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非耕地日光温室油桃根域限制对冠层特征及果实品质的影响

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摘 要:【目的】探明非耕地日光温室油桃根域限制对冠层特征的影响。【方法】以油桃品种'中农金辉'为试验材料,在西北地区戈壁非耕地日光温室中测定不同根域限制体积(135 L、225 L、360 L、576 L和对照1 440 L)对油桃树体生长、结果特性的影响,并用CI-110冠层分析仪分析不同处理对冠层特征参数的影响。【结果】L135、L225和L360限根体积处理的树体干径显著低于对照处理(L1440),但仅有135 L处理显著降低了油桃平均单果质量及产量。利用CI-110冠层分析仪分析叶面积指数(LAI)、散射辐射透过系数(TCDP),L135叶面积指数为1.81,显著低于L225(2.02)和L360(2.21)限根处理,L576限根处理的LAI为2.87,与对照处理(L1440)无显著差异。限根栽培限制了树体枝叶生长量,造成L135、L225、L360限根处理的TCDP升高到0.34、0.30和0.25。【结论】L225和L360的限根体积可在适当增大栽培密度的条件下,应用于西北非耕地日光温室桃限根生产栽培。

关键词:油桃;非耕地;叶面积系数;果实品质

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Effects of root restriction on canopy characteristics and fruit quality of greenhouse-grown nectarine in non-arable land

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Abstract:【Objective】The shortage of arable land resource is a serious situation in China. The Gobi area located in Hexi Corridor of Gansu Province, has suitable natural conditions for fruit development such as light density and light period. However, Gobi is covered by coarse sands and gravels, which form a hard top soil layer in the desert terrain. Therefore, cultivating nectarines in the non-arable lands of Gobi needs to remove 80 cm deep gravel, then backfill soils from arable lands which are limited in Hexi Corridor. Such a practice seriously affects the quality of farmland and causes serious damage to the fragile ecological environment. Nectarine trees grow vigorously in greenhouses, which substantially affect photosynthesis and growth of the trees and the quality of the fruit. Branch pruning for controlling canopy is nutrition-consuming and costly and causes physiological diseases. Root restriction can save water and fertilizer in Gobi non-arable lands. It is good for high-density, high-yielding and high-efficiency cultivation through controlling vegetative growth. Soil volume in root restriction influences tree growth, canopy characters and economic characters. Suitable tree canopy characteristics are the basis for high yield. Studying the effects of root restriction on nectarine tree canopy characteristics can provide a theoretical basis and practical experience for nectarine cultivation in non-arable lands in greenhouse.【Methods】The field experiment was

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conducted to examine the effects of soil volume in root restriction on the vegetative growth, yield, fruit quality and canopy characteristics of greenhouse-grown nectarine 'Zhongnong Jinhui' in non-arable land. The experiment included four treatments, where the dimensions of the root restriction containers (Length × width × depth) were 0.9 m × 0.5 m × 0.3 m (135 L), 0.9 m ×0.5 m × 0.5 m (225 L), 0.9 m ×0.8 m × 0.5 m (360 L) and 0.9 m ×0.8 m × 0.8 m (576 L), and root restriction material was geotechnical cloth. The local traditional cultivation method was adopted as the control, where backfilling soil was conducted after removing 80 cm of the original Gobi surface soil (control, 1 440 L). Randomized block design was used for this experiment, with three replicates in each treatment. The plant and row space was 0.9 m × 2 m, and the whole experimental area was 150 m^2. Canopy images were collected by a CI-110 canopy analyzer. After zenith angle (140°-170°) and azimuth angle (45°-135° and 225°-315°) were removed using a plant canopy analysis system V6.0, leaf area index (LAI) and transmission coefficient for diffuse penetration (TCDP) were calculated with the CI-110 canopy analyzer software. Sugar content and soluble solid content (SSC), single fruit weight, fruit number per tree and yield were collected to evaluate the economic characters, and trunk diameter 10 cm above graft joint was used to evaluate plant growth.【Results】Root restriction had significant inhibitory effect on vegetative growth of the greenhouse-grown nectarine trees in non-arable land, which was shown by the impact on the stem diameter. The stem diameter in L135 treatment was 21.7 mm, which was 49.7% that of the control. The treatments of L225 and L360 caused 20% reduction in stem diameter compared to the control. The treatment of L135 reduced the average fruit weight and yield but increased SSC significantly (P<0.05). The treatment of L225 had significant differences from the control in average fruit weight, however its production had no significant differences. The results showed that leaf area coefficient was in the range of 1.81-2.90. Different soil volumes had significant influence on LAI. The LAI in the treatment of L135 was 1.81, which was significantly lower than that in L225 (2.02) and L360 (2.21) treatments, which equaled to 63%, 70% and 77% that of the control, respectively. There was no difference between L576 (2.87) and control (L1440) in LAI. Root restriction limited the branch and leaf growth. As a result, TCDP increased. In 135 L treatment, the TCDP increased to 0.34, which was three times that of the control, indicating serious light-leaking. The TCDP in the L225 and L360 treatments was 0.30 and 0.25, respectively, which were also significantly higher than that of the control. TCDP of treatment of L576 was slightly higher than the control, but no significant difference was observed.【Conclusion】LAI is an important parameter of canopy structure character. The highest LAI measured by CI-110 was 2.90, which was smaller than the results from direct measuring method and other methods. Quantitative analysis and measurement by CI-110 needs correction on the top of direct measuring method. Although the canopy analyzer method was not very accurate, it is still a fast and efficient canopy analysis method. The results showed that root restriction volume of L135 increased SSC but decreased yield and fruit weight. Therefore, it is not suitable for greenhouse-grown nectarine in non-arable lands. Light loss in root restriction treatment with soil volumes of L225 and L360 was higher than in the control. The L225 and L360 treatments could be used for growing nectarine in non-arable land greenhouse, provided high planting density is adopted. These two treatments need only 15.6% and 25% of the soil volume in the control. According to the comparison and analysis of the three methods of images processing, removing zenith angle (from 140° to 170°) and azimuth angle (from 45° to 135° and from 225° to 315°) could reduce the experiment error caused by the surrounding environment. This images processing method could reveal the actual differences between experimental treatments.

key words: Nectarine; Non-arable land; Leaf area index; Fruit quality

我国耕地资源紧缺[1-2]。甘肃省以戈壁为主的河西走廊地区,有着发展设施果树产业得天独厚的自然气候条件。戈壁是粗砂、砾石覆盖在硬土层上的荒漠地形,因此在戈壁非耕地发展设施桃产业,需要将温室内80 cm深的沙砾清除,然后回填土壤。这样,每座日光温室(500 m^2)至少需要“客土”400 m^3,这些土壤一般都要从周围面积有限的良田中挖取。建造一座日光温室,需挖取双倍面积良田的40 cm表土层,这严重影响到原耕地的质量,并对原本脆弱的生态环境造成严重破坏[3]。

桃树营养生长旺盛,往往影响到树冠内部光照及果实品质,通过地上部枝条修剪技术来控制树势不仅费时费工,增加管理成本[4],并会造成生理性病害,因此,种植者尝试了很多办法来控制树体过度生长,如根系修剪技术,可以打破原来的生长平衡,改变营养分配及激素水平,促进新根的发生,控制旺长并改善果实品质[5-6]。通过矮化砧木也可以控制树体旺盛生长[7-10]。还有一种控制树体营养生长的方法——根域限制(Rooting restriction)[11-13],是指人为地把植物根系限制在一定介质或空间中,控制根系体积和数量、改变根系分布与结构、优化根系功能,通过根系调节整个植株生长发育,从而实现优质高产高效的一项技术。有研究表明,根域限制可促进成花、提高果实品质、控制树体营养生长,桃树适度限根可提高坐果率、增加产量,而果实大小和可溶性固形物含量(SCC)不受影响,但限根过度则起抑制作用[14-17]。

科学合理的树冠结构指标是培养良好的树体结构、确立丰产树冠结构参数的参考依据。近年来随着设施桃的发展,如何提高温室桃的产量、果实品质一直是设施栽培果树研究的重点,桃树冠层参数是影响产量、果实品质的重要因素。合理的冠层结构是从果树树体结构和植物生理学的观点探讨果树合理负荷及营养物质合理分配,使其既有良好光照体系的牢固骨架,又具备高效稳产的侧生部分。因此,合理的根域限制,可以在既保证日光温室高密度油桃正常生长、结果的前提下,同时大量减少客土量,从而达到保护当地生态环境及降低成本的目的。笔者以‘中农金辉’油桃为试材,主要研究在河西走廊地区日光温室内不同限根体积对主干形桃树树体生长、冠层特征和结果的影响,为确定该区域根域限制体积和适宜的栽植密度提供理论参考,同时为正在发展的戈壁非耕地日光温室果树栽培提供理论依据。

1 材料和方法

1.1 试验材料与试验设计

试验在甘肃省嘉峪关市新城镇非耕地设施产业园区新建的日光温室内(98°22′22" E,39°55′8" N)进行,该温室所在地原貌为戈壁滩非耕地类型。苗木定植前,沿南北向在温室内原戈壁地表上机械辅助开沟,长度×宽度×深度(限根体积 L)分别为0.9 m×0.5 m×0.3 m(135 L),0.9 m×0.5 m×0.5 m(225 L),0.9 m×0.8 m×0.5 m(360 L)和0.9 m×0.8 m×0.8 m(576 L),以土工布作为限根材料。以当地“客土”栽培模式为对照处理,即将原地表下80 cm戈壁砂石清除后回填土壤,这种模式的体积为0.9 m×2 m×0.8 m(对照,1 440 L)。对照设独立小区,顺序排列,重复3次;其余各处理均按照随机区组试验设计分布,重复3次,每重复2株,区组面积150 m^2。2012年8月以山桃为砧木带木质部芽接‘中农金辉’油桃品种,芽苗于当年12月按照株行距0.9 m×2 m定植。主干形树形,主干离地面50 cm以下不留结果枝。为明确限根效果,本试验花期蜜蜂授粉后不疏果,其他栽培技术按照王鸿等[3]的栽培管理技术操作。

1.2 测定指标及方法

1.2.1 *冠层特征指标测定* 用CI-110数字式植物冠层结构分析仪(美国CID公司)于2015年4月18日,早晚没有强烈直射光时[18],测定叶面积指数(leaf area index,LAI)及散射辐射透过系数(Transmission coefficient for diffuse penetration),将鱼眼探测头置于树下离地面高度0.2 m处,于各处理小区内2重复株间截获图像。每个处理重复3次,测定时为保证图片质量与稳定性,每个重复连续拍摄测定5次。获得的图片用Adobe photoshop CS6软件进行后期处理,除去图片天空背景中温室屋顶钢架部分,再经植物冠层分析软件(Plant canopy analysis system V6.0)除去图像天顶角140°~170°(最大)部分,再除去方位角45°~135°及225°~315°部分,图像经CI-110植物冠层分析软件分析后,可得到叶面积指数(LAI)、散射辐射透过系数(TCDP)等参数。

1.2.2 *干径、产量与果实品质测定* 于2015年4月果实成熟后,采用单株法测定单株产量、单果质量及可溶性固形物含量[15],折算666.7 m^2产量。2015年4

月对树体冠层结构进行测定分析，调查嫁接口上10 cm处干径。

1.3　数据处理

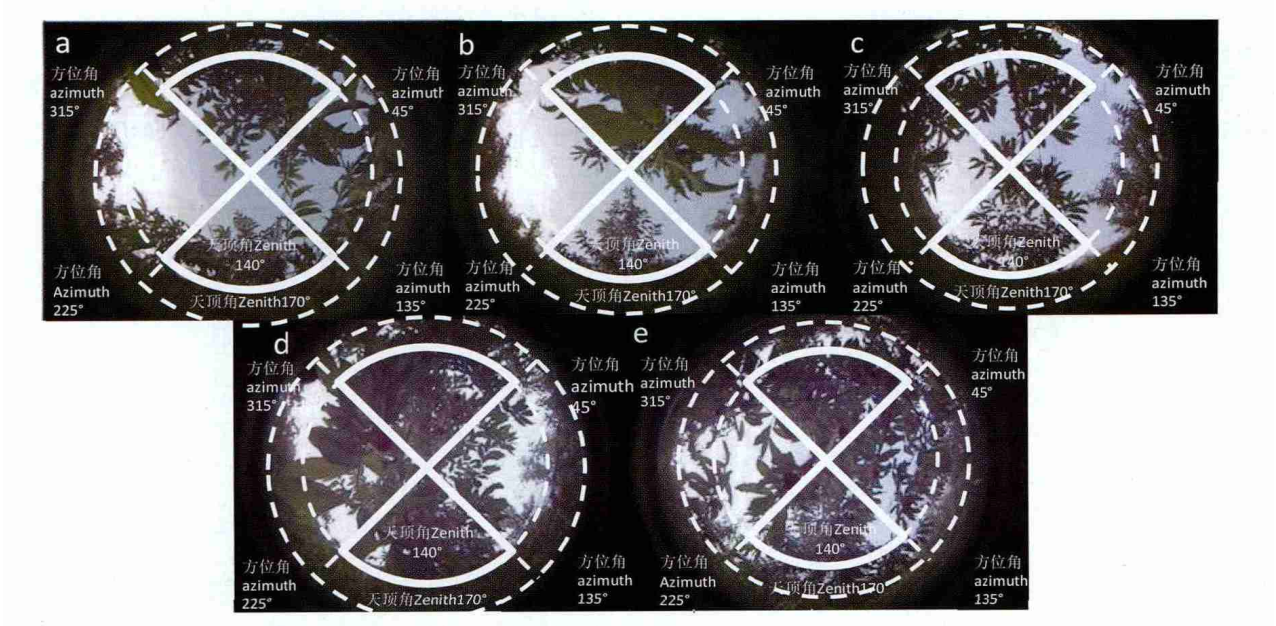
采用DPS 14.5统计分析软件对数据进行差异显著性检验（Duncan's新复极差法）。

2　结果与分析

2.1　冠层与光辐射特征比较

由CI-110植物冠层分析仪采集的图片如图1所示，不同限根处理，其株间叶片群体分布密度不同，随着限根体积的增大，图1中可见天空部分面积减小。

本试验中，叶面积系数（LAI）值的范围在1.81~2.90，不同限根体积对叶面积系数有显著影响（表1）。L225和L360处理的LAI值在2.02~2.21，为对照的70%~77%，L135处理的LAI低至1.81，仅为对照的63%。L576处理的LAI与对照差异不显著。



a. L135; b. L225; c. L360; d. L576; e. L1440.

图1　日光温室内不同限根体积油桃树株间冠层

Fig. 1 The images taken by canopy analyzer CI-110 of nectarine canopy in trees under different root restriction treatments in sunlight greenhouse

表1　不同限根体积对日光温室油桃叶面积系数和散射辐射透过系数的影响

Table 1 Effects of different soil volumes in root restriction treatments on leaf area index (LAI) and transmission coefficient for diffuse penetration (TCDP) in sunlight greenhouse

处理 Treatment	叶面积系数 Leaf area index (LAI)	散射辐射透过系数 TCDP
L135	1.81±0.03 c	0.34±0.04 a
L225	2.02±0.06 b	0.30±0.02 ab
L360	2.21±0.03 b	0.25±0.03 b
L576	2.90±0.18 a	0.17±0.03 c
L1440	2.87±0.16 a	0.11±0.04 c

注：表中数值为均值±标准差。同一列不同字母表示$P<0.05$水平上的差异显著性。下同。

Note: Values are means ± S.D. Values followed by different letters within same column and in the same year are significant difference at $P<0.05$. The same below.

群体散射辐射透过系数（TCDP）是描述群体内散射太阳辐射到达群体内部程度的指标。太阳散射辐射对光合作用有较大的辅助作用。本试验表明，限根处理整体上群体散射辐射透过系数较大，限根体积越小，TCDP越大。L135的限根体积条件下，TCDP达到0.34，是对照的3倍多（表1），说明漏光严重。L225和L360处理的TCDP也显著高于对照。L576处理的TCDP较对照高，但其差异不显著。

2.2　限根对干径、产量和果实品质的影响

限根对日光温室桃的营养生长有明显的抑制作用，主要表现为对干径的影响。对照L1440的干径为43.6 mm。L135处理的干径为21.7 mm，是对照处理的49.7%。处理L225和L360的干径分别为29.2 mm和34.6 mm，显著低于对照。L567的干径为40.9

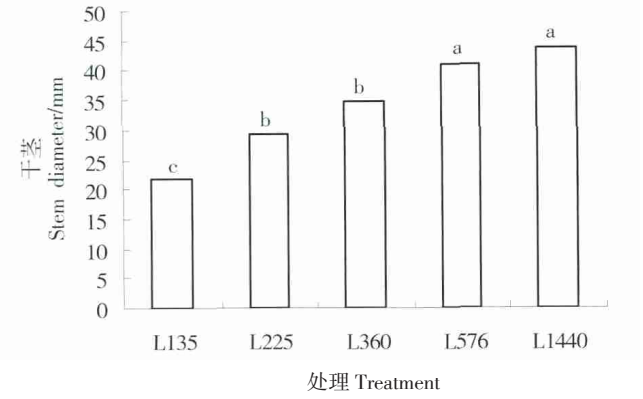


图2 日光温室内不同限根体积对油桃树干径的影响

Fig. 2 Effects of soil volumes in different root restriction on stem diameter of nectarine trees grown in sunlight greenhouse

mm，对干径的抑制作用与对照差异不显著（图2）。受干径减小的影响，L135处理的平均单果质量、单株结果数量和产量均较其他处理分别显著减小为58.6 g、66个和3.8 kg，但果实的可溶性固形物含量显著提高为13.8%。L225处理的平均单果质量与对照相比显著降低，为75.5 g，但其产量与对照并无差异。其他处理的可溶性固形物含量、平均单果质量、单株结果数量及产量相对于对照差异均不显著（表2）。

3 讨 论

桃树是中国主要的果树树种之一[19]，喜光。西北非耕地区域日光温室桃普遍采用的主干形，利于

表2 不同限根体积对日光温室油桃可溶性固形物含量、平均单果质量、单株结果数量和产量的影响

Table 2 Effects of different root restriction volumes on soluble sugar content (SSC), single fruit weight, fruit number per tree and yield in sunlight greenhouse

处理 Treatment	ω（可溶性固形物） Soluble solids content/%	平均单果质量 Single fruit weight/g	单株结果数量 Fruit number per tree	产量 Yield per plant/kg
L135	13.8±1.34 a	58.6±3.91 c	66.0±11.55 b	3.8±0.29 b
L225	12.1±1.41 b	75.5±2.19 b	89.2±16.13 a	6.7±0.74 a
L360	12.0±1.18 b	79.8±2.95 ab	87.7±18.25 a	7.0±0.62 a
L576	11.8±0.96 b	85.8±3.77 a	87.6±17.89 a	7.5±0.43 a
L1440	11.4±1.04 b	81.7±4.91 a	90.5±15.13 a	7.4±0.31 a

密植和轻简化操作，但生长旺盛、影响光照、造成果实品质下降。限根栽培通过根系调节整个植株生长发育，树体生长受到不同程度的抑制，从而实现优质高产高效省力化栽培模式。因此通过探究叶片和光照在冠层空间内分布状态与树体生长及产量的关系，可以确定最适宜的限根体积，最终提高树体的光能利用效率。叶面积指数与散射辐射透过系数是表征植被冠层结构的重要参数，与果园的光能截获及利用、产量和品质的形成等过程关系密切，在一定程度上决定了果园的生产效率[20-22]。赵宝龙等[17]研究认为早露蟠桃限根后能够不同程度地降低新梢生长量，适度限根可以控制树冠，提高平均单株产量，同时平均每株果个数、平均单果质量、可溶性固形物含量都有不同程度的提高，但限根过度则抑制植株生长，会使产量降低，果个变小，品质变差。李勇等[16]认为限根栽培显著抑制了地上部的营养生长，促进果实发育期光合同化产物向果实的积累。本试验结果发现，限根体积为L135时，LAI显著降低并且漏光严重，虽然可溶性固形物含量显著上升，但是产量和单果质量却显著下降，因此不适宜于西北地区非耕地日光温室桃生产中应用。L225和L360两个处理，相对于对照处理，单株产量差异不显著，但其冠层LAI较低，散射辐射透过系数（TCDP）较高，仍然造成漏光损失，因此，这2种限根体积的栽培模式，可以适当增加栽植密度，在保证单株产量的前提下实现单位面积产量的增加。综合分析，225 L和360 L的根域限制体积，可在适当调整栽培密度后，作为该地区日光温室桃限根栽培最佳限根体积。这2种限根体积所需要的“客土”量只有对照的15.6%~25%，有利于保护该区域有限的耕地资源和生态环境。

本研究中使用了全图、除去天顶角（140°~170°）、除去天顶角（140°~170°）与方位角（45°~135°及225°~315°）3种方式处理图像后对冠层指数进行分析，未处理的图像由于鱼眼镜头将日光温室后墙及后屋面包含在内，因此所得出的结论表现为叶面积指数高，辐射透过系数低，在除去图像天顶角140°~170°部分后，由于日光温室桃栽培行间距为2 m，相邻行的树冠对数据分析也造成了很大影响，因此为了减小误差，采用再除去方位角45°~135°及225°~315°部分后再进行分析，根据对这3种图片处理方法的对比分析，认为除去图像天顶角140°~170°（最大）部分，再除去方位角45°~135°及225°~315°部分

后经CI-110植物冠层分析软件分析，这种方法可以减小周围环境所引起的误差，真实表现处理之间的差异。一般主干形桃树的LAI为2~4[23-24]，本试验中由冠层仪CI-110所获得的LAI最大为2.90，该方法获得的数值较直接测量法偏小[25-26]，可能与主干形树冠层重叠和集聚效应有关。建议在应用冠层分析仪定量分析测量LAI时，先用直接法校正[27]。

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