Vitis **55**, 45–51 (2016) DOI: 10.5073/vitis.2016.55.45-51

Winter chill protection of grapevines by burial: Evaluation of the crawled cordon training system

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Summary

The objective of this work was to select a training system suitable for grapevines grown in areas where vine burial is practiced for protection against winter chill (especially as it is practised in the arid/semiarid areas of northern China). We evaluate the influence of a new training system crawled cordon training (CCT) and compare it with a traditional training system independent long-stem pruning (ILSP). The study considers fruit quality, sensory evaluation of wines and an analysis of labour practices at Rongchen Chateau in China during the years 2011, 2012 and 2013.

During the first three years under CCT, average yield was 39.69 % lower than under ILSP but CCT showed higher yield stability. The ripeness of grapes under CCT was higher than under ILSP, so sensory evaluation of CCT wines was also higher. Moreover, CCT also reduced the labour involved for winter pruning, summer pruning and harvesting by 24.4 %, 25.0 % and 37.5 %, respectively. This study shows that under CCT grape quality, yield stability and wine quality were significantly higher than under ILSP, while labour inputs (costs) were significantly lower.

K e y w o r d s : grapevine; training system; fruit quality; wine quality; labour costs.

Introduction

In viticulture, appropriate vine training is critical if fruit quality, and thus wine quality, are to be maximised. Training is traditionally achieved through winter pruning (SABBATINI and HOWELL 2010) with some summer pruning also being required in some systems. There are two predominant training systems used in northern China where there is a need to reposition the vines in autumn in order to bury them under a layer of soil during winter (vine burial) to protect them from severe winter chill. These systems are: fan training and independent long-stem pruning (ILSP) (ZHAO *et al.* 2008). With ILSP, the main trunk can be pulled down easily, avoiding fractures. However, the associated irregular fruiting may result in poor grape quality (LI 2001). Moreover, the ILSP system is not well adapted to mechanised harvesting. Thus ILSP becomes a significant problem in ensuring sustainable development of viticulture and the wine industry in northern China and also in other parts of the world that impose similar climatological constraints (LI *et al.* 2009).

Between 2000 and 2011, China's total vineyard area (including that devoted to fresh and dried grape production) nearly doubled to an estimated 560,000 ha (1,384,000 acres). This suggests China has become the world's sixth most important wine producer since the turn of the century (JOHNSON and ROBINSON 2013).

Most of China's best winegrowing regions are in arid and semiarid areas in the north of the country such as in Ningxia and Hebei Province which also suffer severe winter chill, so require winter vine burial. Along with the enlargement of China's viticulture areas, the growing demand for labour has also put pressure on the labour market in these regions (ZHAO *et al.* 2008). Hence, there is an urgent need to improve labour efficiency, and to decrease labour intensity at peak times when the local labour resource can be severely stretched. The associated reduction in labour will also reduce production costs and so will improve industry profitability (GAMBELLA and SARTORI 2014).

A combination of mechanisation and the adoption of novel, less-intensive, management systems have been identified as the twin solutions for these problems. The most appropriate vine training system is also key if mechanised operations are to be introduced for harvesting and also for vine burying, and these changes must also align with fruit and wine quality requirements (HU 2005). Some of the technological alternatives suggested here are the introduction of a different vine training system - crawled cordon training (CCT) - in conjunction with use of an understorey of wild grass within the rows as a replacement for the traditional clean tillage (LI *et al.* 2010). The CCT training system has one horizontal cordon lying along the soil surface, with regularly spaced vertical shoots along the cordon arising from about the level of the first wire (0.2 m). The new season's growth is then trained vertically during the growth period to form a regular canopy.

Although in Shanxi and Hebei provinces, CCT has been employed successfully in commercial vineyards for over 20 years, there are few reports on the effects of CCT

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on wines and vineyard management in areas requiring vine burial. ZHAO *et al.* (2013) studied the effects of multiple main vine fan-training, cordon-training and CCT in the area 111°02'-111°41'E, 34°02'-35°19'N, on factors relating to yield stability, fruit quality and disease incidence. Compared to ILSP, CCT has a strong positive effect on the aroma compounds of young wines from 'Ecolly' (*Vitis vinifera*) in the Weibei Plateau region of China (NAN *et al.* 2013).

The aim of the experiments reported here was to investigate the applications of CCT and ILSP in three *V. vinifera* cultivars - 'Chardonnay', 'Merlot', and 'Cabernet Sauvignon' with the effects on grape and wine quality being recorded. To help growers and winemakers to optimise vineyard management, the labour involved in all the main vineyard operations was also recorded and analysed.

Material and Methods

Experimental vineyard and site description: The experimental vineyard (ca. 80 ha) is located in Sangyang Basin, Rongchen Chateau, 115 °E, 40 °N, Huailai County of Hebei Province, China. Field experiments were conducted from 2011 to 2013, in vineyards with cinnamon soil that is partly sandy. The climate is characterised as a semiarid continental monsoon climate, with approximately 3,027 h per year of sunshine and an average annual rainfall of 413 mm. The mean annual temperature is approximately 12.5 °C and the minimal temperature in winter is -23.3 °C. Active accumulated temperature (growing-degree-days, base 10 °C) is about 3,586 °C. The Winkler Index is 1,850 °C. The duration of the frost-free season is 149 days per year, and the aridity index is 2.03. Due to the very cold winter temperatures, the vines require winter burial.

Material: Three grape cultivars were used, 'Chardonnay', 'Merlot', and 'Cabernet Sauvignon'. These were all planted in 1998 with 3 m row spacing, and 1 m in-row spacing. Each cultivar extended over about 27 ha. The grapevines were originally trained to ILSP in 1998, but half were re-trained to CCT in 2010. All vineyard managements (irrigation, fertiliser etc) were the same for the CCT and the ILSP trained vines.

ILSP: An upright model of a single dragon cordon, the shoots were randomly distributed, but no shoots were retained under the first wire (0.2 m). All fruit-bearing branches were cordon-spur for winter pruning, and remained a two (or three)-node spur at a node. In general, the greater numbers of spurs retained resulted in significantly more clusters per vine (Fig. 1).

CCT: All vines were pruned to one cordon along the surface of the soil. Selected shoots (spaced about every 15-20 cm) were trained to a vertical trellis during the growing period. It also was cordon-spur for winter pruning, but there was only one spur at a node (Fig. 2 and Fig. 3).

Yield components: Yield components of all vineyard plots were assessed at Rongchen Chateau at harvest. The yield of grapes per ha was calculated using Equation (1):

$$Y = 10000 \times \left(\sum_{a=n}^{n} \frac{Y_a}{S_a}\right) / n \qquad (1)$$

where Y, yield of grape per ha, kg·ha^{-1}; Ya, yield from the plot a which area was Sa, Kg; Sa, surface area of the plot a which has the yields (Ya) of grapes, m2; n: number of the plot.

Winemaking: Healthy berries were manually harvested at commercial harvest (in September 2011 and

Fig. 1: Vines under the "independent long-stem pruning" (ILSP) training system.

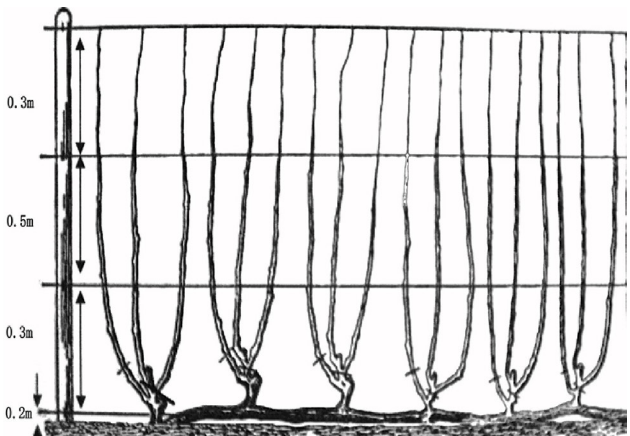

Fig. 2: Diagram of vines under the "crawled cordon training" (CCT) training system.

Fig. 3: Vines under the "crawled cordon training" (CCT) training system.

October 2012) and destemmed and crushed on the same day. The 'Merlot' and 'Cabernet Sauvignon' were processed with the skins present, but the 'Chardonnay' only as the juice. The three musts were placed in separate 5 hL stainless steel tanks and treated with 1 $L \cdot hL^{-1}$ sulphur dioxide (6 %). After 12 h, the wines were inoculated with 200 $g \cdot hL^{-1}$ of yeast (*Saccharomyces cerevisiae* RC212, Lallemand, Danstar Ferment AG, Switzerland). Temperature and density controls were monitored during the whole fermentation period, and the tank content was homogenised every day to disperse the cap into the wine for 'Merlot' and 'Cabernet Sauvignon'. Once fermentation was completed (residual sugars < 2 $g \cdot L^{-1}$), the young wine was transferred to smaller stainless steel tanks to separate the must and pomace (lees) for spontaneous clarification. After three days the samples were inoculated with appropriate lactic acid bacteria (Oenococcus oeni CN0912, Danstar Ferment AG, Switzerland) for malolactic fermentation. The winemaking procedures were the same in each of the three years. After the final racking, the wines were cold-stabilised, then bottled and stored at 10 °C prior to sensory analyses on 20 May of the following year.

Basic chemical composition analyses: On the day of harvest, the reducing sugar (RS, $g \cdot L^{-1}$) and titratable acid (TA, $g \cdot L^{-1}$) of grapes were analysed according to GB/T 15038-2006. For the wines, after the alcoholic fermentation had finished, alcohol strength (ALC, %) and titratable acid were assessed according to GB/T 15038-2006. All parameters were analysed in triplicate.

Sensory evaluation: The sensory evaluation was performed by ten oenologists and workers. The research established consistency among replicated years in all vintages. Thus, for each vintage, wines of three cultivars obtained at bottling from each canopy management (CCT and ILSP) were analysed according to the Asia wine quality competition-tasting form (still wine) for two triangle tests (LI 2006). The wine sensory evaluations were made only in 2011 and 2012.

Labour time in the vineyard - statistical analyses: The labour time for each work phase was counted for both training systems, and the results used to calculate the time consumed by the main labour items per capita of skilled workers in the vineyard from 2011 to 2013.

Statistical analyses: One-way and two-way analyses of variance (ANOVA) were used to determine the differences between the training systems with three replications of each sample. All statistical analyses were carried out using Excel 2007 or SPSS 16.0.

Results and Discussion

Grape yield and quality: Tab. 1 shows the yield, reducing sugar and titratable acid of the three cultivars. When data from the three years were combined, yields were significantly reduced by 39.69 % in CCT compared with ILSP ('Chardonnay', 39.95 %; 'Cabernet Sauvignon',

Table 1

Key parameters from 2011 to 2013 for 'Chardonnay', 'Merlot' and 'Cabernet Sauvignon' winegrapes under two different training systems: "crawled cordon training" (CCT) and "independent long-term pruning" (ILSP)

Different varieties		Harvest time day/month/year	Yield $kg \cdot ha^{-1}$	RS $g \cdot L^{-1}$	TA $g \cdot L^{-1}$
Chardonnay	CCT	28/09/2011	7,680a	209.6d	8.1a
		24/09/2012	10,620b	230e	6.3b
		26/09/2013	12,300c	230.5e	6.1c
	average		10,200 ± 2,338.5	223.37 ± 11.92	6.83 ± 1.1
	ILSP	28/09/2011	22,665d	159.8a	9.4d
		24/09/2012	12,195e	189.2c	6.7e
		26/09/2013	16,095f	169.8b	8.6f
	average		16,985 ± 5,291.4	172.93 ± 14.95	8.23 ± 1.39
Merlot	CCT	08/10/2011	7,605a	212.3a	7.1c
		09/10/2012	10,560b	249.6b	6a
		16/10/2013	12,195c	251c	5.9a
	average		10,120 ± 2,326.4	237.63 ± 21.95	6.33 ± 0.67
	ILSP	08/10/2011	22,530d	169.9d	8.8e
		09/10/2012	12,105e	208.4e	6.4b
		16/10/2013	15,810f	178.9f	7.3d
	average		16,815 ± 5,284.66	185.73 ± 20.14	7.5 ± 1.21
Cabernet Sauvignon	CCT	12/10/2011	7,395a	230.1a	8.2d
		13/10/2012	10,470b	268.7b	6.1a
		19/10/2013	11,925c	269.6c	6.1a
	average		9,930 ± 2,312.7	256.13 ± 22.55	6.8 ± 1.21
	ILSP	12/10/2011	22,425e	167.4d	8.9e
		13/10/2012	11,835c	209e	6.5b
		19/10/2013	14,820d	180.2f	7.5c
	average		16,360 ± 5,460.38	185.53 ± 21.31	7.63 ± 1.21

RS: reducing sugars; TA : titratable acid. Different letters in the same column indicate significant differences ($p < 0.05$). Values are from the mean of three treatments ± standard deviation (SD).

39.82 %; and 'Merlot', 39.30 %). In the first three years of training to CCT (2011, 2012 and 2013), the yield of the three cultivars was: 'Chardonnay', reduced by 66.12 %, 12.92 % and 23.58 %, respectively (over the three years); 'Cabernet Sauvignon', 67.02 %, 11.53 % and 19.53 %, respectively; and 'Merlot', 66.25 %, 12.76 % and 22.87 %, respectively. At winter pruning of spur number (one two-node spur at a node for CCT; several for ILSP) and retained node number of the two training systems, indicated that the yield and bunch number of ILSP was higher than of CCT. In 2012, the yields of the three cultivars under ILSP were lower than in 2011 or 2013 due to heavy rain and an associated high incidence of disease. For CCT, the yield was increased in 2012. The yield of vines under CCT sustained growth in the three years. From 2011 to 2012 and from 2012 to 2013, the yield for 'Chardonnay' increased by 27.68 % and 13.66 %, for 'Cabernet Sauvignon' by 29.37 % and 12.20 %, and for 'Merlot' by 27.98 % and 13.41 %. In the third year of training, the average yield under CCT was about 12,000 kg·ha^{-1}, and the difference in yield between CCT and ILSP was reduced.

There were significant differences in yield stability between CCT and ILSP. Compared with ILSP, the yield values for CCT showed a significantly lower standard deviation (SD) which can be interpreted to indicate a significantly higher yield stability. This was in agreement with the results of ZHAO *et al.* (2013).

The reducing sugar and titratable acid levels of the three cultivars were significantly affected by training system from 2011 to 2013. For the three cultivars, 'Chardonnay', 'Cabernet Sauvignon' and 'Merlot', the average reducing sugars under CCT were 22.58 %, 27.56 % and 21.84 % higher than under ILSP, the averaged titratable acidities under CCT were 17.01 %, 15.60 % and 10.88 % lower than under ILSP, and the sugar-acid ratios under CCT averaged 34.85 %, 35.44 % and 34 % higher than those under ILSP. The sugar-acid ratio indicates a satisfactory degree of grape ripeness of vine (LI *et al.* 2009). There was a general increase in grape ripeness with the increase in sugar-acid ratio.

The reasons for this trend could be that ILSP vines had an upright cordon and the associated irregular fruiting may have resulted in poor quality fruit. In this connection, the work of SHEN (2014) on leaf area index under ILSP showed shooting was more dense under CCT which would have contributed to increased canopy shading. The transmission coefficient (TR) for radiation penetration under ILSP was lower than that under CCT. This showed very low light levels in the middle of dense canopies under ILSP. Shaded berries are expected to have lower soluble solids contents and a higher titratable acid contents than unshaded berries (MACAULAY *et al.* 1993, DOKOOZLIAN *et al.* 1996, MABROUK *et al.* 1998). Another factor is that under CCT, the horizontal cordon might have reduced apical dominance, improved nutrient transport between root and fruit, and advanced maturity (PALLARDY 2011). Vertical shoot positioning generally reduces shading (Fig. 3).

Chemical analyses of wines: SWIEGERS *et al.* (2005) showed that higher alcohol content together with homologous esters contributed positively to the fruity characters of a wine. The CCT wines had higher alcohol content than the ILSP ones (Fig. 4), as evidenced over the

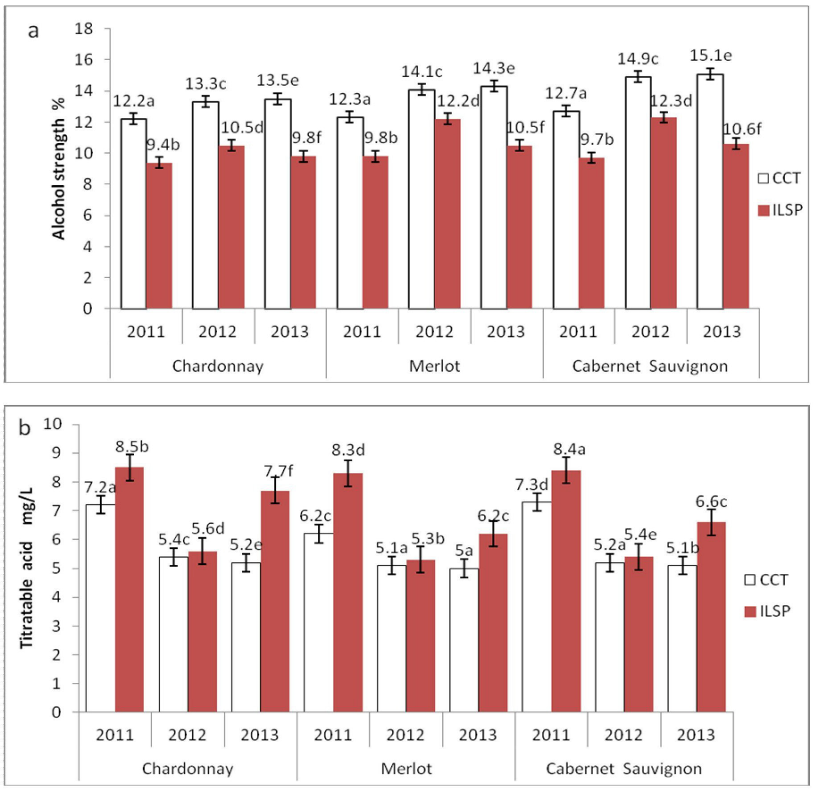

Fig. 4: (**a**) Levels of alcohol (%) and (**b**) of titratable acidity (g·L^{-1}) in three different grape cultivars grown under two different training systems - "crawled cordon training" (CCT) and "independent long-term pruning" (ILSP) from 2011 to 2013. Different letters in each cultivar indicate significant ($p < 0.05$) differences.

three years by an increase of 23.85 % (CCT = 13 %; ILSP = 9.9 %) in 'Chardonnay' wines, 23.61 % (CCT = 14.23 %; ILSP = 10.87 %) in 'Cabernet Sauvignon' and 20.19 % (CCT = 13.57 %; ILSP = 10.83 %) in 'Merlot'. However, the titratable acidities under CCT were lower than under ILSP which aligned with the titratable acidities.

Sensory evaluation: For the basic sensory analysis, the results indicate that all measured parameters were higher under CCT than under ILSP. Also, under both training systems values in 2012 were higher than in 2011 (Tab. 2).

The vines were trained to CCT in 2010. By 2011 and 2012 some of the parameters measured had not changed significantly – these included taste and overall quality in 'Chardonnay', aroma and overall quality in 'Merlot' and aroma and overall quality in 'Cabernet Sauvignon'. These parameters were stable relative to ILSP although differing significantly each year due to seasonal differences in the weather. It is well known that weather variations affect a vine's key phenological stages, especially berry development (Parpinello *et al.* 2015). Nevertheless, under CCT, it would seem the influence of the weather on fruit develop-

Table 2

(**a**) One-way and two-way ANOVA showing mean separation of sensory evaluation of 'Chardonnay' wines obtained from grapes managed with "crawled cordon training" (CCT) and "independent long-term pruning" (ILSP) during the 2011 and 2012 seasons

ANOVA factor	Year of harvest/Mng	Appearance	Aroma	Taste	Overall quality	Total score
CCT	2011	13.95b	28.20c	41.85c	9.30c	93.30c
	2012	14.25c	28.50d	42.30c	9.40c	94.45d
ILSP	2011	13.80a	25.50a	36.00a	8.10a	83.40a
	2012	13.95b	26.70b	37.35b	8.30b	86.30b
Management (M)	CCT	14.10b	28.35a	42.08d	9.35c	93.88d
	ILSP	13.88a	26.10a	36.68a	8.20a	84.85a
Year (Y)	2011	13.88a	26.85a	38.93b	8.70b	88.35b
	2012	14.10b	27.60a	39.83c	8.85b	90.38c
M × Y	*p*-value	0.0851	5.27E-05	0.16038	0.412	1.59E-07

b: One-way and two-ways ANOVA showing mean separation of sensory evaluation of 'Merlot' red wines obtained from grapes managed with CCT and ILSP training systems during 2011 and 2012 seasons.

ANOVA factor	Year of harvest/Mng	Appearance	Aroma	Taste	Overall quality	Total score
CCT	2011	13.65c	27.90b	41.40c	9.10b	92.05c
	2012	13.80a	28.20b	42.30d	9.20b	93.50d
ILSP	2011	13.05d	24.00a	33.75a	7.50a	78.30a
	2012	13.50b	27.30b	40.95b	9.00b	90.75b
Management (M)	CCT	13.73d	28.05c	41.85d	9.15b	92.78d
	ILSP	13.28a	25.65a	37.35a	8.25a	84.53a
Year (Y)	2011	13.35b	25.95a	37.58b	8.30a	85.18b
	2012	13.65c	27.75b	41.63c	9.10b	92.13c
M × Y	*p*-value	0.00861	0.00091	2.16E-12	0.043	2.51E-14

c: One-way and two-ways ANOVA showing mean separation of sensory evaluation of 'Cabernet Sauvignon' red wines obtained from grapes managed with CCT and ILSP training systems during 2011 and 2012 seasons.

ANOVA factor	Year of harvest/Mng	Appearance	Aroma	Taste	Overall quality	Total score
CCT	2011	13.8c	28.2c	41.85c	9.2c	93.05c
	2012	14.1d	28.5c	42.75d	9.3c	94.65d
ILSP	2011	12.75a	23.4a	34.2a	7.6a	77.95a
	2012	13.35b	27b	40.5b	8.9b	89.75b
Management (M)	CCT	13.95d	28.35d	42.30d	9.25d	93.85d
	ILSP	13.05a	25.20a	37.35a	8.25a	83.85a
Year (Y)	2011	13.28b	25.80b	38.03b	8.40b	85.50b
	2012	13.73c	27.75c	41.63c	9.10c	92.20c
M × Y	*p*-value	2.56E-09	1.17E-11	3.78E-11	7.13E-08	1.12E-11

M × Y: management × year interaction; The letters represent the results of Duncan comparison tests: different letters in the same column indicate significantly ($p < 0.05$) different means among different wines.

ment was less marked, which may have been responsible for the higher yield stability under CCT than under ILSP.

There were also different average yields in 2011 and 2012, for 'Chardonnay' (CCT: 9,150 kg·ha^{-1}; ILSP: 17,430 kg·ha^{-1}), for 'Merlot' (CCT: 9,082.5 kg·ha^{-1}; ILSP: 17,317.5 kg·ha^{-1}) and for 'Cabernet Sauvignon' (CCT: 8,932.5 kg·ha^{-1}; ILSP: 17,130 kg·ha^{-1}). This shows that yields under CCT were lower than under ILSP. More nutrients were transferred to berries under CCT which improved quality and reduced the influences of the weather. Factors such as wind and humidity affected the incidence of disease, berry ripeness and berry size. The high proportion of gaps in the canopy under CCT allowed sunlight to be lost to photosynthesis but instead to reach the fruit whereas the more shaded fruit under ILSP delayed fruit ripening and reduced wine quality (SMART *et al.* 1990).

The two-way ANOVA showed a significant year effect for most of the sensory parameters analysed, with the exception of aroma and overall quality in 'Chardonnay'. The first interactive effect between management (M) and year (Y) was limited to the appearance, taste and overall quality of the 'Chardonnay' wine (a: 0.05).

Labour time: The labour time per year per ha expended under CCT was 24.47 % less than under ILSP (Fig. 5).

In China, winter pruning must be finished before the soil freezes if vines are to be buried. However, to delay and minimise drought damage during cold, dry periods, vines need as much time as possible to complete their vegetative growth before pruning. Hence, there is quite a narrow window available for winter pruning that requires a last-minute burst of very high labour input. Labour input from winter pruning to spring unearthing under CCT was reduced by 23.0 % compared to that under ILSP. This is because under ILSP, minor shoots (e.g. sublaterals) had to be removed in the winter pruning. Also, irregular shoots had to be unmounted from the wires to allow vine burial. However, under CCT, pruning was more straightforward as it avoided operations such as sublateral removal (Fig. 2). Furthermore, because the shoots were positioned regularly, CCT did not require unmounting before burial. Some of this work could be carried out next spring during a less-pressured labour period. Thus, compared with ILSP, CCT mitigates the twin problems of high labour input and also of high labour intensity at a time-pressured time of year.

Under CCT, summer pruning was reduced by 25.0 %, as ILSP vines required repeated removal of axillary shoots during summer. In contrast, the CCT vines had a regular canopy (like a hedgerow, 0.5 m wide × 1.5 m high × 1.0 m long) which allowed mechanised pruning – *i.e.* the removal of any shoots growing beyond this spatial envelope.

In the experimental vineyard, the more onerous operations were soil management, including inter-row tillage, irrigation and fertilisation. For these operations there were no significant differences between CCT and ILSP. Only inter-row tillage was carried out under CCT (a wild grass understorey covered the within-row surfaces), whereas ILSP required tillage of both the within-row and the inter-row surfaces. Both the irrigation and fertilisation times for CCT were reduced compared to those for ILSP. In line with ZHAO *et al.* (2013), the ILSP vines required more pruning cuts after winter pruning than the CCT ones, leading to more physical damages and (possibly) tylosis formation in the xylem vessels. Since both sap flow and nutrient transport are blocked by tyloses, the management impacts on water

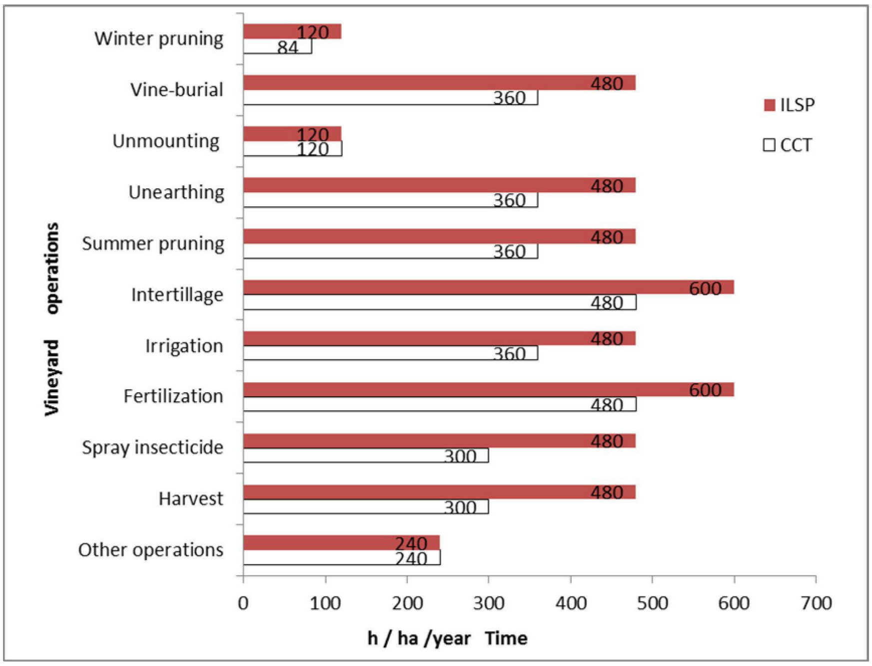

Fig. 5: Average values from 2010 to 2013 for the main annual vineyard labour items under two training systems - "crawled cordon training" (CCT) and "independent long-term pruning" (ILSP). Legend: Vine burial, the vine must be removed from the wire after pruning and covered with soil; unmounting, the branches of the previous season are removed from the wire; unearthing, the buried vine must be dug up in spring; summer pruning, includes bud picking, pinching and canopy management; other operations, clean up all dead leaves, prunings and weeds after vine-burial also stripping old bark from trunk etc.

and nutrient transport were likely reduced. The labour associated with soil management under CCT was reduced by 21.43 % compared with ILSP.

The time required for harvest under CCT was reduced by 37.5 % compared with that under ILSP. At first, the CCT vines had lower yields which reduced labour, but a more permanent gain was that CCT positioned the vines and also the fruiting/renewal zones much more uniformly (Zhao *et al.* 2013) (Fig. 3). This eased the labour requirements at harvest as the fruit was at a single height, so workers did not have to search for more widely-distributed fruit. With ILSP fruit is presented at many different heights.

Conclusions

The results clearly demonstrate that average yield under CCT was 39.69 % lower than under ILSP over the first three years following conversion of the training system. However, yield stability was higher under CCT, as also were sugar-acid ratios. These result in much better fruit ripeness under CCT.

Wine sensory evaluation was higher under CCT than under ILSP. Some parameters of sensory analysis, taste and overall quality in 'Chardonnay'; aroma and overall quality in 'Merlot'; aroma and overall quality in 'Cabernet Sauvignon' under CCT were not significantly different in the different seasons. This implies that vintage quality was less susceptible to seasonal weather variations under CCT which would represent a significant commercial benefit for growers. This aspect of our results requires confirmation in further study.

The overall labour input under CCT was reduced by 24.47 % compared with that under ILSP. Thus the labour input from winter pruning to spring unearthing was reduced by 23.0 %, and the labour inputs for summer pruning, soil management and harvesting were reduced by 25.0 %, 21.43 %, and 37.5 %, respectively.

All these, lead to the conclusion that CCT is simpler and more labour-efficient than ILSP. CCT also eases the periods of high labour intensity at critical times when labour may be scarce. This reduces conflict between the labour demands of viticulture and that for other crops at critical times of the year. Finally, CCT is more straightforward than ILSP for vine-burial in high winter-chill areas, and particularly in those of northern China.

Acknowledgements

The authors gratefully acknowledge the funding support and the enological assistance of the Rongchen Chateau. We are also grateful to the National "Twelfth Five-Year" Plan for Science & Technology Support for supporting this work under Key Technology Research and Industry Demonstration of High Quality Fruit Wine (No. 2012BAD31B07).

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Received February 23, 2015