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A COMPARATIVE ECOPHYSIOLOGY OF ECOLLY (*VITIS VINIFERA* L.) UNDER THE TRADITIONAL INDEPENDENT LONG-STEM PRUNING AND CRAWLED CORDON TRAINING

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Abstract

The aim of this study was to compare the ecophysiology character of Ecolly grape (*Vitis vinifera* L.) with the new technology-single crawled cordon training (SCCT) and traditional method-independent long-stem pruning (ILSP). The connections among net photosynthesis rate (Pn), transpiration rate (Tr), instantaneous water utilization efficiency (WUEi), stomatal conductance (Cs) and intercellular CO_2 concentration (Ci) were always mutual and inextricable in the trial. The leaves in every stage had the highest Pn respectively when growing under the light irradiance of the different period. The ILSP showed a lower total photosynthetic capacity than the SCCT. There was the total semblable Tr for two pruning plants, but lower Tr in ILSP at the every position of the prior stage and riping stage (PS and RS) excluding the growing stage (GS). The WUEi declined because of the net CO_2 assimilation saturated and the transpiration constantly fleetly increased before the photosynthetic active radiation (PAR) increased to 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The increased WUEis from the first to the second stage deduced that stomatal closure at high irradiance reduced more Tr than Pn, while the values decreased again in the last stage indicated that stomatal opening at low irradiance added more Tr than Pn. These results suggested that it may be possible technology to change trellises in order to obtain better ecophysiology character in this study. The growth variability of vine may be affected by a particular training style.

Introduction

90% of grapevines in North China, including Weibei Tableland, were buried during the overwintering period, which, however, lacked matched pruning system before SCCT. The SCCT, suitable pruning system for grapevine at the dormant, was born before twenty years. It is commonly observed, from an economical point of view, that pruning system is a widespread practice to secure and stabilize grape production (Dos Santos *et al*., 2003) without affecting wine quality (Intrigliolo *et al*., 2005) and to maintain an equilibrium in the vegetative-reproductive growth (De la Hera *et al*., 2004; Ozer *et al*., 2012) by modulating canopy configuration of grapevines in the viticultural areas. Traditional pruning strategies (Zhao *et al*., 2013), such as the fan-shaped training, "V" type training, "U" type training and independent long-stem pruning, were characterized by inconvenient mechanized operation owe to cumbersome and complex pruning procedure, unloading from wires before winter dormancy and loading to wires after coming up. Perennial continuously extended parts of vine using these systems stretched the nutrition transportation distance and led to discrepant maturity of berries under irregular height, affected yield and quality of grape and wine seriously. Consequently, this situation has stimulated the development and application of different training technologies adapting the location in order to save and improve survival environment of grape under semiarid conditions (Romero *et al*., 2004a & 2004b; Baloch *et al*., 2013).

From 1991 to 2012, a number of wine grape area, including Shaanxi province, the Ningxia Hui Autonomous Region, Gansu province, the Xinjiang Uygur Autonomous Region, Inner Mongol Autonomous Region and other places in China, has popularized more than 13, 400 hectares by the ways of close coalition among the experimental study, demonstration and teaching, which finally promoted the mode of durable and optimal viticulture at the buried area - SCCT, with the objectives of guaranteeing high quality of grapes, stable yield, longevity and beauty of the vineyards (Li & Fang, 2005; Li *et al*., 2010). This innovational system provided scientific basis for mechanization, scale and standardization of production, therefore, the system has been applied successfully in commercial grapevines in order to adjust vine vigor (Dry *et al*., 1996) while maintaining the rate of photosynthesis, and improving adaptability of harvesting and pruning compared to conventional cropping manners at same conditions, but there are not enough physiological and agronomical scientific data to sustain these results.

Trellises of SCCT included two specific types, namely single SCCT and double SCCT. The single SCCT was applied in the trial. There is a single cordon paralleling to the ground about 20 cm over the ground, and the shoots with a space of approximately 15 - 20 cm adopted vertical trellis over cordon with 1.5 m height and 0.5 m width. Natural cover crop was used in rows in vineyard. Renewal of SCCT method is carried through in winter pruning, and the one bud per bearing branch is reserved every year (Fig. 1).

The aim of this work was to estimate the feasibility of SCCT from physiological standpoint as an alternative planting technology of wine grape Ecolly (*Vitis vinifera* L.), a white variety grown widely in the Chinese northern region, such as Xinjiang Uygur Autonomous Region, Shanxi Province, Gansu Province, Shaanxi Province and Ningxia Hui Nationality Autonomous Region, compared with ILSP (Fig. 2). The experiment applied the same variety and routine management system during two consecutive years in order to distinguish the preliminary effects of the two pruning methods on the physiological and agronomical response.

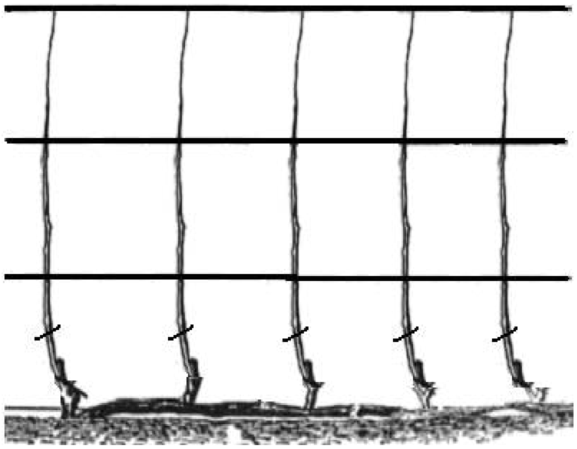

Fig. 1. diagram of SCCT.

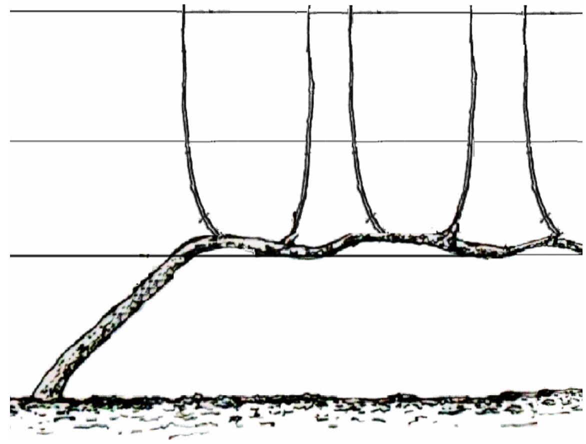

Fig. 2. diagram of ILSP.

Materials and Methods

Experimental site: The trial was established in 2010 and 2011 with wine grape Ecolly (*Vitis vinifera* L.). The vineyard was located at the Chateau Heyang of 100 m^2 (Heyang grape experiment and demonstration stations of Northwest A&F University, Heyang County, Shaanxi Province, China, longitude 109° W; latitude 34° N; 780 m above sea level).

Weather: A region is characterized by a semiarid continental monsoon climate, with hot and dry summer and cold winter, having sunshine hours of approximately 2528.3 per year and the mean annual temperature of 11.5 . An average annual rainfall is between 500 and 540 mm, while frost-free season occurs on 208 d per year. Compared with the same latitude, there are the more favorable light and heat resources.

Mowing and soil tillage treatment: The field was intercropped with a variety of wild grass between rows in order to reduce the amount loss of water stored in the soil during significant spring-summer water consumption. And the overground part of the vegetation was mowed by a lawn mower to a height of 10 - 15 cm; while soil tillage (a rotary tiller) between rows was carried out twice per year, namely mid-April and mid-August respectively.

Vine pruning trials: The grapevines were trained to two different trellises - SCCT and ILSP (Figs. 1-2, 5 rows per trellis). Vines spacing was 3.0 m × 0.5 m, and rows were orientated north-south. Every grapevine was trained to one vertical shoot during the growth in the first year and developed the cordon further and pruned to five one - node spur in the late October in the same year. The next year, all vines planted were pruned to one cordon paralleling to the ground and five shoots per cordon. The vines of the third year were pruned according to the method of the second year. While in ILSP, there was an acclivitous stem extending to the first wire situated at 50 cm from the ground and continued to elongate horizontally and keep the five shoots trained to the "V" type trellis above the wire during the growth period (Fig. 2). The other follows the method of SCCT. And other practices followed normal procedures in the area.

Experimental design: The experimental design consisted of two trellises with three replicates per trellis in a randomized, complete block at the second developmental period in 2010 and 2011. Each replicate consisted of 60 vines. The basal, middle and apical leaf positions per shoot per vine were defined according to the height of the shoot. A portable photosynthesis system (Li-6400, LI-COR Co. Ltd., America) was used for simultaneous measurements of PAR, Pn, Tr, WUEi and Ci on healthy, intact and fully expanded leaves from the basal, middle and apical section at the sun exposure side. Mean PAR was not more than 1400 mmol·m^{-2}·s^{-1} during all measurement. Data were collected on cloudless days between 8:00 and 18:00 from August to September (9:00 to 19:00 in October) in order to minimize disturbances from the atmosphere and changes in solar elevation.

Statistical analysis: Graphics and curve fitting were performed using Origin and Microsoft Excel 2000 software (Microsoft Corporation), respectively. The results obtained for each pruning system and every stage were compared by using Duncan analysis of variance test and, when significant differences were found, a least significant difference (LSD) test of a LSD value calculated at the 5% level was used to identify differing mean values.

Results

Diurnal patterns of the photosynthetic light response curves: In terms of SCCT and ILSP, the Pn value increased rapidly as the PAR increased to 200 μmol·m^{-2}·s^{-1} and augmented fastly to a maximum, then followed by a slow decrease or increase as PAR was increased to 1400 μmol·m^{-2}·s^{-1} (Fig. 3). The light compensation point (LCP) in SCCT was the lowest at 8:00 at the PS and the highest at 8:00 at the GS, while the peak at the RS was at 13:00 (Fig. 3 left panel). It's interested that in ILSP, the highest LCP was found at 10:00 (at 11:00 of the third stage) during the whole developmental period (Fig. 3 right panel).

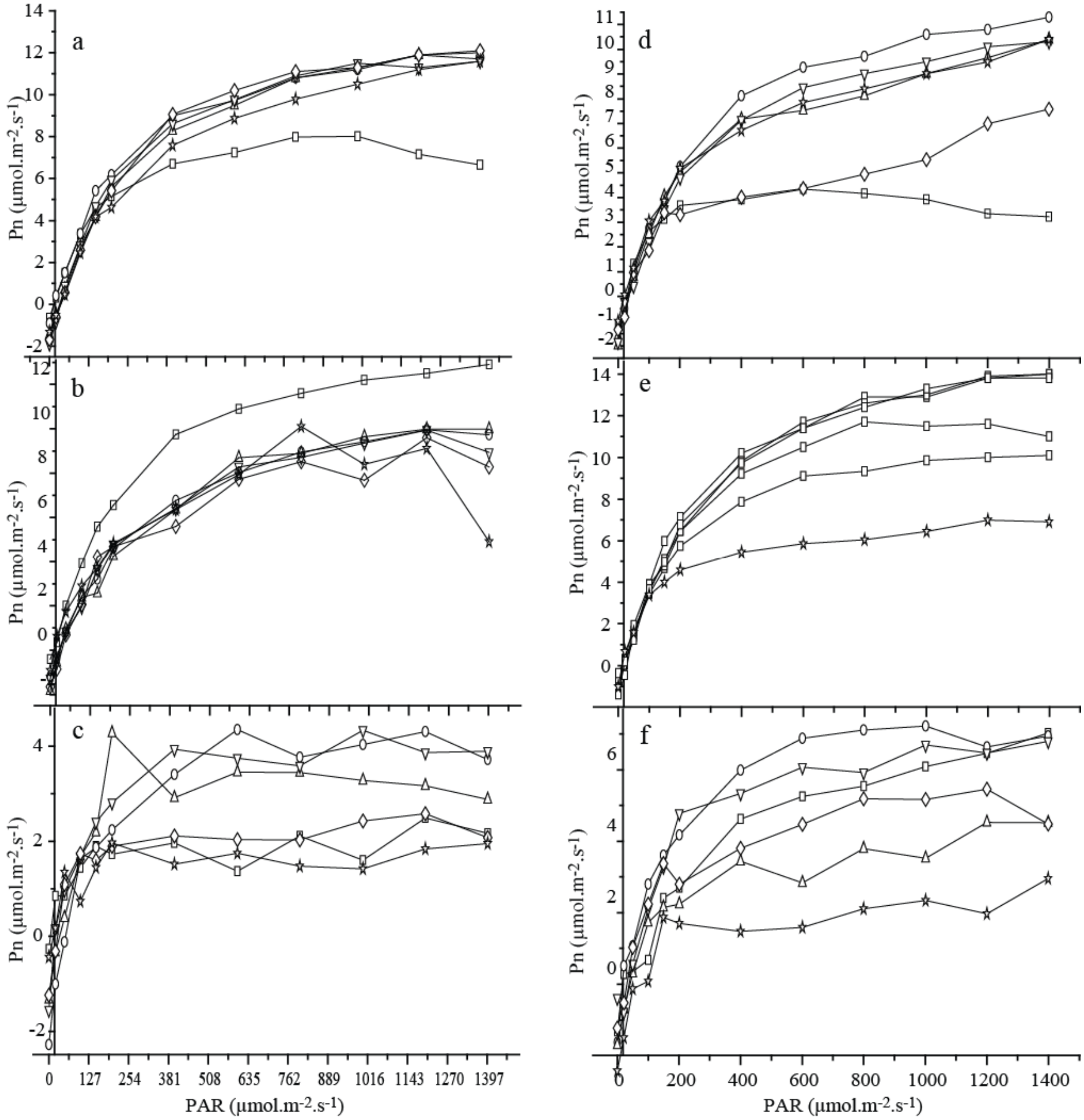

Fig. 3. The mean diurnal changes of photosynthetic light response curves of grape leaves in wine grape Ecolly (*Vitis vinifera* L.) at the prior (a), growing (b) and riping (c) stages with the single crawled cordon training (SCCT) and at the prior (d), growing (e) and riping (f) stages with independent long-stem pruning (ILSP) of the secondary growing period in 2010 and 2011.Values shown are mean ± standard error of the mean (n = 5). Data correspond to measurements carried once every two hours between 8:00 and 18:00 solar time at the prior and growing stages; while those at the riping stage from 9:00 to 19:00 solar time. (□) 8:00 or 9:00; (○) 10:00 or 11:00; (□): 12:00 or 13:00; (□): 14:00 or 15:00; (□): 16:00 or 17:00; (□): 18:00 or 19:00.

The light saturation points (LSP) followed LCP in SCCT in this experiment. The lowest at the PS was at 8:00 and the highest at the GS at 8:00 under 1400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR, and the value at 13:00 at the RS reached LSP first as for the same system (Fig. 3, basal-left panel). It is obvious that in ILSP, the best values at the first and second stages were of 1400 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR at 10:00, and results at 12:00 and 14:00 at the second stage were also included. Especial difference occurred at the RS and the curve at 11:00 was the prominent, it's LSP was from 600 to 1000 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (Fig. 3f). The Pn-PAR curves for two systems were almost coincident within 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ during the experiment other than the two at the RS (Fig. 3).The total Pn per vine at 2 systems decreased with advanced season and weather without exception, the highest Pn in SCCT was observed in the first stage and declined whereafter. It is different that value dropped after ascending in ILSP and the highest value was higher in ILSP than in SCCT (Table 1). Both Pn and maximum Pn varied significantly ($p<0.05$) with both trellises at the prior stage while those at the other stage were not significant.

Table 1. Pn, Cs, Tr, WUEi, and Ci indices for vines trained to various trellises (SCCT and ILSP) at different times of the season[a].

Pn ($\mu mol \cdot m^{-2} \cdot s^{-1}$)		Cs ($mmol \cdot m^{-2} \cdot s^{-1}$)		Tr ($mmol \cdot m^{-2} \cdot s^{-1}$)		WUEi ($\mu mol \cdot mmol^{-1}$)		Ci ($\mu mol \cdot mol^{-1}$)	
SCCT	YTT	SCCT	YTT	SCCT	YTT	SCCT	YTT	SCCT	YTT
13.4404	5.4388	0.2317	0.1033	3.5201	3.5034	3.8405	1.5116	265.8133	216.4933
12.45	14.168	0.2981	0.3222	2.3853	2.7128	5.1959	5.2226	288.6933	288.4677
6.8369	7.3187	0.1030	0.0953	2.4603	2.2865	2.8133	3.2001	270.72	251.7267
32.7273	26.926	0.6328	0.5208	8.3657	8.5027	11.85	9.9343	825.2266	756.6877
16.3637	13.463	0.3164	0.2604	4.1829	4.2514	5.9249	4.9672	412.6133	378.3439

[a]Data are means from the prior stage until defoliation during the second developmental period. Letters indicate statistical differences by Duncan analysis of variance test (n=5, p<0.05).
The values of the first three rows were of the average at the three stages at the second growth period, respectively. The sum at the three stages was showed above the fourth row, while the average values of the whole trial the late one. Values shown are mean ± standard error of the mean (n = 5).

Change relationship of photosynthetic character: During the whole trial duration, total trend of mean net photosynthesis rate (Pn) in every position decreased for the SCCT and ILSP, Pn value of SCCT was significantly higher than that of ILSP at the PS of the whole vine (Figs. 4-6, upper row). Other results were found at the growing and riping stages of the whole trial, respectively. A similar trend was observed for the stomatal conductance (Gs). However, on a relative basis, ILSP effected change as expressed by Gs, and which was higher for all positions at the growing and riping stages considered, respectively (Figs. 4-6, upper and basal-right panel).

Although Pn and Gs clearly decreased as a response to season (Figs. 4-6, upper and basal-right panel), intercellular CO_2 concentration Ci floated only slightly during the experimental period, except for the basal leaves of the prior stage (Figs. 4-6, middle-right panel). For SCCT, Ci increased significantly at the almost every stage compared with values of ILSP.

Variation of Pn and transpiration rate (Tr) in grapevine leaves under different training showed that Pn and Tr of SCCT kept the similar trends with those of ILSP at the different stage and leaf position, respectively, which resulted in semblable tide of instantaneous water use efficiency (WUEi). However, the total trend of Pn and Tr in SCCT was decreased under the most circumstance, respectively. On the contrary, in ILSP, there was slight drop after quick rise for Pn, and Tr seldom change during the experimental period beside leaf position, which resulted in similar result with Pn of ILSP (Figs. 4-6, left rank).

Discussion

In this experiment, there were diversity ($p<0.05$) in terms of total level of the photosynthetic character at the different stage and the disparate leaf position per stage. Previous description in *Vitis vinifera* concentrated on the day from morning to evening (Chaumont *et al*., 1994), time arrangement in this experiment was of the second growth period from August to October.

Diurnal patterns of the photosynthetic light response curves: The light compensation point (LCP) occurred at lower compensation irradiance was used to judge the low light adaptation (Rena *et al*., 1994). It is interested that the LCP of SCCT entered earlier than that of ILSP in the trial. Previous reports about plants acclimating to a high light environment indicated increase of respiration and LCP, the LCP at noontime in our experiment equated to the reports, which implied that sunlight at the different stages would affect grapevine growth at every point.

The level of the light saturation points (LSP) embodied grapevines adaptation to intensive light (Zhang *et al*., 2010). The lower the LSP was, the easier was to achieve the highest value for Pn. Contrarily, Pn under lofty LSP is not easy to reach LSP. Therefore, routine photosynthesis required a lower LSP level. Compared with different light response curves, a higher photosynthetic rate was showed above 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR. The product of photosynthesis, thus, depended mainly on the photosynthetic accumulation under a higher light intensity. It is speculated that the result in the trial came from degradation of physiological function besides the factors such as leaf age, season, and trellis configuration during the experiment. On the one hand, the leaves in SCCT stepped into ripeness and wane, on the other hand, the lower light intensities at the end-growing period reduced the Pn values. Our results showed that the sunlight at 8:00 at the prior stage reduced the LSP while hoisted that at the growing stage, meanwhile the light at noon at riping stage increased the LSP in SCCT (Figs. 3a, 3c). LCP followed LSP in ILSP (Figs. 4a, 4c).

The light intensity at the leaf position of ILSP was greatly reduced compared with SCCT at the prior stage, the foregoing might be explained by the low Pn found for the ILSP leaves (Figs. 4-6, top row). The similar Pn could be formed by no different light intensity at the middle stage (Figs. 4-6, middle row). While at the riping stage, the light angle and leaf age resulted in higher values in ILSP than in SCCT (Figs. 4-6, basal row). Therefore, the Pn of the three leaf positions of the two trellises corresponded to the PAR patterns respectively. This finding suggested that the movement of the Pn did not result solely from an improved microclimate, but rather from season and canopy control, as was not previously mentioned. This is also evident from Fig. 3, which shows the response of photosynthesis to increasing PAR levels at the different time of days.

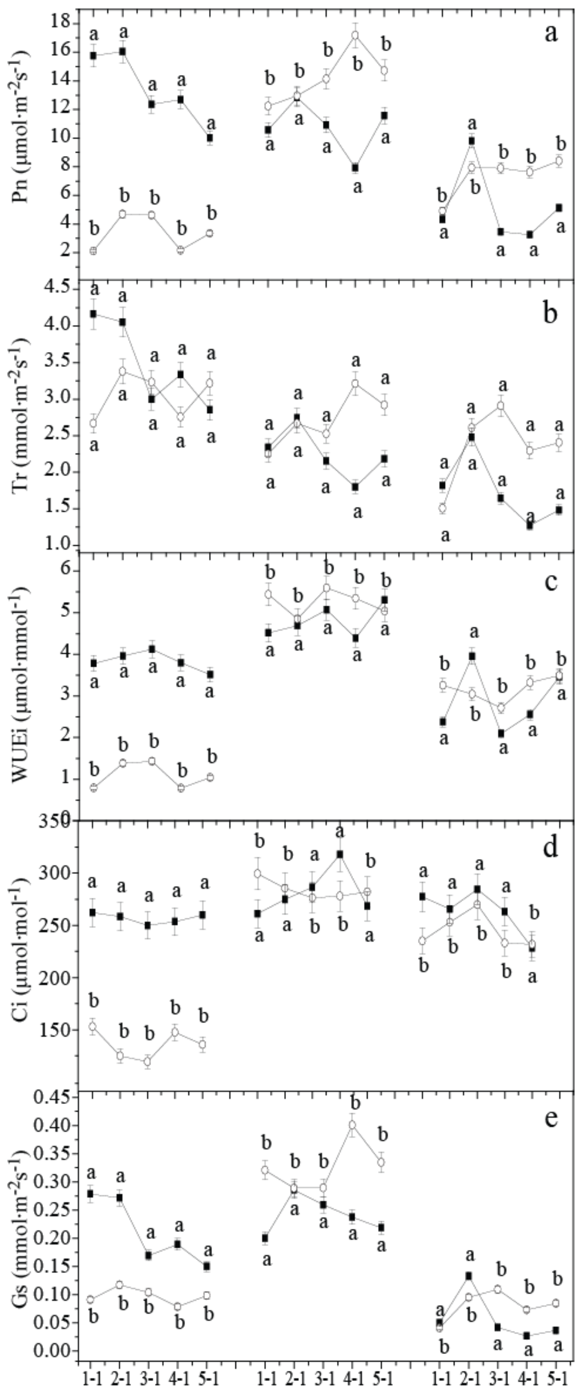

Fig. 4. Adaptation of (a) net photosynthetic rate; (b) transpiration rate; (c) instantaneous water utilization efficiency, (d) intercellular CO_2 concentration, (e) stomatal conductance of the basal leaves in Ecolly at the second developmental period of 2010and 2011. Values shown are mean ± standard error of the mean (n = 5).

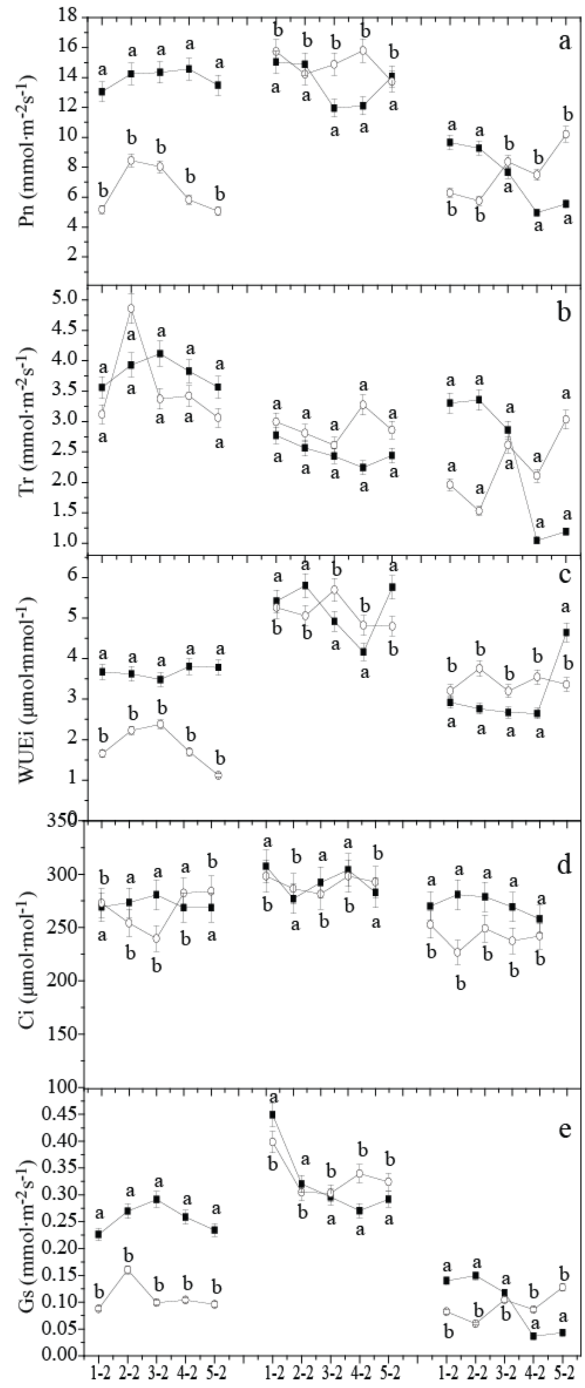

Fig. 5. Adaptation of (a) net photosynthetic rate; (b) transpiration rate; (c) instantaneous water utilization efficiency, (d) intercellular CO_2 concentration, (e) stomatal conductance of the middle leaves in Ecolly at the second developmental period of 2010 and 2011. Values shown are mean ± standard error of the mean (n = 5).

Datas correspond to measurements carried between 8:00 and 10:00 solar time at the prior and growing stages; while values at the riping stage from 13:00 to 15:00 solar time. (○) ILSP; (■) SCCT. The same as follows below.

The serial number of every shoot beginning from the basal position is marked by 1, 2, 3, 4, 5, respectively; and the serial number of the basal, middle and apical leaf positions of every shoot from the basal leaf position to the apical one is 1, 2, 3, respectively. Thus, the basal leaf position was numbered by 1-1, 2-1, 3-1, 4-1, 5-1, respectively; the middle leaf position was numbered by 1-2, 2-2, 3-2, 4-2, 5-2, respectively; the apical leaf position was numbered by 1-3, 2-3, 3-3, 4-3, 5-3, respectively. The same as follows below.

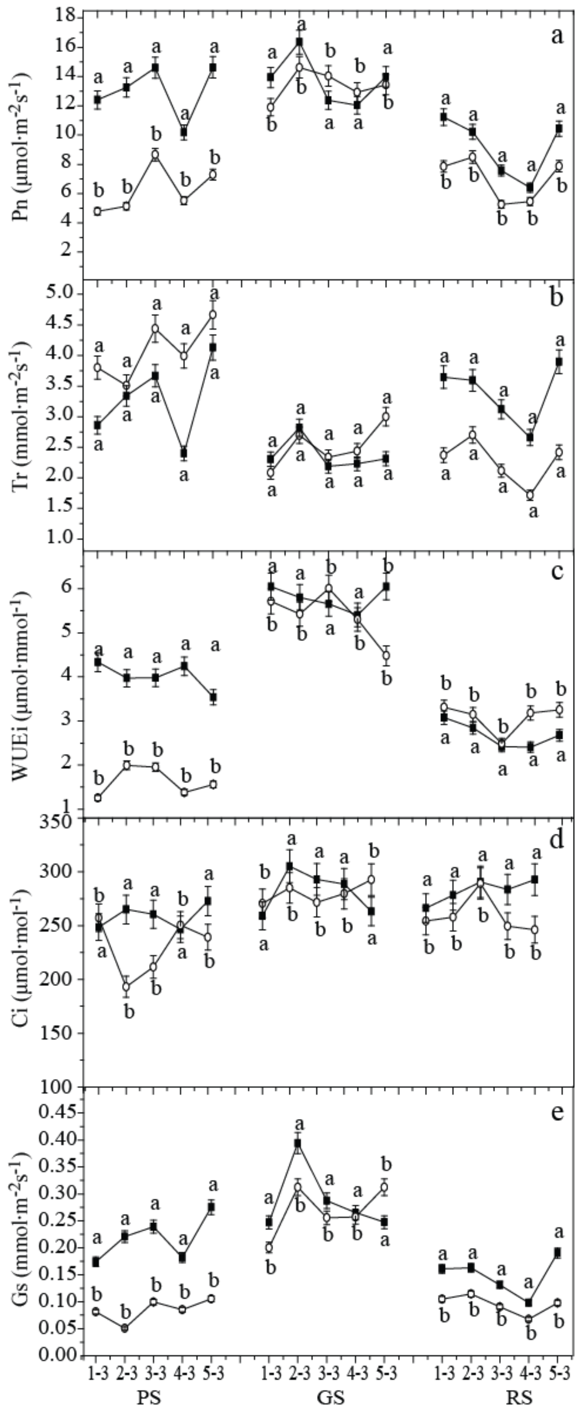

Fig. 6. Adaptation of (a) net photosynthetic rate; (b) transpiration rate; (c) instantaneous water utilization efficiency, (d) intercellular CO_2 concentration, (e) stomatal conductance of the apical leaves in Ecolly at the second developmental period of 2010 and 2011. Values shown are mean ± standard error of the mean (n = 5).

According to Smart (1974), Pn depended on the PAR onto the leaf surface, which could be direct or diffused light. Therefore, Pn could show significant variation along the PAR ($p<0.05$) among the canopy locations in the SCCT and ILSP vines in the day (Fig. 3. upper and basal row). The diurnal patterns of the photosynthetic light response curves of SCCT at the whole developmental period except for the riping stage indicated that the trend of the positive correlations responded to the relationships between Pn and PAR within the most time and these leaves adapted to the high light level under the most condition, respectively. In SCCT, the curves of PS were nearly identical to those of GS because of the similar environmental factors such as temperature and humidity of the leaves within the 8:00-18:00 at the two stages (Figs. 3a, 3b). Light harvesting of the leaves on the PS almost equals at 5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ Pn below 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR while there was disparate diversity over 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR. Owe to the same reason, data of the GS kept at 2 - 3 $\mu mol \cdot m^{-2} \cdot s^{-1}$ around besides that at 8:00. However, the value at 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR reduced suddenly by 0.737 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at 19:00 of the riping stage owing to LSP and LCP (Zhang *et al*., 2010; Aminim & Ezhiann, 2003) related with the radial angle, CO_2 concentration of the reference chamber and sample chamber, and which was more helpful to the acclimation of alimentation component (Mierowska *et al*., 2002) in SCCT than in ILSP. As drought developed, there was a marked reduction of the maximum Pn at the same PAR, as reported by Escalona *et al*. (1999), but Pn of SCCT was lower than that of ILSP at the same condition, which was guessed the more reduction of assimilation ability in SCCT than in ILSP with age.

Change relationship of photosynthetic character: Based on a field experiment in China, Zhang *et al*., (2010) reported the Pn values for the mature vines. During the trial, Pn showed significant variation along the leaf positions ($p<0.05$) as well as between pruning systems ($p<0.05$). From table 1, it is obvious that the earlier into the pinnacle for the total Pn of the leaves, the earlier the Pn declined (SCCT vs ILSP), which were beneficial to the maturity of the canes and the accumulation of the nutrient (conjectured by the color and lignification of trees). Luckily, it appeared in the SCCT vines without another.

Figures in the three leaves positions for SCCT were similar at the growth season compared with these for ILSP. In the first stage, SCCT stimulated the Pn (Figs. 4-6, top row), which is in general agreement with the findings of Hodgkinson *et al*., (1974). The graphs of the middle leaf at the PS were similar, adown in ostium and smoother in SCCT than in ILSP. It is interested that the result was inverse in the second and three stages, which implied that the leaves of SCCT riped earlier than that of ILSP after the prior (Fig. 5a). It isn’t hard that the Pn in SCCT still struggled along after the upmost activity. The Pns were similar in SCCT and ILSP (the similar change tide but dissimilar range) for the apical leaves at three stages (Fig. 6a), which indicated that behavior of photosynthetic activity at the apical leaves was consistent, no matter what trellises. However, the differences of SCCT and ILSP were always significant in the values, which had some connection with the altitude of the leaves and the radiation quantities the leaves incepting under the different pruning systems. On the contrary, the Pns of the basal leaves went up, and yet those of the middle and apical dropped after raising in ILSP under the same condition, which comprised primarily some reasons such as the radiant angle and canopy frame, PAR and the maturity rates of the leaves caused by canopy structure besides the antihypothermia ability themselves compared with SCCT. While Pn of the SCCT was higher than that of the ILSP at the PS, respectively, but noticeably lower than that of the ILSP in the case of the growing and riping stages other than the middle leaf position at the ripeness stage (Figs. 4-6, top row). Comparatively, the photosynthetic accumulation was better in SCCT than in ILSP, and the photosynthetic contribution of every point for SCCT in all cases was relatively even compared with ILSP because their leaves were exposed vertically in the sun that broad area received effective light while a number of leaves for ILSP were shaded with the sun beams due to oblique configuration.

A gradual fluctuation (decline for SCCT vs. drop after raise for ILSP) in Pn associated with a change in stomatal conductance during three stages. And, the vine in SCCT showed the high Pn as for the total gain compared with ILSP. In our study, we mentioned that the leaves showed a slight chlorosis but darker in SCCT than in ILSP at the final trial, which was related to more reductions in chlorophyll and carotenoid contents of SCCT grapevine than ILSP. Hence, the trellis is one of the major factor regulating the growth and nutrient distribution of the grapevine to the trunk and branches during the developmental period, and thus the SCCT should be a system with traits for optimization of light capture in this study.

Stomatal closure is the first event occurring in the leaves in response to drought. The lower soil water deficit, the tighter stomatal closure leading to a rapid reduction of Cs in many vines (Chaves *et al*., 2010). The ILSP plants had lower Cs than the SCCT plants along the developmental period except for the growing stage consistently. Accordingly, the stomatal resistance and Pn could keep the corresponding negative relationship. We presume that, in our study, the stomatal conductance was mainly affected by differences in foliar age, leaves position, season, leaves temperature, air temperature, Pn, Tr and water supply caused by the disparate configuration (Figs. 4-6). It is likely that one of the leaves in SCCT and ILSP had a variant Pn based on Cs (Figs. 4a, 5a, 6a; 4e, 5e, 6e). A Pn-Cs curve shape represented a case where stomatal aperture responses regularly to change in the photosynthetic process no matter what stages. This means that the leaf did meet the basic requirement of Pn having a corresponding response to changes in Cs. Although we did not currently have an explanation for the Pn-Cs curve, there was a possibility that the light intensity for this leaf fluctuated during its vegetal growth and resulted in the durative change of Pn when reexposed to light intensity. Cowan (1972) also found effects of stomatal oscillations on Pn and Tr, which may optimize the relationship between assimilation and growth. Tan and Buttery (1986) found a close relationship between Pn and Cs over a range of light levels as well as temperatures. These conclusions supplemented a new content in this trial.

The shape of curves for SCCT and ILSP indicated an increase or decrease in WUEi with decline or raise in Cs as expected. WUEi of ILSP leaves sharply increased with leaves age and surpassed SCCT at the RS; this level was essentially maintained under continuous changed light angle caused by alternative season (Figs. 4c, 5c, 6c).

Ci is usually affected by air CO_2 concentration, stomatal conductance, and the efficiency of CO_2 assimilation during photosynthesis. In this study, the increased Ci for leaves could possibly have been caused by trellises, leaf positions and ages besides above (Table 1; Figs. 4-6). The lowest Ci was found in the basal leaves of ILSP at the PS and in the middle leaves of SCCT at the RS. The Ci of ILSP at the PS was the highest (Figs. 4d, 5d, 6d). The phenomena could be explained by selection and adaption of leaf to the circumstance. In addition, carbon dioxide was more effectively assimilated in SCCT than in ILSP during the trial (Figs. 4d, 5d, 6d). Therefore, a better influx of CO_2 could come from the more open structure of the palisade and mesophyll tissues of mature or senescent foliage (Kriedemann *et al*., 1970) and the decrease in selective permeability of membranes of aged leaves decided by trellis and season.

Regulation of pruning system on photosynthesis trait under drought: Drought is an important abiotic stress factor limiting the plant growth and productivity (Riaz *et al*., 2013). Photosynthesis responses of three phases were differentiated when using Cs as an integrative parameter for the degree of drought (Flexas *et al*., 2002a). However, training techniques such as SCCT and ILSP were also a crucial factor in this study. Hence, the PS and GS of SCCT and the GS of ILSP were defined as a phase of mild water stress (0.5-0.7 > Cs > 0.15, $mmol \cdot m^{-2} \cdot s^{-1}$), while a moderate water stress phase appeared at the PS and RS of ILSP and the RS of SCCT (0.15 > Cs > 0.05, $mmol \cdot m^{-2} \cdot s^{-1}$) in this experiment according to Flexas *et al*., (2002b). Under mild water stress, this is characterised by a relatively small decline of Pn and Ci, increase of WUEi. While at a moderate water stress phase, a further reduction in Pn and Ci occured and WUEi usually increased, then the photosynthesis efficiency characteristically declined during this phase (Flexas *et al*., 2002a). It is worth notice that non-stomatal limitations were already developing (Flexas *et al*., 2002a & 2002b).

The second stage was just under mild water stress, and stomatal closure was probably the only limitation factor to photosynthesis. Therefore, the Pns of the different leaf positions were decided by mild fluctuation of Cs besides leaves age and leaves configuration. Moderate water stress also controlled Pn at the last stage. Therefore, non-stomatal limitations were already developing at the phase when Cs was rather low (Cs < 0.05 $mmol \cdot m^{-2} \cdot s^{-1}$) (Flexas *et al*., 2002a & 2002b). From Figs. 4e, 5e and 6e, a large number of the basal leaves and a small quantity of middle leaves in SCCT had dominated by non-stomatal inhibition; consequently, photosynthetic process did not affected by the stomatal activity any more. In other words, they had stepped into maturity stage. The peak leaves of SCCT and the all leaves of ILSP were still developing under moderate water stress by contrary. WUEi recorded in ILSP induced no more apparent stomatal closure than SCCT, and therefore it did not limit photosynthesis. Thus, it is not hard for ILSP to gain ripeness before dormancy. A more probable explanation for altered canopy is linked to the seasonal dynamics of canopy growth and movement for the different trellises. Lower character had often been associated with increased shaded-canopy (Smart, 1987). Poni *et al*., (1996) found a reduplication in the mean leaf layer number in vines after investigating the incremental canopy density caused by asymmetric growth compared with symmetric growth. In this trial, SCCT conquered asymmetric canopy because of inerratic one compared with ILSP.

Conclusions

In conclusion, the diurnal changes of the photosynthetic light response curves were smoother in SCCT than in ILSP at the second growing period other than at the riping stage. Therefore, steadier ecological environment SCCT created made for absonant vegetative growth caused by leaf maturation and season.

Evidently, sunlight penetration was more in SCCT than in ILSP during the secondary growing circle, thus, the effects of SCCT on vegetative growth of grapevines during the circle were advantageous not only to canopy microstructure, but also to the photosynthetic character of the entire vine compared with ILSP. Definite light saturation responses occurred earlier in SCCT than in ILSP along the day. SCCT seems to be an appropriate means of accommodating the effects of PAR distribution on some physiological parameters. The research would be helpful for developing improved and effective canopy management strategies in high-efficiency grapevine orchard systems.

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References

Aminim, B. and N. Ezhiann. 2003. Photoinhibition of photosynthesis in mature and young leaves of grapevine (*Vitis vinifera* L.). *Plant Sci.,* 164(4): 635-644.

Baloch, J.U.D., M. Munir and M. Abid. 2013. Flowering response of facultative short day ornamental annuals to artificial light intensities. *Pak. J. Bot*., 45(3): 999-1004.

Chaumont, M., J. Morotgaudry and C. Foyer. 1994. Seasonal and diurnal changes in photosynthesis and carbon partitioning in *Vitis vinifera* leaves in vines with and without fruit. *J. Exp. Bot.,* 45: 1235-1243.

Chaves, M.M., O. Zarrouk, R. Francisco, J.M. Costa, T. Santos, A.P. Regalado, M.L. Rodrigues and C.M. Lopes. 2010. Grapevine under deficit irrigation: hints from physiological and molecular data. *Ann. Bot*., 105: 661-676.

Cowan, L.R. 1972. Oscillations in stomatal conductance and plant functioning associated with stomatal conductance: Observations and a model. *Planta*, 106: 185-219.

De la Hera, M.L., A. Martínez-Cutillas, J.M. López-Roca and E. Gómez-Plaza. 2004. Effects of moderate irrigation on vegetative growth and productive parameters of Monastrell vines grown in semiarid conditions. *Span. J. Agric. Res*., 2: 273-281.

Dos Santos, T., C.M. Lopes, M.L. Rodrigues, C.R. Souza, J.P. Maroco, J.S. Pereira, J.R. Silva and M.M. Chaves. 2003. Partial rootzone drying: effects on growth, and fruit quality of fieldgrown grapevines (*Vitis vinifera* L.). *Funct. Plant Biol*., 30: 663-671.

Dry, P.R., B.R. Loveys, D. Botting and H. Düring. 1996. Proceedings of the Ninth Australian Wine Industry Technical Conference: Effect of partial root-zone drying on grapevine vigour, yield, composition of fruit and use of water, 126-131.

Escalona, J.M., J. Flexas and H. Medrano. 1999. Stomatal and non-stomatal limitations of photosynthesis under water stress in field-grown grapevines. *Aust. J. Plant Physiol*., 26: 421-433.

Flexas, J., J. Bota, J.M. Escalona, B. Sampol and H. Medrano. 2002a. Effects of drought on photosynthesis in grapevines under field conditions: an evaluation of stomatal and mesophyll limitations. *Funct. Plant Biol*., 29: 461-471.

Flexas, J., J.M. Escalona, S. Evain, J. Gulías, I. Moya, C.B. Osmond and H. Medrano. 2002b. Steady-state chlorophyll fluorescence (Fs) measurements as a tool to follow variations of net CO_2 assimilation and stomatal conductance during water-stress in C_3 plants. *Physiol. Plant.*, 114(2): 231-240.

Hodgkinson, K.C. 1974. Influence of partial defoliation on photosynthesis, photorespiration and transpiration by Lucerne leaves of different ages. *Aust. J. Plant Physiol*., 1: 561-578.

Intrigliolo, D.S., C. Chirivella and J.R. Castel. 2005. International Symposium on Advances in Grapevine and Wine Research: Response of grapevine cv. Tempranillo to irrigation amount and partial rootzone drying under contrasting crop load levels. Congress ISHS, Venosa.

Kriedemann, P.E., W.M. Kliewer and J.M. Harris. 1970. Leaf age and photosynthesis in *Vitis vinifera L*. *Vitis*, 9: 97-104.

Li, H. and Y.L. Fang. 2005. Study on the Mode of Sustainable Viticulture: Quality, Stability, Longevity and Beauty. Science & Technology Review, 23(9): 20-22.

Li, H., H. Wang and Y.L. Fang. 2010. A new method of CCT mode [P]. China Patent: 201010013581.4, 06-30

Mierowska, A., N. Keutgen, M. Huysamer and V. Smith. 2002. Photosynthetic acclimation of apple spur leaves to summer-pruning. *Sci. Hortic*., 92: 9-27.

Ozer, C., A.S. Yasasin, O. Ergonul and S. Aydin. 2012. The effects of berry thinning and gibberellin on Recel Uzumu table grapes. *Pak. J. Agri. Sci*., 49: 105-112.

Poni, S., B. Rebucci, E. Magnanini and C. Intrieri. 1996. Preliminary results on the use of a modified point-quadrat method for estimating canopy structure of grapevine training systems. *Vitis*, 35: 23-28.

Rena, A.B., R.S. Barros, M. Maestri and M. R. Söndahl. 1994. Sub-Tropical and Tropical Crops (vol. II.). In: *Handbook of Environmental Physiology of Fruit Crops*. (Eds.): B. Schaffer and P.C. Andersen. CRC Publishers, Boca Raton, pp. 101-122.

Riaz, A., A. Younis, A.R. Taj, A. Karim, U. Tariq, S. Munir and S. Riaz. 2013. Effect of drought stress on growth and flowering of marigold (*Tagetes erecta* L.). *Pak. J. Bot*., 45(S1): 123-131.

Romero, P., J.M. Navarro, F. García and P. Botía. 2004b. Effects of regulated deficit irrigation during the preharvest period on gas exchange, leaf development and crop yield on mature almond trees. *Tree Physiol*., 24: 303-312.

Romero, P., P. Botia and F. Garcia. 2004a. Effects of regulated deficit irrigation under subsurface drip irrigation conditions on vegetative development and crop yield in mature almond trees. *Plant Soil*, 260: 169-181.

Smart, R.E. 1974. Photosynthesis by grapevine canopies. *J. Appl. Ecol*., 11: 997-1006.

Smart, R.E. 1987. Influence of light on composition and quality of grapes. *Acta Horticulturae*, 206: 36-47.

Tan, C.S. and B.R. Buttery. 1986. Photosynthesis, stomatal conductance, and leaf water potential in response to temperature and light in peach. *Hort. Sci*., 21: 1180-1182.

Zhang, Z.W., B.Y. Zhang, H.F. Tong and L. Fang. 2010. Photosynthetic LCP and LSP of different grapevine cultivars. *J. Northwest Forest. U*., 25: 24-29.

Zhao, X.H., C.X. LI, L.J. Nan, H. Wang and H. Li. 2013. A New grape shaping method in the soil-bury over-wintering zone of arid and semiarid areas. *Pak. J. Bot*., 45(4): 1307-1314.

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