al. compared wind speed changes at different locations in a windbreak vineyard and an exposed vineyard in the soil burial cold protection zone in northern China [14,60]. The wind speed from 48 m on the windward side of the windbreak to 34 m on the leeward side (including the suspension area of the windbreak, the width is 60 m) was measured at a height of 1 m (Figure 4). The wind speed at the same height at different locations varied greatly. Compared with the wind speed in the exposed vineyard, the maximum wind speed reduction of the shoots windbreak vineyard was 84.20%. At some locations, such as 5H (H = 2 m, represents the height of the branch wind barrier), 12 H, and B0H ("Y" refers to the windward side and "B" refers to the leeward side), the wind speed increased. In general, wind speeds at most observation locations decreased. In the entire windbreak zone and the range from B0H to B17H on the leeward side of the windbreak, the wind speed was lower than the field value on the windward side, with an average reduction of 40%.

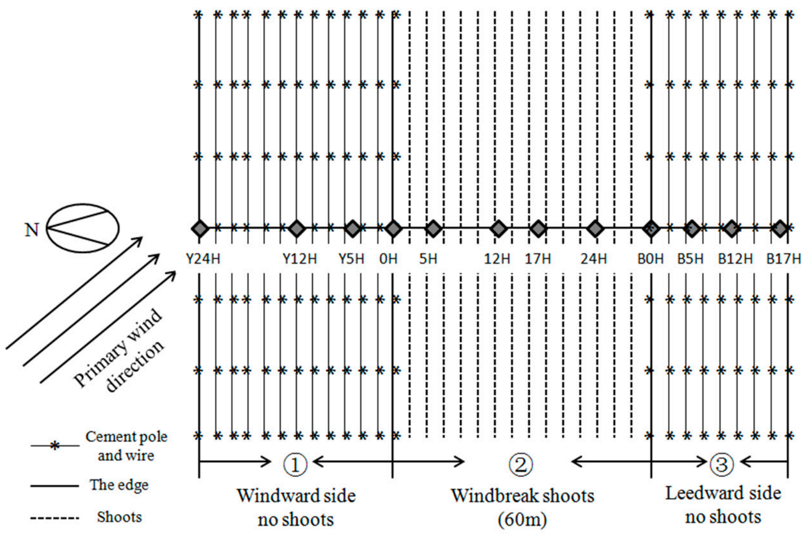

Figure 4. Schematic diagram of field wind speed measurement test layout. The field plots Y24H, Y12H, and Y5H at the windward side, that is, 48, 24, and 10 m away from the windward edge of the windbreak; the field plots 0 H, 5 H, 12 H, 17 H, and 24 H in the windbreak means far away from the windward edge 0, 10, 24, 34, 48 m; the field plots B0H, B12H, B17H at the leeward side means far away from the leeward edge 0, 24, 34m. The width of this windbreak was 60 m (0 H–30 H). The data has been modified based on the study of Wang [14].

To avoid the interference of uncontrollable variables in the field test, an indoor wind tunnel was used to simulate the handling of hanging branches in winter and analyze the influence on wind speed [13]. Consistent with the outdoor experiment, the length H of the branch wind barrier is used as the unit of measurement; the difference is that, at this time, H is the reduced model length = 40 cm. The first layer branch model on the windward side was designated 0 H, the windward side was designated "-", and the leeward side was designated "+". The actual wind speed in the area of 0–60 cm (from the ground) height and 3 H–11 H positions under a fixed wind speed level were measured for bare soil control (no branches hanging) and with hanging branches. The acceleration rate is the ratio of the actual wind speed at the observation point to the set wind speed in the wind tunnel. A value of a less than 1 means decreased wind speed and a value of a greater than 1 indicates increased wind speed.

There were significant differences in different positions and different heights [13]. The shoots windbreak treatment decreased the wind speed in vineyards within the range of 10–40 cm in height, and at the windward side at one height of the branch model (Y1H) and the leeward side of five height regions (B5H). The wind speed was measured at six positions, and the acceleration rate contour maps of 8–16 m/s all showed the same trend. As shown in the figure, in the windbreak, a deceleration zone formed on both the windward and leeward sides. In the Y1H to B5H zone, the acceleration (a) rate near the 20 cm height range reached a minimum value in the range of 0.3 to 0.5 cm, and the deceleration zone (a < 1) is closed. The acceleration rate increases at 0.5 cm, creating an acceleration zone (a > 1) (Figure 5). The maximum acceleration rate occurs at the height of 0.5 cm for each wind speed, and B5H is the deceleration center, with a minimum value between B3H and B7H. At the top of the windbreak, there is little change in the acceleration rate at the same height, but at the bottom of the windbreak, there is a large change in the horizontal gradient of the same height acceleration rate. The trend of the acceleration rate in the horizontal direction is consistent with the observation of Wang Shan et al. [60] that the wind barrier weakened, the current accelerated, and the rapid weakening, the recovery, and the leeward side were reduced as airflow passed through the grape branch wind barrier.

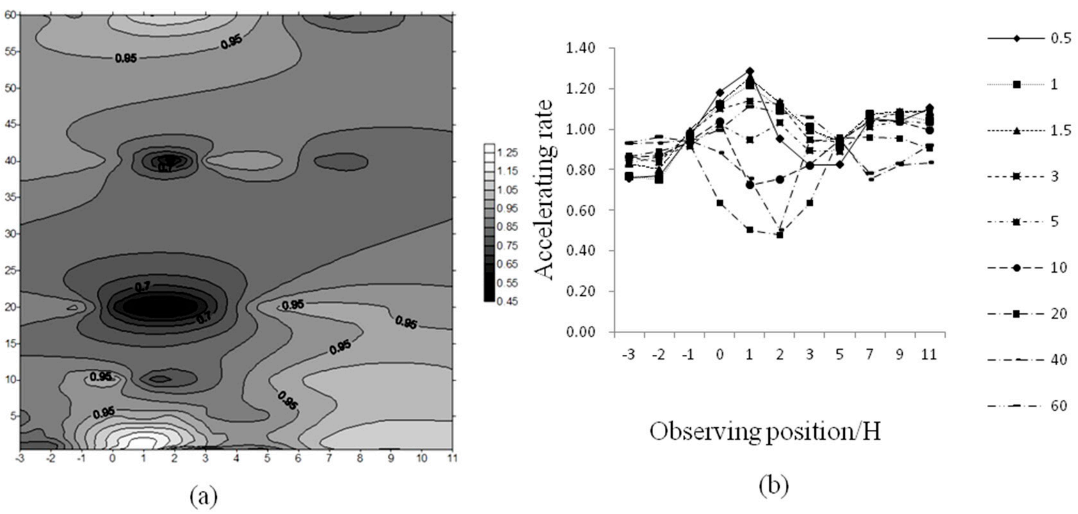

Figure 5. Isolines (**a**) and variation trend of accelerating rate (**b**) of 16 m/s [13]. Note: The left graph is the contour map of acceleration rate, and the right graph is the trend line of acceleration rate change at different heights. The abscissa of the left graph is the observation position/H, the field plots "-" at the windward side, the field plots "+" at the leeward side, H = 40 cm, and the ordinate is the height/cm.

Due to the effect of the forest belt, the wind speed and turbulence exchange in the vineyards are weakened, which can change the microclimate [14]. The air temperature and humidity of the vineyard with a windbreak of shoots and a control vineyard (without this windbreak) exhibit the same trend over time, with no significant effect on temperature. When the temperature is very low in winter, the branch wind barrier provides thermal insulation, significantly increasing the temperature by about 1.17 °C. There is a greater impact on humidity. Compared with the soil of the control vineyard, there was an approximately 2% higher water content of the different soil layers of the vineyard with windbreaks. The average soil water content of different soil layers showed a small change range, with obvious water retention effect after precipitation.

The use of a windbreak of shoots significantly influenced the sediment discharge distribution near the surface, which may alter wind speed and soil water content [60]. Wang et al. established the relationship between sediment discharge and different heights in the vineyard (with or without a shoot windbreak) and found it followed a power function. The amount of sediment transport decreases with the increase of height and is mainly concentrated at 5–40 cm near the ground. The windbreak has a significant impact on the distribution of sand transport near the surface, but this effect gradually goes away as the height increases. Vineyards with a windbreak of shoots exhibit higher total sediment discharge than the control, with more near-surface (5–40 cm) sediment transport. The presence of the windbreak of shoots effectively reduces the movement of dust particles caused by wind and causes the sand particles carried in the airflow to settle [61–63]. Significant differences were also observed in the amount of soil wind erosion in different positions.

5. 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 [64] 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. Natural regulating mechanisms and resources should replace environmentally unfriendly practices to ensure a long-term sustainable production system of high-quality vines. 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 [20]. Thus, the goal of sustainable viticulture can be defined as high quality, stable, and long-term production with vineyards that are pleasing in appearance [21].

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 [21]. CCM proposes to replace the traditional burial method that destroys the ecology with BLF protection, combined with the strategies of inter-row grass and in-row branch coverage, and winter shoots windbreak, which is of great significance for protecting vineyard biodiversity and improving and rebuilding the ecological environment. 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.

6. Conclusions

Sustainable development is a major goal of the international community and is a priority guiding China's national policies. In the viticulture area of China, more than 90% of the areas require the burial of vines in winter to prevent cold damage. The traditional viticulture mode does not meet the requirements of sustainable viticulture in the winter soil-burial zone of China. For this reason, an alternate cultivation program has been designed and implemented. This system is based on minimum pruning and pool-source relations regulation theory, with specific cultivation strategies to achieve mechanized management of vine production. Importantly, the CCM method allows sustainable viticulture.

CCM includes the use of a degradable liquid film to protect the vines as an alternative to the traditional method of soil burial in winter for cultivation in northern China. CCM includes key methods, such as winter suspension of shoots, growth of natural grass between rows, branch covering of rows, and physical methods of flower and fruit thinning. The use of CCM results in an improved microenvironment of the garden, reduced wind erosion of vineyard soil, and improved fruit quality. This simplified approach allows improved mechanized management. With more than 20 years of research and promotion, this cultivation strategy largely meets the natural, ecological, and cultural needs for the cultivation of vines grown in cold regions in China, and meets the requirements for sustainable development of vines with high quality, sustainable, and stable production, using aesthetically pleasing vineyards.

Future work should examine alternatives to soil burial using natural regulation mechanisms to safeguard the diversity of viticulture and related ecosystems, minimize the use of inputs and energy, and protect and improve the appearance of vineyards. These measures should allow increased quality, reduced costs, and more efficient energy use in vine cultivation and wine production.

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