



## Article

# Ecosystem Service Function and Assessment of the Value of Grape Industry in Soil-Burial Over-Wintering Areas

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**Abstract:** As a representative economic crop with the potential for long-term sustainable development, grapevines (*Vitis vinifera* L.) bring direct economic benefits to the people, and the indirect ecological benefits produced by grapevines cannot be ignored. This study utilized relevant statistical data from the government sectors and data obtained at vineyards and wineries through interviews and surveys. The value of the ecosystem service of the grape industry in soil-burial over-wintering areas was first evaluated from four first-level indicators types and 10 s-level indicators types, using Hongsibu of the eastern foothill of Helan Mountain, Ningxia, as an example. The results show that the total current benefits of the grape industry ecosystem service function in Hongsibu are ¥ 1067 million. The direct economic benefits are ¥ 660 million and indirect ecological benefits are ¥ 407 million. The value ranking of the first-level function types is as follows: supply services > cultural services > support services > regulatory services. The ranking of the value of second-level function types is as follows: food production > ecological poverty alleviation > biodiversity > carbon fixation and oxygen release > ecotourism > air purification > nutrient accumulation > water conservation and efficiency > water holding > soil conservation. Cultivation measures (such as burial-free cultivation technology, inter-row grass technology, and suspending grape branches after winter pruning technology) increased the value of the service function of the grape ecosystem and explored some potential benefits. The results indicated the necessity of assessing ecosystem service value of the grape industry, which could enable people to realize the direct economic benefits as well as the ecological benefits. Meanwhile, the positive effects of cultivation techniques on the value of ecosystem service function were demonstrated in soil-burial over-wintering areas. This study provides important reference value and comprehensive guidance for the healthy and sustainable development of the grape industry.

**Keywords:** viticulture; soil-burial over-wintering areas; grape industry; ecosystem service function



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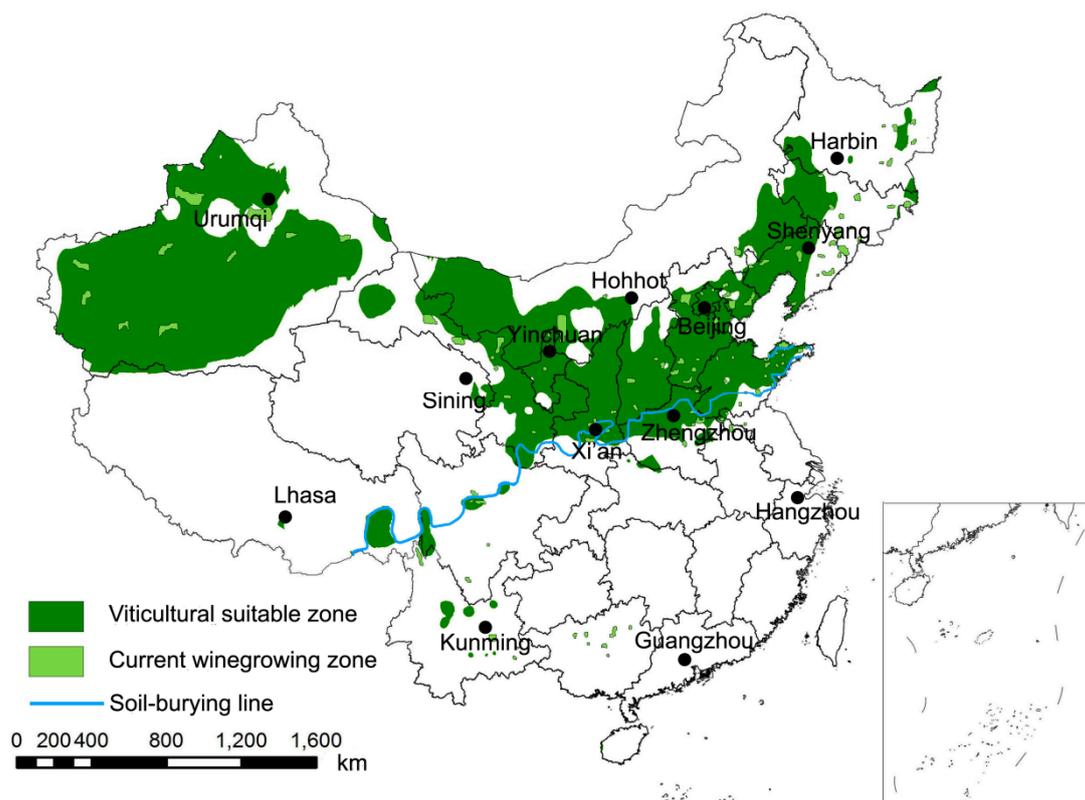
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## 1. Introduction

Statistics released by the OIV (International Organization of Vine and Wine) indicated that the total area of global grape cultivation was 7.4 million ha in 2018, of which 875,000 ha are cultivated in China [1]. Thus, China has become the world's second largest grape-growing country. China has a wide range of grape-growing areas. There are grapevines grown in 32 provinces across the country [2]. However, excellent grapevines growing areas are primarily concentrated in arid and semi-arid areas in northern China [3]. These regions have cold winters, strong wind and blowing sand, and low temperatures [4]. If the vines

are not insulated in time, they will dry in the air and develop freeze injuries, which will affect the growth and yield of the grapevines in the following year [5].

Grapevines are thermophilic plants. Most grapevines cultivated in China are *V. vinifera* varieties, which require soil-burying to safely over-winter, as the mature shoots of *V. vinifera* can only tolerate a low temperature of about  $-15\text{ }^{\circ}\text{C}$  during winter dormancy [6–8]. Wang et al. analyzed 30 years (1982–2011) of meteorological data from 2294 meteorological stations in China. They selected the soil-burial over-wintering areas using the location that experienced an annual extreme minimum temperature of less than or equal to  $-15\text{ }^{\circ}\text{C}$  more than three times within 30 years [9,10], as shown in Figure 1.



**Figure 1.** Distribution of suitable viticultural zone and current winegrowing zone in viticultural climatic zoning map of China. Viticultural suitable zone according to the special continental monsoon climate characteristics in China; current winegrowing zone according to the distribution of Chinese wine regions; soil-burying line according to the annual extreme minimum temperature was less than or equal to  $-15\text{ }^{\circ}\text{C}$  for more than three times within 30 years.

Ninety percent of the grapevines in China are located in the soil-burial over-wintering areas [3]. Grapevines are protected from the cold by burying the vines, which damages the soil surface, accelerates wind erosion, increases soil carbon emissions, and affects the grape ecosystem to some extent [3,11]. Liu et al. determined the effect of in-row mulching in the Yinchuan region on the ecological environment of the vineyard [12]. They found that in-row branches and straw mulch can significantly reduce the air temperature and humidity of the canopy of grapevines and soil temperature and increase the number of soil microorganisms. This is consistent with the research of Xi and others on the cover cropping system of vineyards [13–15]. Wang studied the ability of grapevines to serve as windbreaks in winter in the soil-burial over-wintering areas and found that windbreaks of grapevines branches can change the structure of the wind and sand flow near the surface of the vineyard during the period of soil-burial over-wintering and affect the distribution of sand transport near the surface [16]. The grapevines have blocks and cause the wind and sand to subside, resulting in an average value of total sediment transport within 5 to 150 cm from the surface to be 39.0% higher than the control [17]. The study also found that

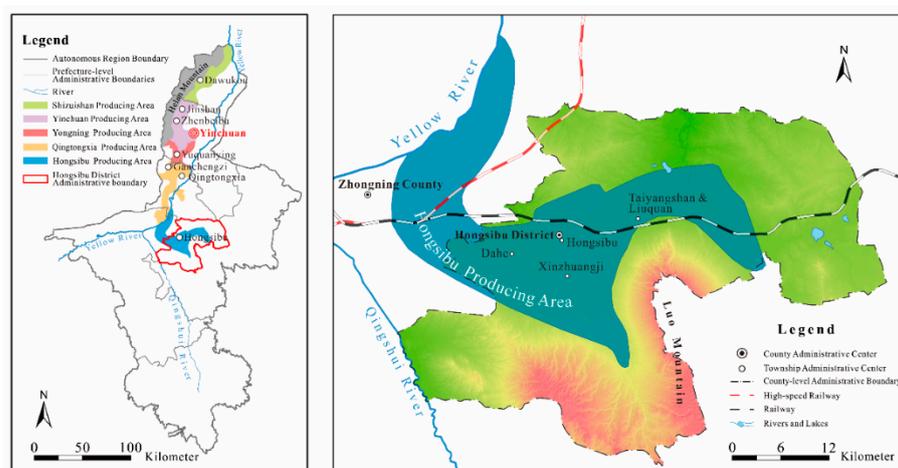
branch wind barriers significantly affect the wind erosion of the vineyard. Wind barriers settle sand particles in the wind, and wind erosion primarily results in sedimentation, which reduces the amount of erosion by 75.85% [17].

As a service crop, grapevines are considered to play a role in soil protection. In addition, the vineyard provides a large number of ecosystem services, such as weed control, pest and disease regulation, water supply, water purification, field trafficability, soil biodiversity, carbon sequestration, alleviating poverty and land degradation [18–21]. Currently, the research on the grape industry in the soil-burial over-wintering areas is primarily focused on the selection and development of new grape varieties, grape quality improvement and efficient cultivation techniques, key technology innovation and application of the wine industry chain, and little research has been conducted in the field of grape ecology [22]. This research aims to understand the economic and ecological value of the grape industry. Based on this, we have made an evaluation system for the value of the ecosystem service function of vineyards and conducted a systematic analysis. Our research will contribute to the sustainable development of the grape industry in soil-burial over-wintering areas.

## 2. Research Areas and Research Methods

### 2.1. Research Areas

As shown in Figure 2. Hongsibu ( $105^{\circ}43'45''$  E,  $37^{\circ}28'08''$  N) is located in the protected area of the National Geographical Declaration of Wine Grapes in the eastern foothills of Helan Mountain, Ningxia. This area is a temperate arid climate zone, and the continental climate is readily apparent. The annual average rainfall is 277 mm, and the annual mean evaporation is 2050 mm. The annual average temperature is  $8.4^{\circ}\text{C}$ , the average temperature in the growing season from May to October is  $17.9^{\circ}\text{C}$ . The annual effective accumulated temperature ( $\geq 10^{\circ}\text{C}$ ) is above  $3200^{\circ}\text{C}$ , and the average frost-free period is more than 170 days, which can fully meet the conditions of middle-late maturity grape cultivation [18].



**Figure 2.** Location Map of Hongsibu District. The eastern foothills of Helan Mountain Region, Ningxia, is an internationally famous wine grapes-producing area, including five wine grapes sub-regions. The Hongsibu producing area is one of them.

### 2.2. Research Methods

Currently, there are many ways to evaluate ecosystem service functions, but evaluation systems for the ecosystem service functions of the grape industry are rare [23–27]. The method of this study is based on the classification of ecosystem services functions in China by Xie et al. [28]. For the first time, the ecosystem service functions of the grape industry are summarized into four first-level and 10 s-level indicator types as alluded to in the “Forest Ecosystem Service Function Evaluation Standards” (LY/T1721-2008) and China’s economic forest ecosystem service value evaluation methods [29]. The evaluation index system of the grape ecosystem service functions is shown in Table 1.

**Table 1.** The evaluation index system of the grape ecosystem service functions.

Ecosystem Service Functions		Evaluation Index	Calculation Formula	Parameter Description
Level 1 Indicators	Level 2 Indicators			
Supply service	Food production	Value of grape	$V_f = P \cdot A \cdot M - C_i$	P: the vineyard yield; A: the vineyard area; M: the market price of grapes; C <sub>i</sub> : the cost input. B: the single bottle price of wine; C: the total wine production; C <sub>i</sub> : the cost input.
		Value of wine	$V_w = B \cdot C - C_i$	
Regulatory service	Carbon fixation and oxygen release	Value of carbon fixation	$V_c = P_c \cdot A \cdot (U_{pc} + U_{dc})$	P <sub>c</sub> : the carbon fixation price; U <sub>pc</sub> : the carbon storage above the vineyard; U <sub>dc</sub> : the carbon storage above the vineyard. P <sub>o</sub> : the price of oxygen; N: the net CO <sub>2</sub> exchange amount of the vineyard ecosystem; b: the proportionality coefficient, which is 0.73. R: the average rainfall; E: the average annual evapotranspiration; P: the unit water storage cost. X: the average water used for grape irrigation; x: the average water used for agricultural irrigation; P: the average price of crop water. H: the stand height; K: the cost of production of negative ions; Q: the concentration of negative ions in the forest; L: the retention time of negative ions; 600 is the lowest air negative ion concentration that is beneficial to human health;
		Value of oxygen release	$V_o = P_o \cdot N \cdot A \cdot b$	
	Water holding	Value of water holding	$V_w = (R - E) \cdot A \cdot P$	
	Water conservation and efficiency	Value of water conservation	$V_w = (X - x) \cdot A \cdot P$	
		Value of negative ion production	$V_i = 52.56 \times 1014 \times A \cdot H \cdot K(Q - 600)/L$	
	Air purification	Value of absorption of harmful gases	$V_h = \sum K_i \cdot Q_i \cdot A$ (i = SO <sub>2</sub> , NO <sub>x</sub> , HF <sub>x</sub> )	K <sub>i</sub> : the unit price of pollution treatment unit; Q <sub>i</sub> : the amounts of pollutants absorbed per unit area of vineyard. K: the unit price of the control cost of dust reduction; Q: the amount of dust reduction blocked by the vineyard per unit area.
Value of dust retention		$V_d = K \cdot Q \cdot A$		
Support service	Soil conservation	Value of soil fixation	$V_s = A \cdot C \cdot (X_2 - X_1)$	C: the soil conservation price; X <sub>2</sub> : the annual soil erosion modulus of the original topography; X <sub>1</sub> : the annual soil erosion modulus after the grapes is planted. C <sub>i</sub> : the pure content of N, P, K and O in the vineyard soil; P <sub>i</sub> : the price of N, P, K and O.
		Value of retaining fertilized	$V_f = \sum A \cdot C_i \cdot P_i \cdot (X_2 - X_1)$ (i = N, P, K, O)	
	Nutrient accumulation	Value of nutrient accumulation	$V_n = A \cdot C_i \cdot P_i$ (i = N, P, K)	C <sub>i</sub> : the annual pure content of N, P and K in grape plants; P <sub>i</sub> is the price of N, P and K. S: the protection value of annual biological species resources per unit area of vineyard.
	Biodiversity	Value of biodiversity	$V_b = S \cdot A$	
Cultural service	Ecological poverty alleviation	Value of employment	$V_e = P \cdot N$	P: the annual salary income per capita; N: the total number of people driving employment. P: the annual per capita tourism expenditure; N: the total number of tourists
	Ecotourism	Value of tourism	$V_t = P \cdot N$	

### 2.3. Data Sources

The data in this study are derived from: (1) relevant statistics from the Water Resources Department of Ningxia Hui Autonomous Region; (2) statistics from the Statistics Bureau of Ningxia Hui Autonomous Region; (3) social and public data released by the Grape Industry Development Bureau of Ningxia Hui Autonomous Region; (4) statistical data of the Grape Industrial Office of Hongsibu District Agricultural and Rural Bureau; (5) data obtained at vineyards and wineries through interviews and surveys.

### 2.4. Data Standardization Procession

Using the sampling survey method, we randomly selected 108 grape growers and 10 chateaus to obtain source data on evaluation indicators of the comprehensive benefits. The actual value of each indicator was then calculated using the formulas listed in Table 1.

## 3. Results

As of the end of 2018, the total grape planting area in Hongsibu has reached 7633.33 ha under conventional cultivation management, of which 7066.67 ha for wine grapes and 566.67 ha for table grapes.

### 3.1. Value of Ecosystem Service Function

#### 3.1.1. Supply Service

##### Food Production Function

We referenced the research by Zhang and Lei on the status of the grape industry in Hongsibu, and the relevant data in 2018 was provided by the Grape Industrial Office of Hongsibu District Agricultural and Rural Bureau [30,31]. The results of this evaluation are shown in Table 2.

**Table 2.** Food production function value of Hongsibu's grape industry.

Evaluation Index		Planting Distribution (ha)	Yield (kg·ha <sup>-1</sup> )	Unit Selling Price (¥·kg <sup>-1</sup> )	Earnings (Million ¥)
Grape	Wine grape	Chateau <sup>a</sup>	3000~6000	5.0~10.0	174
		Farmer <sup>b</sup>	12,000~15,000	3.0~5.0	102
	Table grape	Chateau & Farmer	22,500~30,000	5.0~7.0	89.3

<sup>a</sup> The first ingredient that defines a chateau owning a vineyard in viticultural suitable zone. In the table, chateau refers to a vineyard built by the chateau owner. <sup>b</sup> In the table, farmer refers to a vineyard built by the farmer.

As Table 2 indicates, the income of the fruits production function of the grape industry ecosystem in Hongsibu was ¥ 365.3 million (¥ is the symbol for RenMinBi, Yuan.). Considering the large initial investment in the vineyard, the cost of grapes only uses the labor and material costs for the year being analyzed. Research by Yang and Gao indicated that investment in grapes ranges from 12,500 to 15,000 ¥·ha<sup>-1</sup> [32]. The grape industry in Hongsibu invested ¥ 105 million, and the annual output value of the grapes was ¥ 260.3 million in 2018. In addition, according to the data provided by the Industrial Office of Hongsibu District Agricultural and Rural Bureau, the annual processing capacity of the Hongsibu's grape industry reached 35 million kg in 2018, with an annual output of 8 million bottles of finished wine and an output value of ¥ 400 million in profit. The total value of functional indicators of food production was ¥ 660.3 million. The output value of grapes and fruits accounts for 39.42% of the total value of food production, and the output value of wine accounts for 60.58% of the total value of food production.

#### 3.1.2. Regulator Service

##### Carbon Fixation and Oxygen Release Function

We referenced research by Guo and others on the net CO<sub>2</sub> exchange of vineyard ecosystems in the soil-burial over-wintering areas [33,34]. The amount of oxygen released by the grapes was 648 g·m<sup>-2</sup> during the main growth period. The ecological benefits of carbon fixation and oxygen release adopt the Chinese afforestation cost method. The price of carbon is 273.3 ¥·t<sup>-1</sup>, and the price of oxygen is 369.7 ¥·t<sup>-1</sup>. The results of this evaluation are shown in Table 3.

**Table 3.** Carbon fixation and oxygen release function value of Hongsibu's grape industry.

Evaluation Index		Design Formulas	Contribution Per Unit Area (g·m <sup>-2</sup> )	Total Contribution Amount (t)	Unit Price (¥·t <sup>-1</sup> )	Earnings (million ¥)
Carbon fixation	Aboveground part	$V_c = P_c \cdot A \cdot U_{pc}$	488	$3.72 \times 10^4$	273.3	10.2
	Underground part	$V_c = P_c \cdot A \cdot U_{dc}$	326	$2.49 \times 10^4$		6.6
Oxygen release		$V_o = P_o \cdot N \cdot A \cdot b$	648	$4.95 \times 10^4$	369.7	18.3

Vineyard is a carbon sink during the main growth period. The aboveground part of the sink is mainly concentrated in annual organs (fruits, etc.) and perennial organs (trunk, etc.). The underground part of the sink is mainly concentrated in roots and soil. As Table 3 indicates, the carbon fixation and oxygen release value of the grape industry ecosystem in Hongsibu is ¥ 35.1 million, of which the carbon fixation value is ¥ 16.8 million, accounting

for 47.86% of the total value of carbon fixation and oxygen release. The value of the oxygen released is ¥ 18.3 million, accounting for 52.14% of the total value of carbon fixation and oxygen release.

#### Water Holding Function

Statistics provided by the Water Resources Department of Ningxia indicated that the annual average evapotranspiration of the grape production area in the eastern foothills of Helan Mountain is 184 mm. The annual rainfall in Hongsibu production area is 277 mm. Based on the lowest transaction price of  $0.818 \text{ ¥}\cdot\text{m}^{-3}$  calculated by the Ningxia Academy of Water Sciences as the base price, we used the water balance method to calculate it [35]. The total amount of water conserved by the grape industry ecosystem in Hongsibu is 7.1 million  $\text{m}^3$ , and the ecological economic benefits generated by the water conservation are ¥ 5.81 million.

#### Water Conservation and Efficiency Function

Wang and Song showed that the annual amount of irrigation water used in the Hongsibu irrigation area is  $5710 \text{ m}^3\cdot\text{ha}^{-1}$ , and the annual irrigation water in grape is  $1500 \text{ m}^3\cdot\text{ha}^{-1}$  [26,36]. Compared with other crops, the grape aquatic production value is  $135 \text{ ¥}\cdot\text{t}^{-1}$ , which is 4.2, 7.6, 38.8 and 41.8 times the output value of wolfberry (*Lycium barbarum* L), potato (*Solanum tuberosum* L), corn (*Zea mays* L) and wheat (*Triticum aestivum* L), respectively [36]. Statistics from the Water Resources Department of Ningxia indicated that the price of different crops before the reform was  $0.22 \text{ ¥}\cdot\text{m}^{-3}$ , and the ecological and economic benefits of water-saving and efficiency improvement of the Hongsibu grape industry ecosystem were ¥ 7.08 million.

#### Air Purifying Function

The index of negative ions in the air in vineyard ecosystems is based on previous studies on negative ions in the air of different types of vegetation [37,38]. The amount of harmful gases absorbed and the treatment costs are based on the results of Ma [39]. The results of this evaluation are shown in Table 4.

**Table 4.** Atmospheric purification function value of Hongsibu's grape industry.

Evaluation Index		Design Formulas	Unit price ( $\text{¥}\cdot\text{kg}^{-1}$ & $\text{¥}\cdot 10^{-18}\cdot\text{unit}^{-1}$ )	Total Contribution Amount (kg & unit)	Earnings (¥)
Negative ion production		$V_i = 52.56 \times 1014 \times A \cdot H \cdot K \cdot (Q - 600) / L$	7.29	$5.69 \times 1020$	4150
Absorption of harmful gases	Absorption of $\text{SO}_2$	$V_{\text{SO}_2} = K_{\text{SO}_2} \cdot Q_{\text{SO}_2} \cdot A$	0.6	687,000	412,000
	Absorption of $\text{NO}_x$	$V_{\text{NO}_x} = K_{\text{NO}_x} \cdot Q_{\text{NO}_x} \cdot A$	0.9	509,000	458,000
	Absorption of HF	$V_{\text{HF}} = K_{\text{HF}} \cdot Q_{\text{HF}} \cdot A$	0.6	6100	3660
Dust retention		$V_d = K \cdot Q \cdot A$	170	68,700	11,700,000

The unit price of negative ion production is  $\text{¥}\cdot 10^{-18}\cdot\text{unit}^{-1}$ . The unit price of absorption of harmful gases and dust retention is  $\text{¥}\cdot\text{kg}^{-1}$ .

Table 4 indicates that the annual purification value of the grape industry ecosystem in Hongsibu is ¥ 12.58 million. Among them, the value of providing negative ions is ¥ 4150, accounting for 0.03% of the total value of purifying the atmosphere; the value of absorption of  $\text{SO}_2$  is ¥ 412,000, accounting for 3.28% of the total value of purifying the atmosphere. The value of absorption of  $\text{NO}_x$  is ¥ 458,000, accounting for 3.65% of the total value of purified air. The value of HF is ¥ 3660, accounting for 0.03% of the total value of purifying the atmosphere. The value of retarding the fall of dust is ¥ 11.7 million, accounting for 93% of the total value of purifying the atmosphere.

#### 3.1.3. Support Services

##### Soil Conservation Function

Wang and Gao conducted research on the soil and water conservation monitoring of Hongsibu [40,41]. The original landform soil erosion modulus of the Hongsibu irrigation

area was  $3.50 \times 10^{-3} \text{ t}\cdot\text{m}^{-2}\cdot\text{year}^{-1}$ , and the allowable soil loss in the irrigation area after the development of forest and grasscover management is  $8.00 \times 10^{-4} \text{ t}\cdot\text{m}^{-2}\cdot\text{year}^{-1}$ . Xiao et al. found that the price of soil conservation is  $6.52 \text{ ¥}\cdot\text{t}^{-1}$  [42]. The research of Wang on the mechanisms of nitrogen, phosphorus, potassium and those in the soil of the grape production area in the eastern foothills of Helan Mountain indicated that the content of organic matter in the soil of the vineyard is  $10.79 \text{ g}\cdot\text{kg}^{-1}$  [43]. We converted the total amount of standardized ammonium diammonium phosphate and potassium chloride to facilitate their conversion into pure nitrogen, phosphorus, and potassium. The ratios of the fertilizers are 132/28, 132/31, and 75/39. The price of chemical fertilizers is calculated based on the average cost of Chinese chemical fertilizers equaling  $2.55 \times 10^3 \text{ ¥}\cdot\text{t}^{-1}$  [44]. The ratio of general fuel wood to soil organic matter is 2:1, and the opportunity cost per ton of fuel wood is  $\text{¥} 51.3$  [45]. The results of this evaluation are shown in Table 5.

**Table 5.** Atmospheric purification function value of Hongsibu's grape industry.

Evaluation Index	Design Formulas	Unit Price (¥·t <sup>-1</sup> )	Total Contribution Amount (t)	Earnings (¥)
Soil fixation	$V_s = A \cdot C \cdot (X_2 - X_1)$	6.52	206,000	1,340,000
Fertilizer retained	Retention of organic $V_O = A \cdot (X_2 - X_1) \cdot C_O \cdot P_O$	103	2220	227,000
	Retention of nitrogen $V_N = A \cdot (X_2 - X_1) \cdot C_N \cdot P_N$		3.48	88,700
	Retention of phosphate $V_P = A \cdot (X_2 - X_1) \cdot C_P \cdot P_P$	2550	2.74	69,900
	Retention of potassium $V_K = A \cdot (X_2 - X_1) \cdot C_K \cdot P_K$		18.9	481,000

Table 5 indicates that the annual soil conservation value of the grape industry ecosystem in Hongsibu is  $\text{¥} 2.21$  million. Among them, the value of solid soil is  $\text{¥} 1.34$  million, accounting for 60.74% of the total value of conservation soil. The value of soil is  $\text{¥} 867,000$ , accounting for 39.26% of the total benefit of soil conservation.

#### Nutrient Accumulation Function

Based on the results of research by Ma, on the nutrient accumulation of grapes in soil-burial over-wintering areas, the distribution of nitrogen, phosphorus, and potassium in various parts of grape plants is shown in Table 6 [46]. The N, P, K content ( $\text{kg}\cdot\text{hm}^{-2}$ ) = N, P, K content ( $\text{g}\cdot\text{kg}^{-1}$ )  $\times$  dry weight ( $\text{kg}\cdot\text{strain}^{-1}$ )  $\times$  number of plants ( $\text{strain}\cdot\text{ha}^{-1}$ )  $\times 10^{-3}$ .

**Table 6.** Grape plant nutrient accumulation and distribution chart.

Nutrient ( $\text{kg}\cdot\text{ha}^{-1}$ )	Leaves	Petiole	Shoot	Trunk	Vine Root	Fruit	Total	Earnings (¥)	Value Composition (%)
Nitrogen content of the grapevine	53.5	2.8	36.0	26.1	17.6	60.7	196.7	3,830,000	41.50
Phosphate content of the grapevine	28.5	3.6	24.1	13.2	17.6	19.7	106.7	2,080,000	22.52
Potassium content of the grapevine	29.3	19.2	42.7	15.2	8.6	55.2	170.5	3,320,000	35.98

Table 6 indicated that the total accumulation of annual nutrients in the vines of the grape industry ecosystem in Hongsibu is  $473.9 \text{ kg}\cdot\text{ha}^{-1}$ . The total grapevines planting area in Hongsibu was 7633.33 ha. The total accumulation of annual nutrients in the vines of the grape industry ecosystem in Hongsibu is 36.2 million kg, and the value is  $\text{¥} 9.21$  million. Among them, the accumulated amount of nitrogen in the vine is 15 million kg, with a value of  $\text{¥} 3.83$  million, accounting for approximately 41.50% of the total benefits of the accumulation of material. The accumulated amount of phosphorus in the vine is 8.14 million kg, and the value is  $\text{¥} 2.08$  million, accounting for 22.52% of the total benefits of the accumulation of material. The accumulated amount of potassium in the vine is

13 million kg, and the value is ¥ 3.32 million, accounting for approximately 35.98% of the total benefits of the accumulation of material.

#### Biodiversity Function

Wang and other researchers who have evaluated economic forest ecosystem services in China have reported that the Shannon-Wiener index is an important tool to calculate the conservation value of biological species resources [29]. When the index is 2 to 3, the conservation value of biodiversity is  $20,000 \text{ ¥} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ . When the index is 3 to 4, the conservation value of biodiversity is  $30,000 \text{ ¥} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ . The research on vineyard soil microbial communities by Si, indicated that the diversity index of soil microbial communities in clear plowed vineyards is between 2 and 3 [47]. Therefore, we can estimate that the value of the annual biodiversity function of the grape industry ecosystem in Hongsibu is ¥ 153 million.

#### 3.1.4. Cultural Service

##### Ecological Poverty Alleviation Function

Based on the research by Yang and Gao on the status of Hongsibu's grape industry, the grape labor is 0.7 ha per person [32]. The entire grape base area of Hongsibu is 7633 ha, which requires 10,904 people to stabilize employment. The annual income is calculated at ¥ 15,000 per person, which can increase the income of the production area and surrounding farmers by ¥ 164 million. The grape industry has become a pillar industry to alleviate poverty in soil-burial over-wintering areas.

##### Ecotourism Function

Based on the Hongsibu District People's Government Work Report, the area received 440,000 tourists and achieved a comprehensive tourism income of ¥ 16.6 million in 2017. Hongsibu received 471,000 tourists throughout the year by holding a picking festival for special industries in 2018. Based on the per capita tourism expenditure in 2017, it realized a comprehensive tourism income of ¥ 17.77 million in 2018.

#### 3.2. Direct and Indirect Benefits

As Table 7 indicates, the total current benefits of the grape industry ecosystem service functions are ¥ 1067 million, of which direct economic benefits are ¥ 660 million and indirect ecological benefits are ¥ 407 million. Ecological benefits account for 38.14% of the current total benefits of the grape industry ecosystem service functions. The value ranking of the first-level function types is as follows: supply services > cultural services > support services > regulatory services. The ranking of the value of second-level function types is as follows: food production > Ecological poverty alleviation > biodiversity > carbon fixation and oxygen release > ecotourism > air purification > nutrient accumulation > water conservation and efficiency > water holding > soil conservation.

#### 3.3. Current and Potential Benefits

We designate the current benefits of the grape industry ecosystem service functions, and the potential benefits of the grape industry ecosystem service functions under different models of cultivation technology. This study only considered the burial-free cultivation technology, inter-row grass technology, and suspending grape branches after winter pruning technology of the grape industry in the soil-burial over-wintering areas. By analyzing the data in research by Xue, it was known that the burial-free cultivation as an overwintering measure for soil-burial over-wintering areas reduced the average wintering cost from 22% of the annual management to 6.5%. Converting it into the value of food production, the implementation of burial-free cultivation technology increased the value of food production by ¥ 16.3 million in soil-burial over-wintering areas.

**Table 7.** Direct benefits and indirect benefits of grape industry ecosystem service functions in Hongsibu.

Ecological Functions	Level 1 Type	Level 2 Type	Ecological Service Value (Million ¥)	Value Composition (%)	Ecological Value Composition (%)	
Direct benefits	Supply service	Food production	660.30	61.88	61.88	
Indirect benefits	Regulatory services	Carbon fixation and oxygen release	35.10	3.29	5.67	
		Water holding	5.81	0.54		
		Water conservation and efficiency	7.08	0.66		
		Air purification	12.58	1.18		
	Support services	Soil conservation	2.21	0.21	15.41	
		Nutrient accumulation	9.21	0.86		
	Cultural services	Ecological poverty alleviation	Biodiversity	153.00	14.34	17.04
			Ecotourism	17.77	1.67	

The technique of suspending grape branches in winter reduced the wind blowing on the soil surface particles, thereby reducing the amount of erosion by 75.85% [11]. Converting it into the value of solid soil, the implementation of suspending the grape branches after winter pruning technology increased the solid soil value by ¥ 1.02 million in soil-burial over-wintering areas. In addition, the study found that the implementation of inter-row grass technology in soil-burial over-wintering areas significantly increased the content of soil organic matter. Compared with the control of clear cultivation, the inter-row grass soil organic matter content increased by 1.5 g·kg<sup>-1</sup> [18]. Converting it into organic matter preservation value, the implementation of inter-row grass technology in soil-burial over-wintering areas, preserved the value of the fertilizer by ¥ 31,700.

Moreover, the implementation of inter-row grasscover technology in vineyards significantly increased the richness of soil microbial communities, resulting in a 0–20 cm soil layer microbial community diversity index greater than three [41]. The implementation of inter-row grasscover technology in soil-burial over-wintering areas increased the biodiversity value by ¥ 76.3 million following converting into this value. However, the vineyard inter-row grass technology reduced the soil water storage, and the average decline for two consecutive years reached 9.15% [42]. Following conversion into the value of water holding, the implementation of inter-row grass technology in vineyards reduced the value of conservation water by ¥ 532,000. The potential benefits assessment does not cover all ecological service functions related to the current benefits, as some of the research has not been conducted in soil-burial over-wintering areas. The results of this evaluation are shown in Table 8.

**Table 8.** Current and potential benefits of the grape industry ecosystem service functions in Hongsibu.

Ecological Functions	Level 1 Type	Level 2 Type	Current Benefits (Million ¥)	Potential Benefits (Million ¥)	Potential Benefits Composition (%)	
Direct benefits	Supply service	Food production	660.30	676.63	58.33	
Indirect benefits	Regulatory services	Carbon fixation and oxygen release	35.10	/	5.18	
		Water holding	5.81	5.28		
		Water conservation and efficiency	7.08	/		
		Air purification	12.58	/		
	Support services	Soil conservation	2.21	3.26	20.82	
		Nutrient accumulation	9.21	/		
	Cultural services	Ecological poverty alleviation	Biodiversity	153.00	229	15.67
			Ecotourism	17.77	/	

Table 8 indicates that the potential benefits of the grape industry ecosystem service function under the supporting cultivation technology are ¥ 92.85 million. Combined with Table 7, the total potential benefits of the grape industry ecosystem service that functions under supporting cultivation technologies are ¥ 1160 million, of which direct economic benefits are ¥ 677 million and indirect ecological benefits are ¥ 483 million. Ecological benefits account for 41.67% of the total potential benefits of the grape industry ecosystem service functions. The value of first-level indicator types supports service functions exceeds those of cultural service functions, exerting a greater ecological value embodied in the richness of biodiversity.

## 4. Discussion

Grapevine ecosystems both provide and rely upon important ecosystem service, which can be classified into four main categories: supply service, regulating service, supporting service and cultural service [48]. Understanding the value of ecosystem service function is necessary for soil-burial over-wintering areas, which is of great significance to the sustainable and healthy development of grape industry [36]. This research mainly evaluated the ecological service function value of grape industry in soil-burial over-wintering areas, and analyzed the direct and indirect ecological benefits of the grape industry. In addition, a comparative analysis of potential benefits and current benefits of the grape industry under some cultivation measures in the soil-burial over-wintering areas has been done, which provides a potential direction for subsequent research.

### 4.1. Grape Industry Provides Important Ecosystem Service Value

Grape ecosystem services confer benefits and costs, respectively, to agriculture. These are supplied by varied species and functional groups in grapevine yards over a range of scales, and influenced by human activities [48]. The grape industry ecosystem not only provides food for humans but also includes enormous environmental regulatory and ecological service functions in the soil-burial over-wintering areas [36]. Our research results showed that the value of food supply accounted for 61.88% of the entire grape industry ecosystem service value which was the greatest value of the grape industry ecosystem; these results were consistent with previous research results [36]. The second was cultural services. Among them, the value of ecological poverty alleviation contributes the most to the cultural service value. This shows that the development of the grape industry has increased the income of residents, and solve the employment problem of the poor effectively, thus producing significant social benefits [18].

However, the low value of eco-tourism was derived in this study. The reason may be that Hongsibu production area, on the eastern foot of Helan Mountain, is small. On the one hand, the superior local resources are significantly lower than the average level of the entire production area. On the other hand, the regional tourism industry is not well developed and is still lagging behind [49,50]. The potential role of biodiversity in the grape ecosystem can help provide economically relevant ecosystem services [19]. In this study, the functional value of biodiversity contributed the greatest to support service value, indicating that cultivating grapes help enrich the biodiversity in soil-burial over-wintering areas. Microorganisms (bacteria, fungi, actinomycetes) are critical mediators of this ecosystem service. For example, bacteria enhance nitrogen availability through the fixation of nitrogen from the atmosphere. This occurs most often in plants that have symbiotic relationships with N-fixing bacteria, but free-living soil bacteria fix nitrogen as well [51]. Microorganisms also enhance soil fertility by liberating nutrients from detrital organic matter (e.g., plant leaves) and retaining nutrients in their biomass that might otherwise be lost downstream [52]. Therefore, rich biodiversity is of great significance to the accumulation and circulation of soil nutrients.

However, in this study, although the biodiversity value of vineyards was much higher than that of sea buckthorn, the soil conservation value and nutrient accumulation value were only ¥ 2.21 and ¥ 9.21 million, respectively, which were far lower than the soil conservation value of sea buckthorn [53–55]. The reason may be that vineyard farming methods (such as burying and unearthed mechanical farming) will damage the soil surface, limiting soil conservation to a certain extent [11]. Grapevines are not only an economic forest, which produces fruits, but also a characteristic green forest, which is conducive to the improvement of the ecological environment, mainly through carbon fixation and oxygen release [36], water conservation and water-saving and efficiency-enhancing [56], as well as atmospheric purification [36].

Trees improve water infiltration within woodlands, and reduce surface runoff and soil salinization [57]. Wetlands and riparian vegetation can also improve water quality and attenuate floods [58]. In this study, the total value of water holding and water conservation

of the vineyard accounted for 1.20% of the total value, which is still higher than many traditional local crops, such as corn, wheat, rice and potatoes [36]. It shows that grapes consume less water during cultivation and are suitable for planting in arid and semi-arid areas in northern China.

Carbon fixation and oxygen release as well as air purification are important parts of the regulation service function. In this study, carbon fixation and oxygen release accounted for a relatively high proportion of the regulation service value, followed by air purification. Studies found that total carbon storage of the *Vitis vinifera* 'Cabernet Sauvignon' vineyard ecosystem is  $55.35 \text{ t} \cdot \text{ha}^{-1}$ , most of which is distributed in the soil surface (underground), and the remaining part is mainly distributed in the perennial, leaf and fruit parts of the vine (the aboveground) [59]. Grapes, as a protective forest in soil-burial over-wintering areas, are much more effective in cleaning the atmosphere than sea buckthorn, with a value of ¥ 1648 per ha for grapes and only ¥ 54.9 per ha for sea buckthorn [55].

#### *4.2. Grape Industry Plays an Important Role in Direct and Indirect Ecological Benefits*

Direct benefits mainly refer to the profit value of grape and wine; the indirect benefits are mainly reflected in the ecological benefits of the grape industry. In this study, the direct benefits of the grape industry accounted for 61.88% and the ecological benefits accounted for 38.12% of the total benefits of the ecosystem service value of the grape industry in soil-burial over-wintering areas. This indicates that the grape industry ecosystem not only provides direct benefits but also provides significant economic benefits for human society [36]. Among the ecological benefits, the value of ecological poverty alleviation was the highest, followed by the value of biodiversity. This shows that, in the context of the relatively fragile ecological environment of the soil-burial over-wintering areas, with the continuous expansion of the area of grape cultivation, the direct economic benefits are becoming more and more evident, while the ecological and biodiversity benefits it generates cannot be ignored [18]. Because of this, the importance of the long-term objectives of the vineyard system deserves to be considered. As a woody perennial crop, grapevines can be considered a service crop in the agricultural landscape, i.e., providing more overall services than products for sale. This cash crop is prone to delivering ecosystem services agro-ecosystems [18]. In addition to their ability to increase soil organic matter and fertility, and reduce runoff and erosion processes, service crops provide a large variety of ecosystem services in vineyards such as weed control, pest and disease regulation, water supply, water purification, improvement of field trafficability and maintenance of soil biodiversity [19]. It contributes to the protection and improvement of the ecological environment and is of great importance to the goal of sustainable development.

#### *4.3. Grape Industry Has Great Potential Benefits*

This study conducted an assessment and analysis of the ecosystem services value of vineyards with three cultivation techniques, showing that there is important potential benefits could be exploited in the grape industry. To a large extent, these potential benefits depend on the strategies of farmers and the tactical operations they set up [60]. We designated the current benefits of the grape industry ecosystem service functions, and the potential benefits of the grape industry ecosystem service functions under different models of cultivation technology. Only the burial-free cultivation technology, inter-row grass technology, and suspending grape branches after winter pruning technology of the grape industry in the soil-burial over-wintering areas were considered in this study. The implementation of burial-free cultivation technology added ¥ 16.3 million to food production value in soil-burial over-wintering areas. As part of the conservation tillage, costs (for example, labor, facilities, and operating costs) are decreased by reducing winter burial and spring emergence tillage, thus increasing the value of food supply service [61].

In addition, mulching techniques may also decrease soil evaporation [62] and prevent runoff and erosion from vineyard soils [63]. The implementation of the suspending grape branches after using winter pruning technology in vineyards reduces the amount of wind

blowing on soil surface particles and the amount of soil erosion [17], while increasing the value of soil conservation by ¥ 1.02 million in soil-burial over-wintering areas. The implementation of inter-row grass technology in the soil-buried overwintering zone increased the value of fertilizer retention and biodiversity by ¥ 31.7 and ¥ 76.3 million, respectively, but reduced the value of water retention by ¥ 532,000. This is due to the fact that the implementation of inter-row grass mulching in vineyards significantly increases the soil organic matter content and soil microbial community richness, but reduces soil water storage [12–14]. Several interventional strategies such as rational fertilization, cover crops, non-tillage, and other agronomic measures enhance soil structure and associated productivity, thereby improving the efficiency within the orchard ecosystem while simultaneously reducing net carbon emissions [19]. Therefore, it is possible to exploit the potential value of the vineyard ecosystem by changing some of the current cultivation practices.

Considering the potential value that can be realized, cultivators need to be managed, as does any other crop is grown with a direct economic purpose. The introduction of cultivation practices that help farmers overcome the problems often faced by vineyards (water loss, soil erosion and carbon emission) is developing, though it has not been systematically adopted by vineyard growers [18]. As the main reason for service crop rejection is still competition with grapevines, more research is needed to develop appropriate cultivation techniques according to the targeted services and tactical management options to achieve trade-offs between ecosystem service without impairing economic return of farmers [19].

Although this study quantitatively analyzed the current and potential benefits of the grape industry ecosystem service function in Hongsibu, due to the limitation of evaluation methods and data in the research process, not all the use values and non-use values of the system were evaluated, and the protection value, scientific research value, heritage value, and aesthetic value were absent from our study. Therefore, as far as the results of these evaluations are concerned, the actual ecological service value of the study area is much larger than the current results of this evaluation. In addition, during the process of evaluation, due to the lack of local research data for the evaluation of a single ecological function, some data indicators refer to the comparison of research results in other regions, which inevitably introduces certain errors. To more comprehensively and accurately evaluate the ecological benefits of the grape industry ecosystem service functions in the soil-burial over-wintering areas and minimize these types of errors, we need to explore the data in more detail and improve them in practice.

## 5. Conclusions

Among the four first-level functional values, supply services and cultural services account for the highest proportion. Among the 10 s-level functional values, food production, ecological poverty alleviation and biodiversity account for a relatively high proportion. Some cultivation measures, such as burial-free cultivation technology, inter-row grass technology, and suspending grape branches after winter pruning technology, increase the value of the ecosystem service function of grape industry and offer new opportunities to exploit the potential benefits of the grape industry. The development of the grape industry in the over-wintering areas help drive the local economy and employment, and provide income increases and poverty alleviation for the growers and solves the livelihood problem of the poor residents in sandy areas. Generally, the development of local grapevines industries effectively improves the local ecology, thus providing solutions to the dual pressures of poverty and environmental degradation, as well as providing a method of sustainable development worldwide.

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