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不同灌溉阈值对'巨峰'葡萄树体生长与果实品质的影响

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摘 要:【目的】验证之前研究所确定的'巨峰'葡萄果实发育不同时期开始灌溉的土壤水势阈值。【方法】以6 a生盆栽'巨峰'葡萄自根植株为试验材料,设定在果实发育不同时期按照之前研究所确定的阈值进行灌溉(中度灌溉),并设置过度灌溉、胁迫灌溉和严重胁迫灌溉3个对照处理,比较各处理的新梢生长、果实生长、果实品质以及劳动力消耗等指标。【结果】中度灌溉处理的葡萄新梢生长适中,摘心次数较少,叶片净光合速率最高,果实生长最快,可滴定酸含量低(0.33%,ω,后同),可溶性固形物含量高(19.0%),糖酸比高(57.6),上色较好(花青素含量0.078 mg·g^{-1}),综合表现最佳。【结论】从发芽期到幼果期适宜开始灌溉的土壤水势阈值为-10.0 kPa,之后到转色期之前为-15.0 kPa,转色期到成熟期为-20.0 kPa,采收后为-10.0 kPa。

关键词:'巨峰'葡萄;灌溉阈值;树体生长;果实品质

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Effect of different irrigation thresholds on tree growth and fruit quality in 'Kyoho' grape

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Abstract:【Objective】To verify the reliability of the established soil water potential threshold values to trigger irrigation at different fruit developmental periods in 'Kyoho' grape. The soil water potential threshold value was -10.0 kPa after berry set, -15.0 kPa from berry first rapid growth period to seed hardening, and -20.0 kPa from veraison to the maturation period, which were established in our previous studies based on berry growth, leaf photosynthetic rate, and the allocation of photosynthetic products to fruit. These threshold values should enable rapid berry expansion and more photosynthetic products transported to fruit, and have no significant influence on leaf net photosynthetic rate.【Methods】6-year-old potted own-rooted 'Kyoho' grapevines were used as the experimental materials. Medium irrigation (according to the established soil water potential threshold values before to trigger irrigation during pivotal fruit developmental periods, which were berry set, the first rapid growth period, and veraison) and three treatments of over irrigation, stress irrigation and high stress irrigation were set up. The soil water potential threshold value to trigger irrigation of over irrigation was -5 kPa during the whole growing season. The threshold values for stress irrigation and high stress irrigation were 5 kPa and 10 kPa, respectively, smaller than the established soil water potential threshold value during pivotal fruit developmental periods (-15 kPa, -20

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kPa, and −25 kPa for stress irrigation, and −20 kPa, −25 kPa, and −30 kPa for high stress irrigation). Soil water potential was determined with three waterproof soil moisture tension meters for each treatment during the whole experiment process. Then the phenological periods, shoot length, shoot diameter, leaf area per shoot, leaf chlorophyll content, the diurnal variation of photosynthetic rate, berry diameter, total soluble solid content, titratable acid content, ratio of soluble solid content to titration acid, anthocyanin content and pinching times per shoot were determined to compared tree growth, berry growth, fruit quality, and labor costs for the four treatments. Leaf chlorophyll content was determined by SPAD−502 chlorophyll meter. The electronic digital display saccharometer (DR103) was used to determine the total soluble solid content in fruit juice. The titratable acid content equivalent to tartaric acid content was determined using the acid−alkali neutralization titrimetric method. The spectrophotometer method was used to determine anthocyanin content in grape skins. 【Results】The lower the soil water potential threshold value to trigger irrigation, the earlier the flowering period, but the later the veraison. Shoot length, shoot diameter, and leaf area per shoot increased during the whole growing season. Shoot growth slowed down after flowering, and shoot growth became rapid again during seed hardening. The amount of shoot growth was reduced with the decreasing of the soil water potential threshold value, and shoot growth of over irrigation was significantly greater than that of the other three treatments. Medium irrigation had moderate shoot length, shoot diameter and leaf area with less pinching times than over irrigation. The leaf chlorophyll content of the four treatments increased first, then decreased with the progress of phenological periods, and reached a peak value at seed hardening. The differences in leaf chlorophyll content in medium irrigation from the other three control treatments were not significant. The diurnal variations of photosynthetic rate of the four treatments at flowering, the first rapid berry growth period and seed hardening were similar, which presented bimodal curves and reached peak values between 8:00 to 10:00. The differences in maximum value of photosynthetic rate of the four treatments were not significant. As a whole, the photosynthetic rate in over irrigation and medium irrigation was higher than that in stress irrigation and high stress irrigation. Leaf photosynthetic rate during the first rapid berry growth period was higher than that during the other two periods, and the diurnal fluctuation of photosynthetic rate was smaller during seed hardening. Berry growth followed a classical double sigmoid pattern. Before veraison, the higher the soil water potential threshold value to trigger irrigation, the bigger berry diameter. While berry growth became the fastest of all after veraison, and berry diameter at ripening of medium irrigation was larger than that of the other three control treatments. The total soluble solid content in fruit decreased gradually with the increasing of soil water potential threshold value at veraison. During ripening, medium irrigation had the highest total soluble solid content, which was 19.0% and significantly higher than the other three control treatments. Over irrigation had the lowest total soluble solid content, which was 16.1%. The titratable acid content of medium irrigation and stress irrigation were lower than that of the other two treatments. They were both 0.33% and significantly lower than over irrigation and high stress irrigation. The titratable acid content of over irrigation was the highest of all, which was 0.39%. At veraison, the ratio of total soluble solid content to titratable acid reduced with the increasing of the soil water potential threshold value. This was consistent with the veraison of each treatment. While the ratio of total soluble solid content to titratable acid of medium irrigation was the highest at ripening, which was 57.6. The next was that in stress irrigation, which was 53.2. The ratios of total soluble solid content to titratable acid of these two treatments were significantly higher than those of over irrigation and high stress irrigation. The anthocyanin content decreased with the increasing of soil water potential threshold value to trigger irrigation at veraison and ripening. The anthocyanin content of medium irrigation was 0.078 mg·g^{-1} at ripening, which was significantly higher than that of over irrigation.【Conclusion】Compared with over irrigation, stress irrigation, and high stress irrigation, medium irrigation had the best fruit quality and tree growth. This indicated that the established soil water potential threshold values to trigger irrigation at different fruit developmental periods reported in our previous studies were practical. The optimal soil water potential threshold values to trigger irrigation are −10.0 kPa after berry set, −15.0 kPa from berry first rapid growth period to seed hardening, −20.0 kPa from veraison to the maturation period, and −10.0 kPa after harvest for 'Kyoho' table grape. These soil water potential threshold values could keep moderate tree growth, high leaf photosynthetic rate, rapid berry growth, and high quality fruit.

Key words: 'Kyoho' grape; Irrigation threshold; Tree growth; Berry quality

传感器技术、通信技术、自动控制技术和计算机技术在农业领域中的应用与发展为果树的自动化灌溉提供了重要的基础条件[1]，自动化灌溉技术正在逐步成为发展高效节水农业的重要措施。农业自动化灌溉实施的关键是选择合适的灌溉指标和制定合理的灌溉决策[2]。

生产上用来指导农业灌溉管理的指标主要有土壤水分状况、植物水分状况和冠层温度[3]。作物所需的水分主要是通过根系从土壤中获取，土壤水势与土壤水分含量、土壤空隙大小、土壤颗粒组成和土壤水分的表面张力等因素有关，是反映土壤水的流动性及对植物有效性的关键指标[4]。在不同土壤条件下，果树维持正常生命所需要的土壤水势是相同的，因此土壤水势具有通用性[5]。另外，土壤水分张力计可以连续自动地监测土壤的水势变化，是用于指导果树自动化与智能化灌溉的较好指标[1,5]。

目前，国内外关于灌溉阈值的确定标准不一。有研究者认为应将土壤水分含量保持在作物光合速率或者产量最高时的土壤水分阈值，这样才能有效地提高水分的生产率[6]。Abrisqueta等[7]将土壤水分含量从缓慢下降到快速下降的转折点作为桃树开始受到水分胁迫的关键点，并将90%田间持水量作为采收后'Flordastar'桃树开始灌溉的阈值。刘洪光等[8]研究表明，'克瑞森'葡萄的产量在萌芽期和抽穗期保持灌溉下限为40%田间持水量的情况下达到最大。Zsófi等[9]的研究发现，50%田间持水量能够很好地提高水分利用率。李洪艳等[10]的研究表明，转色期'峰后'葡萄果实的糖卸载速率在土壤水势为−16.86 kPa时最高，并将此值作为转色期葡萄开始灌溉的临界值。而梁鹏[11]的研究表明，将葡萄转色后开始灌溉的土壤水势阈值控制在−30 kPa左右(约70%田间持水量)时，水分利用率提高，且果实的产量与品质不受影响。

Lou等[12]基于果粒膨大、叶片净光合速率和光合产物向果实中分配确定了'巨峰'葡萄幼果期、果实第1次快速膨大期和转色期到成熟期开始灌溉的土壤水势阈值分别为−10、−15和−20 kPa。为了验证该阈值的可行性和实用性，笔者在果实发育的关键时期设置了按照该阈值进行灌溉的处理，通过与过度灌溉、胁迫灌溉和严重胁迫灌溉处理比较，以新梢生长、果实品质和劳动力消耗为指标，最终确定合理的灌溉指标阈值。

1 材料和方法

1.1 材料

本试验于2014—2015年在上海交通大学现代工程训练中心的玻璃温室(31°11′N，121°29′E)中进行。2014年进行材料培养，1月初选取长势一致、处于结果期的5 a(年)生'巨峰'葡萄自根植株24株作为试验材料，移栽于容积为78.5 L的花盆中(上口径55 cm、下口径45 cm、高40 cm)，花盆底部留有6个直径为1 cm的排水孔，栽培基质为$V_{园土}$：$V_{有机肥}$：$V_{珍珠岩}$=5：1：1，施肥管理按照Wang等[13]的方法。发芽后每株选留5个新梢斜向上牵引，每个新梢上留1串果穗，每个果穗留果40~50粒。

2015年进行正式试验，将24株植株随机分成4组，新梢与施肥管理同2014年，水分管理按照表1设定的阈值进行自动化灌溉。新梢第1次摘心在第7枚叶片长到1/3成熟叶片大小时进行；之后顶部的副梢和其他副梢摘心均留2枚叶片进行。2015年3—8月温室内平均温度为25.0 ℃，白天平均光照强度为221.6 μmol·m^{-2}·s^{-1}(夏季中午高温时段展开遮阳网)。

1.2 方法

1.2.1 *灌溉处理设计*　土壤水势的测定采用从日本购买的土壤水分张力计（SP-3100S-01, Sprout, Japan），每盆土壤3个，插入深度为25 cm的根系密集分布区，土壤水势通过数据记录仪（R4109，上海绎捷自动化科技有限公司，中国）记录。在果实发育的关键时期设置了4个灌溉阈值处理，即过度灌溉（over irrigation，OI，全生育期始终以-5 kPa为阈值指标）、中度灌溉（medium irrigation，MI，按照之前笔者研究所确定的阈值进行灌溉）、胁迫灌溉（stress irrigation，SI，比MI低5 kPa）和严重胁迫灌溉（high stress irrigation，HSI，比MI低10 kPa）（表1）。

表1　4个处理在不同时期灌溉的土壤水势阈值

Table 1 The soil water potential thresholds to trigger irrigation in four treatments　　kPa

处理 Treatment	时期 Period				
	发芽期-开花期 Budbreak-flowering	幼果期 After berry set	果实第1次快速膨大期-硬核期 The first rapid berry growth period-seed hardening	转色期-成熟期 Veraison-ripening	采收后-休眠期 Postharvest-dormancy
严重胁迫灌溉HSI	−10.0	−20.0	−25.0	−30.0	−10.0
胁迫灌溉SI	−10.0	−15.0	−20.0	−25.0	−10.0
中度灌溉MI	−10.0	−10.0	−15.0	−20.0	−10.0
过度灌溉OI	−5.0	−5.0	−5.0	−5.0	−5.0

1.2.2 *新梢与果粒生长的测定*　发芽后，每个处理任选6个新梢作上标记（每株选1个），每7 d测定1次新梢长度和粗度，在各物候期（开花期、果实第1次快速膨大期、硬核期和转色期）测定6个新梢上每个叶片的中脉长度，根据回归方程 $Y = 0.693\,3a^2 + 5.506\,9a - 15.196\,6$（$a$：叶片长度，$Y$：叶片面积）计算新梢总叶面积[14]。坐果后，从上述每个标记新梢上果穗的不同位置（上、中、下）任意选取6个果粒作上标记，用游标卡尺于下午16:00—17:00每3 d测定1次果粒横径直到果实成熟。

1.2.3 *叶片净光合速率日变化和叶绿素含量的测定*　在盛花期、果实第1次快速膨大期和硬核期，选择无雨的晴天于6:00—18:00用便携式光合作用测定仪（CIRAS-2，PP Systems，USA）测定4个处理植株上果穗节位或上端叶片的净光合速率日变化，每2 h测定1次，每个处理6次重复。

在测定叶片净光合速率的同时，用叶绿素仪（SPAD-502，Konica Minolta Sensing，Inc.，Japan）测定果穗节位和上端叶片的叶绿素含量，每个处理12次重复。

1.2.4 *果实品质的测定*　在转色期和成熟期，分别采集果粒30个，测量果粒横径大小，然后置于-20 ℃冰箱中保存，用于测定果实可溶性固形物（total soluble solid，TSS）、可滴定酸和果皮花色苷含量，具体测定方法参考刘爱玲等[15]的方法，可溶性固形物含量用电子数显式糖度计（DR103）测定，可滴定酸含量用酸碱中和滴定法测定，并换算成酒石酸含量，花色苷含量用分光光度计法测定。

1.2.5 *数据分析*　试验数据用Excel 2010软件进行整理和绘图，用SAS 8.2软件进行统计分析。

2 结果与分析

2.1 4个处理的土壤水势变化

从发芽后到成熟期，4个处理的土壤水势变化情况如图1所示，从图中可以看出，坐果前严重胁迫

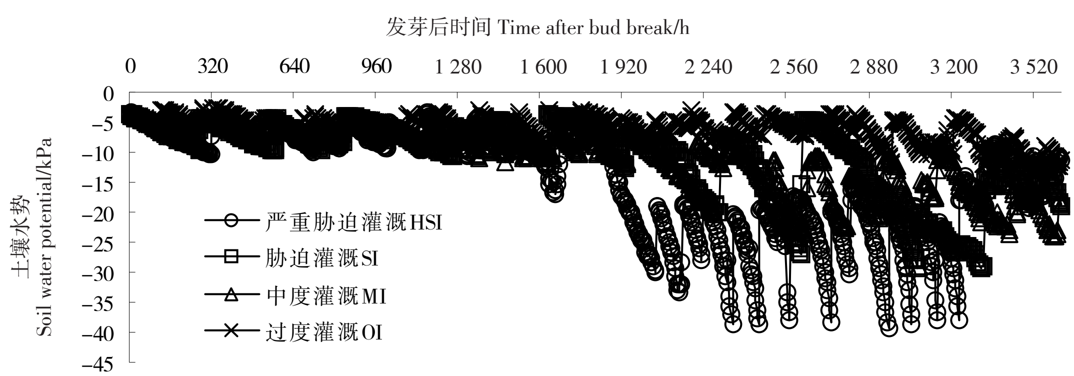


图1　4个灌溉阈值处理的土壤水势变化情况

Fig. 1 Changes in soil water potential in four irrigation thresholds treatments

灌溉(HSI)、胁迫灌溉(SI)和中度灌溉(MI)3个处理开始灌溉的土壤水势阈值均在-10.0 kPa左右,过度灌溉(OI)处理的土壤水势阈值在-5.0 kPa左右;幼果期这4个处理的灌溉阈值依次约为-17.0、-12.0、-10.0和-8.0 kPa;果实第1次快速膨大期到硬核期这4个处理的灌溉阈值依次约为-30.0、-20.0、-17.0和-8.0 kPa,转色期到成熟期这4个处理的灌溉阈值依次约为-39.0、-29.0、-22.0和-12.0 kPa。总体上,4个处理的实际灌溉阈值比设定的阈值略低,且HSI、SI、MI和OI 4个处理的灌溉阈值越来越高。

2.2 不同灌溉阈值对'巨峰'葡萄树体生长的影响

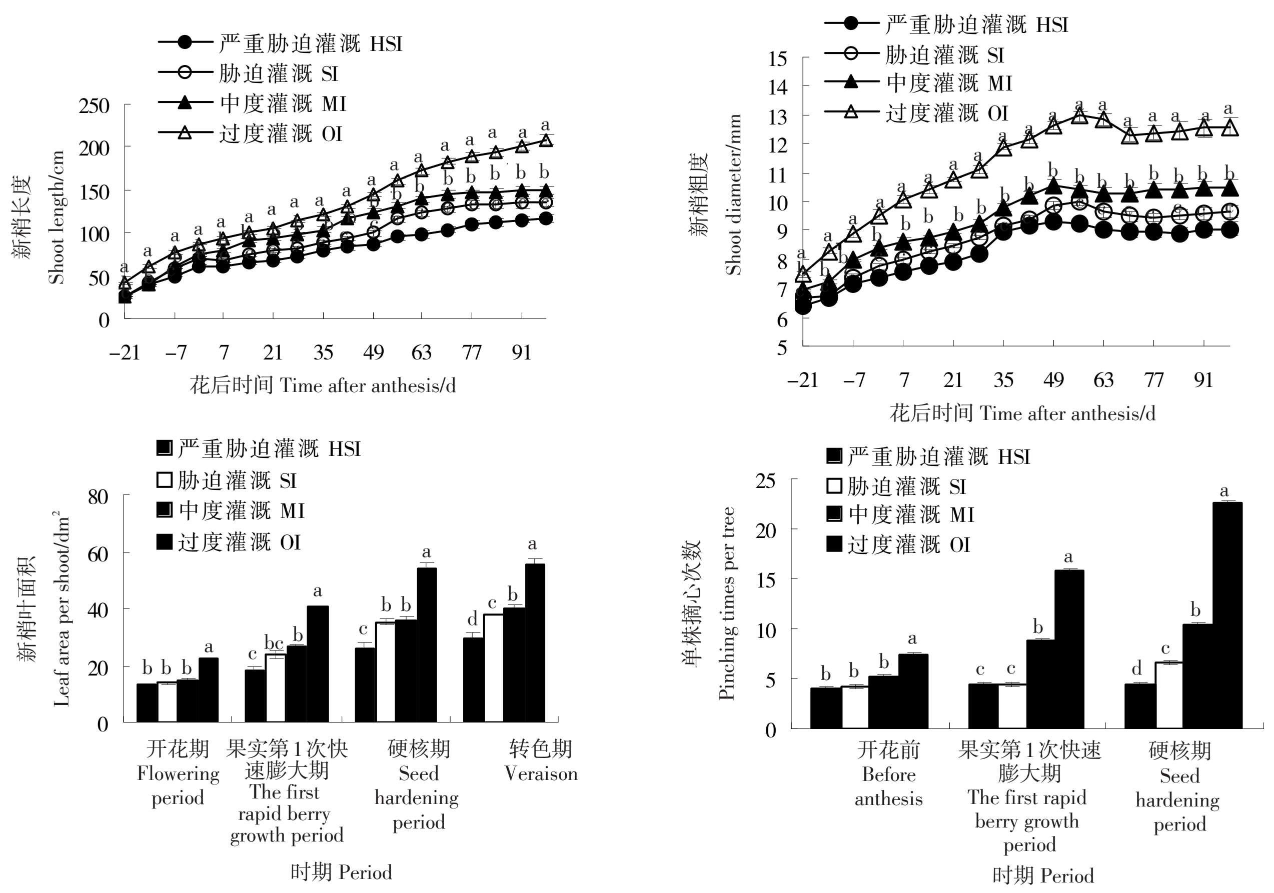
2.2.1 物候期 从表2可以看出,不同灌溉阈值处理对'巨峰'葡萄植株的物候期有一定的影响,开始灌溉的土壤水势阈值越高,葡萄树越早进入开花期,但进入转色期和成熟期的时间推迟;开始灌溉的土壤水势阈值越低则相反。说明干旱胁迫减慢了葡萄进入开花期,但加速了葡萄进入转色期和成熟期。

表2 4个灌溉阈值处理对'巨峰'葡萄物候期的影响

Table 2 Effect of four irrigation thresholds treatments on the phenological periods of 'Kyoho' grape

处理 Treatment	发芽期 Budbreak period	开花期 Flowering period	果实第1次快速膨大期 The first rapid berry growth period	硬核期 Seed hardening period	转色期 Veraison	成熟期 Ripening period
严重胁迫灌溉HSI	3月10日 Mar. 10	5月1日 May 1	5月15日 May 15	6月1日 Jun. 1	6月24日 Jun. 24	7月28日 Jul. 28
胁迫灌溉SI	3月10日 Mar. 10	4月29日 Apr. 29	5月13日 May 13	6月7日 Jun. 7	6月25日 Jun. 25	8月2日 Aug. 2
中度灌溉MI	3月10日 Mar. 10	4月28日 Apr. 28	5月12日 May 12	6月5日 Jun. 5	6月27日 Jun. 27	8月6日 Aug. 6
过度灌溉OI	3月10日 Mar. 10	4月25日 Apr. 25	5月10日 May 10	6月8日 Jun. 8	6月28日 Jun. 28	8月10日 Aug.10

2.2.2 新梢生长 从图2可知,植株新梢长度、粗度、叶面积在整个生长期逐渐增加,开花后,新梢生



不同小写字母表示同一时间不同处理之间差异显著($P \leq 0.05$)。下同。

The different small letters indicate significant difference at the same time at $P \leq 0.05$. The same below.

图2 4个灌溉阈值处理对'巨峰'葡萄新梢长度、粗度、叶面积和单株摘心次数的影响

Fig. 2 Effect of four irrigation thresholds treatments on shoot length, shoot diameter, leaf area per shoot and pinching times per tree in 'Kyoho' grape

长减慢,花后1个月左右新梢再次快速生长。新梢生长量随开始灌溉阈值的降低而减小。差异显著性分析表明,OI处理的新梢长度在所测定的时间段内均显著大于SI和HSI处理;MI处理的新梢长度仅在开花后一段时间与OI处理的新梢长度之间没有显著差异,且在开花后显著大于HSI和SI处理;HIS与SI处理的新梢长度在果实转色期之后差异显著。MI、SI和HSI处理的新梢粗度、新梢叶面积和单株摘心次数在整个生长期内均显著小于OI处理;MI处理的新梢粗度从开花后开始与HSI处理之间差异显著,从花后28 d开始与SI处理差异显著。MI处理的新梢叶面积在果实第1次快速膨大期、硬核期和转色期均显著大于HIS处理,仅在转色期显著大于SI处理;SI与HIS处理的新梢叶面积在硬核期和转色期差异显著。MI处理的单株摘心次数在果实第1次快速膨大期和硬核期显著大于SI和HSI处理;SI与HSI处理的单株摘心次数仅在硬核期差异显著。

2.2.3　叶片叶绿素含量　从图3可以看出,在开花期、果实第1次快速膨大期和硬核期4个处理叶片的叶绿素含量之间差异不显著,而在转色期严重胁迫灌溉和胁迫灌溉处理的叶片叶绿素含量显著高于过

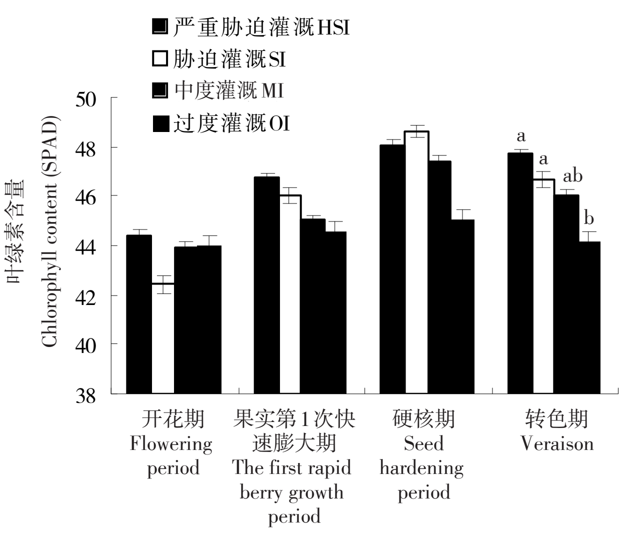
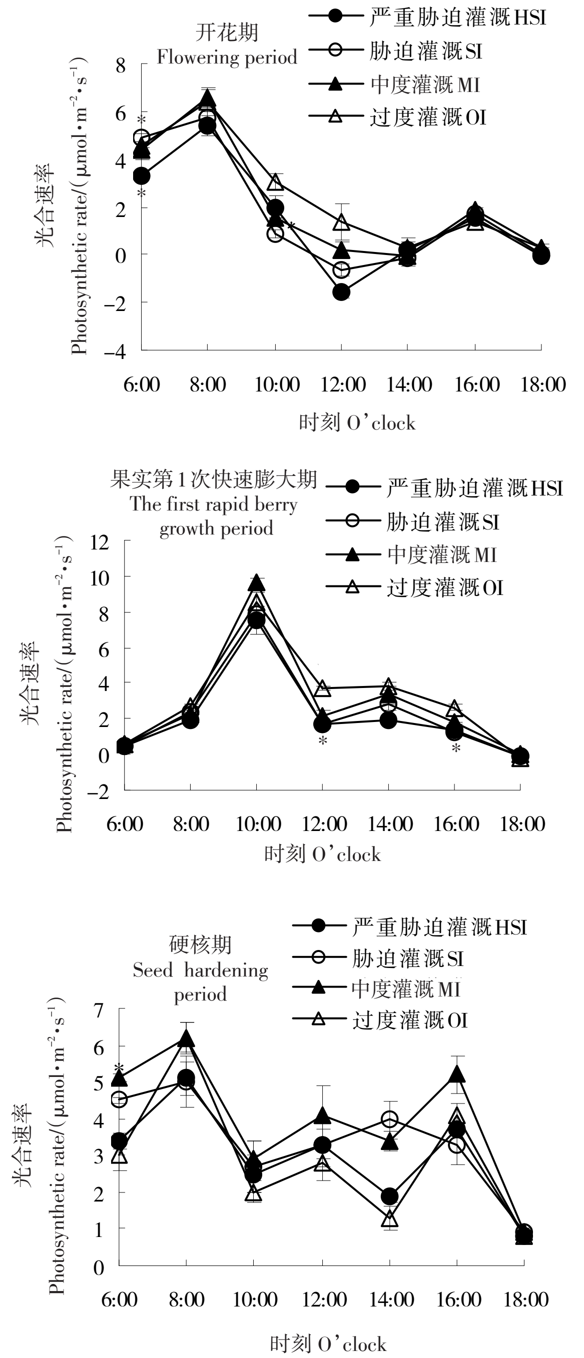


图3　4个灌溉阈值处理对'巨峰'葡萄叶片叶绿素含量的影响

Fig. 3 Effect of four irrigation thresholds treatments on leaf chlorophyll content in 'Kyoho' grape

度灌溉处理,并且随着物候期的进程,葡萄叶片的叶绿素含量先升高后降低,其中,硬核期达到最大值。

2.2.4　叶片净光合速率日变化　在开花期、果实第1次快速膨大期和硬核期,4个处理的叶片净光合速率(P_n)日变化规律相似(图4),上午8:00—10:00达



*表示该值与同一时间过度灌溉处理的叶片净光合速率之间存在显著差异($P \leq 0.05$)。

* indicates significant difference in the photosynthetic rate from over irrigation treatment at the same time at $P \leq 0.05$.

图4　4个灌溉阈值处理对开花期、果实第1次快速膨大期和硬核期'巨峰'葡萄叶片净光合速率日变化的影响

Fig. 4 Effect of four irrigation thresholds treatments on the diurnal variation of photosynthetic rate at flowering period, the first rapid berry growth period and seed hardening period in 'Kyoho' grape

到一天中的最大值，中午叶片 P_n 下降，下午略微回升，在14:00—16:00达到下午 P_n 最大值。其中，果实第1次快速膨大期的叶片 P_n 较高。差异显著性分析表明，4个处理的叶片 P_n 日最大值之间差异不显著，总体上，MI和OI 2个处理的叶片 P_n 较高。在开花期，OI处理的叶片 P_n 分别在6:00和10:00显著高于HSI和SI。在果实第1次快速膨大期，OI处理的叶片 P_n 在12:00和16:00显著高于SI处理。硬核期的叶片 P_n 日变化波动较小。

2.3 果实生长

2.3.1 果粒大小 从图5可以看出，4个处理的葡萄果粒大小生长曲线均呈双"S"形，说明4个处理的葡萄树均未受到严重的水分胁迫。转色前，4个处理的果粒横径随着开始灌溉阈值的升高而增加；转色后，中度灌溉处理的果粒横径增长迅速，最终超过过度灌溉处理，且这2个处理的果粒横径均显著大于胁迫灌溉和严重胁迫灌溉处理的果粒横径。

2.3.2 果实品质 转色期，果实的可溶性固形物含量随着灌溉阈值的升高而降低，这与果实进入转色期的顺序一致，且4个处理之间差异显著；而在成熟期中度灌溉处理的果实可溶性固形物含量最高，其次是胁迫灌溉处理，过度灌溉处理最低，说明转色后

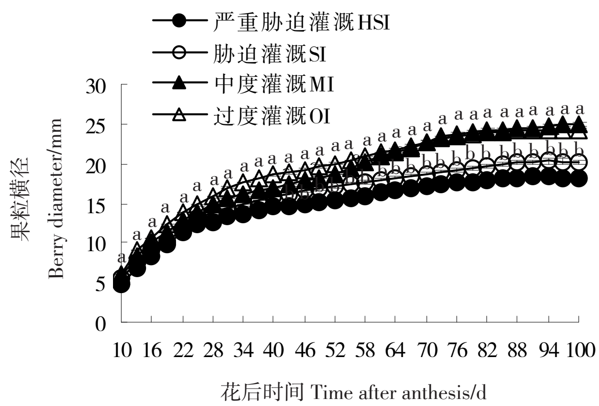


图5 4个灌溉阈值处理对'巨峰'葡萄果粒横径的影响

Fig. 5 Effect of four irrigation thresholds treatments on berry diameter in 'Kyoho' grape

水分过多或过少均会影响果实中的糖分积累。转色期4个处理果汁的可滴定酸含量随着灌溉阈值的升高而升高；而在成熟期SI和MI处理果汁的可滴定酸含量较低，说明转色后合适的灌溉有利于果实中可滴定酸的转化。转色期果实的糖酸比随着灌溉阈值的降低而升高，而在成熟期MI处理的果实糖酸比最高，其次是SI处理，OI处理的果实糖酸比最低。转色期和成熟期的果皮花色苷含量随着灌溉阈值的升高而降低，这主要是果粒变小造成的（表3）。

表3 4个灌溉阈值处理对转色期和成熟期'巨峰'葡萄果实品质的影响

Table 3 Effect of four different irrigation threshold treatments on berry quality during veraison and ripe stages in 'Kyoho' grape

时期 Period	处理 Treatment	果粒横径 Berry diameter/mm	ω(可溶性固形物) TSS/%	ω(可滴定酸) Titratable acid content/%	糖酸比 Sugar acid ratio	ω(花色苷) Anthocyanin content/(mg·g⁻¹)
转色期 Veraison	严重胁迫灌溉HSI	16.32±0.81 a	12.2±0.1 d	0.82±0.01 a	14.8±0.1 c	0.042±0.002 b
	胁迫灌溉SI	17.92±0.95 b	11.4±0.1 c	0.88±0.01 b	13.0±0.2 b	0.034±0.001 a
	中度灌溉MI	20.89±0.60 c	10.4±0.1 b	0.93±0.01 b	11.2±0.2 b	0.033±0.001 a
	过度灌溉OI	21.34±1.14 c	8.8±0.1 a	0.96±0.01 c	9.2±0.1 a	0.032±0.002 a
成熟期 Ripe stage	严重胁迫灌溉HSI	18.25±0.70 a	17.3±0.1 b	0.36±0.00 b	47.5±0.5 b	0.124±0.002 c
	胁迫灌溉SI	20.25±0.77 b	17.5±0.1 c	0.33±0.01 a	53.2±1.7 c	0.085±0.001 b
	中度灌溉MI	24.88±0.86 c	19.0±0.1 d	0.33±0.01 ab	57.6±1.6 c	0.078±0.002 b
	过度灌溉OI	24.28±0.46 c	16.1±0.1 a	0.39±0.01 b	41.7±0.6 a	0.054±0.000 a

3 讨 论

合理的灌溉制度不仅可以提高果树的产量和品质，而且节约劳动力和水资源[16]。研究表明，适度的水分胁迫能够促进更多的光合产物向果实中转运，同时还能抑制过度的营养生长[17]。调亏灌溉[17]、部分根域胁迫灌溉[18]和持续亏缺灌溉[19]均是在此基础上提出来的有效灌溉方式。亏缺灌溉的关键是把握好亏缺灌溉的时间和程度，不合适的水分亏缺对果实的膨大生长和品质形成均有不利影响，甚至造成树体生长停止。

本研究结果表明，随着开始灌溉阈值的降低，葡萄进入转色期和成熟期提前。这与迄今的研究结果一致[20]，说明干旱胁迫加快了果实的成熟，减少了新梢对光合产物的竞争，使得更多的光合产物被运输到果实中。张福庆等[21]的研究表明，葡萄全年60%

以上的新梢生长量在开花前形成,本研究中新梢约一半的生长量在开花前形成,新梢长度、粗度和总叶面积均是随着开始灌溉阈值的降低而减小,摘心次数也相应减少,这与Van Leeuwen等[20]的研究结果相似。叶片是光合产物的主要来源,一定的新梢生长量是保证树体营养和果实生长的前提。新梢生长量少,光合产物的形成则减少;新梢生长量过多,则会造成遮阴,增加修剪量和浪费营养,同时新梢还与果实竞争光合产物,对果实的生长也不利[22]。之前有研究表明,新梢长度和粗度生长速率最快的灌溉量比果穗生长速率最快的灌溉量大,且新梢生长比果实生长对水分胁迫更加敏感[23],因此通过适当降低灌溉阈值可以达到抑制新梢生长和促进果实生长的目的。本研究中,果实生长表现最好的是中度灌溉处理,果粒膨大速率在转色后超越过度灌溉处理,也证实了这一理论。

过高或过低的土壤水势均会对果树的生理指标产生影响,葡萄叶片的叶绿素含量和光合速率在适宜的土壤水势范围内表现最好[24]。本研究中叶片的叶绿素含量随灌溉阈值的降低而升高,这主要是由于低的灌溉阈值造成叶片数量和叶面积减小,而试验各处理的施肥情况一致,从而造成相似数量的叶绿素在面积小的叶片上积累的浓度高。本研究中,4个处理的叶片净光合速率日变化规律相似,均呈"双峰"曲线,这2个高值分别出现在上午8:00左右和下午16:00左右,这与李雅善等[25]在'喜乐'葡萄上的研究结果相似;而严巧娣等[26]在'矢富罗莎'葡萄上的研究表明,叶片P_n 2次高峰分别出现在12:00和15:00左右,这种差异主要是由于环境条件的差异造成的。本试验中4个处理的叶片P_n日最大值之间差异均不显著,说明本试验中的水分胁迫程度没有对叶片P_n造成显著影响。总体上,中度灌溉与过度灌溉处理的叶片P_n较高,这与土壤水分有一定的关系,土壤水分过多会造成新梢生长过旺,叶片之间相互遮阴,叶绿素含量下降,反而不利于光合作用的进行。水分胁迫对光合作用的抑制是气孔因素和非气孔因素共同作用的结果[27],水分亏缺不但抑制了叶面积的扩大,使气孔关闭,降低叶绿体的光化学活性和生物学活性,还使光合速率的CO_2补偿点和光补偿点增高,CO_2饱和点和光饱和点降低,从而使叶片不能有效地利用光能[28]。

果实品质是外在品质和内在品质的统一,其受多种因素影响,其中水分状况起着关键作用[17]。水分亏缺将会造成果实体积减小,果肉紧实;水分过多则会造成果实糖度下降,因此,合适的水分管理对于鲜食葡萄的高产优质生产意义重大[29]。张大鹏等[30]的研究表明,果实第1次快速膨大期和硬核期的水分亏缺对葡萄果实品质均有不利影响,而果实第2次快速膨大期的水分亏缺对果实生长的影响因品种而异,严重的水分胁迫既抑制了'巨峰'葡萄的糖类合成和转运,又减慢了花青素的合成和有机酸的转化。本研究中,4个处理的果粒大小生长曲线均呈现双"S"形,转色前,灌溉阈值越高,果粒越大;转色后,中度灌溉处理的果实生长最快,最终超过过度灌溉处理。说明转色后的合适灌溉对于果粒大小影响很大,灌溉过多新梢生长过旺,不利于果粒的膨大,且果实中糖的积累、酸的转化和降解均减慢,果皮难以上色;严重的水分胁迫对果实生长的抑制作用随着时间的延长而加重。水分胁迫虽然加速了果实进入转色期和成熟期,果实的TSS含量、糖酸比和花青素含量在转色期均是随着灌溉阈值的升高而降低,但是之后果实的品质发生了很大的改变。通常将鲜食葡萄果实的糖酸比达到30作为果实进入成熟的标志,本试验中,成熟期4个处理果实的糖酸比均符合此标准。中度灌溉处理的葡萄果实TSS含量和糖酸比最高,可滴定酸含量最低,风味最佳。严重胁迫灌溉处理的果皮花青素含量最高,这主要是由果粒减小造成的。过度灌溉处理的果实TSS和花青素含量最低,说明水分过多不利于果实中的糖分积累和上色。Santesteban等[31]的研究也有相似的结果,水分胁迫一方面造成营养生长、果实质量和酸含量的减少,另一方面却提高了果实的糖含量和花青素含量。Van Leeuwen等[20]的研究结果也与之相似。还有研究表明,干旱胁迫是通过降低果实中的酶活性来影响果实中的糖分积累,最终造成产量降低;而适宜的水分亏缺会促进叶片光合产物的合成,对果实产量的增加有利[32]。

梁鹏[11]的研究表明,转色后树行两侧交替灌溉的'藤稔'葡萄开始灌溉的土壤水势阈值控制在-30.0 kPa左右比较合适。而李洪艳等[10]根据转色期不同土壤水势条件下'峰后'葡萄的糖卸载情况,得出此时期开始灌溉的土壤水势阈值应为-16.86 kPa。而本研究中转色后-30.0 kPa的土壤水势下限虽然降低了果实的可滴定酸含量和提高了果皮的上

色，但是也显著抑制了果粒的膨大和糖分积累，而这些指标也是评价果实品质的重要因素，所以笔者认为此土壤水势值不适合作为转色期葡萄开始灌溉的阈值。另外，本研究中，中度灌溉处理的实际灌溉下限在转色后接近-25.0 kPa，该处理的果实在成熟期果粒径最大，可滴定酸含量和糖酸比最高，果皮上色较好，综合表现最佳，说明-20.0～-25.0 kPa的土壤水势阈值是转色后开始灌溉的合适阈值范围。

本研究中，中度灌溉处理的新梢生长量适中，叶片净光合速率最高，能够很好地满足果实对光合产物的需要。另外，该处理的果粒径在成熟期最大，可溶性固形物含量和糖酸比最高，可滴定酸含量最低，风味最好，且果皮上色较好，综合表现最佳。说明中度灌溉处理是‘巨峰’葡萄全年灌溉管理的最佳方案。

4 结 论

本试验结果表明，笔者之前研究所确定的‘巨峰’葡萄果实发育不同时期开始灌溉的土壤水势阈值是可行的，从发芽期到幼果期适宜开始灌溉的土壤水势阈值为-10.0 kPa，之后到转色期之前的灌溉阈值为-15.0 kPa，转色期到采收为-20.0 kPa，采收后再次按-10.0 kPa进行灌溉。在这样的水分管理条件下，葡萄新梢长度、粗度、叶面积生长适中，摘心次数较少，叶片净光合速率最高，果实生长快，TSS含量（ω，后同）高（19.0%）、可滴定酸含量低（0.33%）、糖酸比高（57.6），上色较好（花青素质量分数0.078 $mg \cdot g^{-1}$），综合表现最佳。

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