

生草影响果树生长发育及果园环境的研究进展

焦润安^{1,2}, 张舒涵^{1,2}, 李毅³, 李朝周^{1,2}, 王建平^{1,2}, 焦健^{3*}

(¹甘肃农业大学生命科学技术学院, 兰州 730070; ²甘肃省作物遗传改良与种质创新重点实验室, 兰州 730070; ³甘肃农业大学林学院, 兰州 730070)

摘要: 生草是近年来国内外大力推广的一种现代化果园管理模式, 是促进果树生长和果实发育的一个重要果园栽培措施。笔者从果园土壤生物和非生物环境因子、果树根系生长发育、果实发育、丛枝菌根真菌定殖及丛枝菌根发育等方面归纳了生草对果园环境和果树生长发育的影响研究进展。生草对果树生长发育的影响总体表现为: 生草能促进丛枝菌根发育, 有利于提高果树根系吸收性能; 提高果树抗逆性; 改善果实品质。生草对果园环境的影响表现为改善土壤肥力状况和改善土壤结构, 主要提高了土壤有机质含量、营养成分含量和蓄水保墒能力。但是, 在供水不足的果园以及果树生长发育早期, 草与果树的水分竞争有可能造成果树的干旱胁迫, 进而抑制果树营养生长, 降低生长势。笔者还分析并展望了该领域今后的主要研究方向, 旨在为生草在果园的应用和推广提供借鉴。

关键词: 果园; 生草; 生长发育; 丛枝菌根; 土壤性质

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Research progress about the effect of sod-culture on the growth and development of fruit and orchard environment

JIAO Run'an^{1,2}, ZHANG Shuhan^{1,2}, LI Yi³, LI Chaozhou^{1,2}, WANG Jianping^{1,2}, JIAO Jian^{3*}

(¹College of Life Sciences and Technology, Gansu Agricultural University, Lanzhou 730070, Gansu, China; ²Gansu Key Laboratory of Crop Genetics and Germplasm Enhancement, Lanzhou 730070, Gansu, China; ³College of Forestry, Gansu Agricultural University, Lanzhou 730070, Gansu, China)

Abstract: Sod-culture is a modernized orchard management pattern which is being popularized domestic and overseas, and as an orchard cultivation measure sod-culture may promote the fruit growth and development. In this paper, the effects of sod-culture on the growth and development of fruit were summarized from the perspectives of root development, fruit development and arbuscular mycorrhiza formation of fruit. Research progress about the orchard environment of sod-culture was also analyzed from the viewpoints of soil biotic factors, abiotic factors and arbuscular mycorrhizal fungi colonization. The effects of sod-culture on the growth and development of fruit are as follows: promote arbuscular mycorrhiza formation, growth and development, and increase the infection rate, which is beneficial to enhance the root absorption ability of fruit; improve the stress resistance of fruit, in general, to improve fruit quality, is conducive to plant protection of orchard and fruit green production. The effect of sod-culture on the orchard environment is as follows: improve soil organic matter content, meanwhile, improve the physicochemical properties of soil. Sod-culture could also promote the activities of the soil microbial and enzymatic, thus improve the soil fertility. The grass roots played an important part to improve the soil structure, include soil-reinforcement and moisture conservation. Sod-culture promotes arbuscular mycorrhizal fungi colonization that is more beneficial for improving the arbuscular mycorrhizal fungi diversity in the rhizosphere soil of fruiter.

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作者简介: 焦润安, 男, 在读硕士研究生, 研究方向为植物逆境生理。Tel: 15352049205, E-mail: jiaora0328@163.com

*通信作者 Author for correspondence. Tel: 13519498471, E-mail: jiaoj@gau.edu.cn

Compared with clean cultivation, the vesicles, arbuscules and total colonization rate and spore density are higher in sod-culture soil, and the populations of rhizospheric microbes are higher. Sod-culture promote the growth of the soil arbuscular mycorrhizal fungi, at the same time enhance the arbuscular mycorrhizal fungi's ability to infect the root, arbuscular mycorrhizal fungi hyphae stretch in the soil inside, when contact with the root, tend to infect the root, and through the bridge between the hypha, promotes the transfer of nutrients to the fruit. Grass of high infection rate promote the growth of arbuscular mycorrhizal fungi in the soil and arbuscular mycorrhiza, and promote root system to absorb moisture and phosphorus nutrition utilization, improve the fruit physiological metabolism, improve fruit quality. Grass can stimulate arbuscular mycorrhizal fungi colonization, increase the activity of soil phosphatase significantly, and stimulate the development of mycorrhiza, arbuscular mycorrhiza promote by the fruiter to grow. Secreted by the arbuscular mycorrhizal fungi hypha and spore wall of specific glycoprotein Glomalin can prevent loss of the water and nutrient in the soil aggregate. Glomalin related soil protein can stabilize soil aggregate. Grass can stimulate soil hypha growth, significantly increase Glomalin related soil protein and soil organic carbon concentration. The seasonal and circadian rhythm fluctuation of soil temperature is minimized; and improve the orchard temperature and humidity. However, in insufficient water supplying orchard and particularly in the seedlings of fruit, and the water competition between the grass and the fruit could cause drought stress, thus restrained the vegetative growth and reduced the growth vigor. The prospect of this sod-culture was also looked forward, and the main purpose of this paper is to offer some references for the application and promotion of sod-culture in orchard. According to the research achievements that predecessors have obtained, we proposed some emphasis as follows: (1) According to the specific conditions of fruiter and orchard, choose the appropriate sod-culture model and grass species. The ideal herbaceous grass species should provide enough ground cover, shallow root, less water and fertilizer competitiveness, higher mycorrhizal infection rate and can promote fruiter root absorption function; (2) Selection of suitable sowing time, sowing depth and planting density: suitable sowing time can make the critical period of water for grass and fruiter stagger, so that the peak time of water and fertilizer demand to reduce the time; sowing depth of research significance and the selection of shallow grass species consistent, in the space staggered the overlap for water and fertilizer demand between grass and fruiter; the planting density will affect the strength of grass and fruit competition; (3) determine the age of grass: through the timely updating of grass to solve the grass after years of grass aging problem; (4) determine the clipping cycle and cutting the way: cutting can inhibit grass root function, reduce its absorption of water and fertilizer, and through the fruiter disk cover mowing to improve soil fertility. Unreasonable way of clipping may damage the soil structure, so different grass species should take different and appropriate management measures.

Key words: Orchard; Sod-culture; Growth; Arbuscular mycorrhiza; Soil properties

果园生草也称作“果园生草覆盖制”，包括自然生草和人工种草2种形式，其中自然生草是指在果园自然长出杂草后，有选择地去除一些田间恶性草种，保留适宜的草种，一般在当地乡土草种能够形成自然群落时适用自然生草^[1]；人工种草是指在果树采用宽行距的栽培条件下，果园全园行间（或株间）长期种植多年生豆科或禾本科草作为土壤覆盖，根据果树和草的长势决定刈割周期，刈割的青草覆于树

盘或用于发展养殖业。果园生草是果园生长期內采取的一种现代化土壤管理制度和果园管理模式，有利于达到丰产、稳产、优质的目的^[2]。果园生草是维持果园土壤肥力，果园增肥增产的有效方法之一。果园生草可以为果树创造良好的微域环境，保持果园生态平衡，从产业链发展的角度来说这种方式较传统的果树栽培中清耕的土壤管理措施可以减少中耕除草的环节，降低除草过程中人工和除草剂的投

入,降低生产成本。果园生草具有良好的生态效益和经济效益,对于推动我国果树产业可持续发展具有重要意义。笔者综述了生草影响果树生长发育及果园环境的研究进展,并指出了今后的主要研究方向,旨在为生草在果园的应用和推广提供借鉴。

1 果园生草对果园环境的影响

1.1 果园生草的草种类型选择

果园生草作为现代果园常用的配套技术,在产业发展中要起到节约成本(包括人工成本)和扩大效益的作用,陈学森等^[3]提出“培肥”、“节水”及“省力”是草种与生草模式选择需关注的关键问题,所筛选出的拥有生长量大、植株根系浅、无需刈割等多个突出优点并解决了上述3个关键问题的长柔毛野豌豆(*Vicia villosa* Roth.)得到全国示范推广。

有研究^[4]认为较矮且匍匐生长,具有茂盛枝叶的冷季型豆类可能是果园生草的良好选择。Wiedenfeld等^[5]比较了3种冷季型和2种暖季型草坪草对葡萄柚幼苗生长的作用,结果表明在夏季果园间作冷季型豆类较暖季型豆类造成的水分的竞争较小,暖季型草百喜草和野牛草造成了水、氮竞争;钱进芳等^[6]根据山核桃落叶树种的生物生态学特点提出为改良山核桃林地土壤选择冷季型绿肥对林地进行生草栽培十分必要。王富荣等^[7]研究表明,冷季型草种大麦草的生长期与桃园的冬闲期重叠时间最长,可较好地改变桃园冬季落叶后的季相,并确定大麦草为桃园秋冬季间作的适宜草种。因此整体来看冷季性草在果树生长过程中的造成的水肥竞争较低而更受欢迎。

目前应用草种多为长毛野豌豆、白三叶(*Trifolium repens*)、紫花苜蓿(*Medicago sativa*)、黑麦草(*Lolium perenne*)、百喜草(*Paspalum notatum*)、车前草(*Plantago depressa* Willd.)、狗尾草(*Setaria viridis* (L.) Beauv.)、虎尾草(*Chloris virgata* Swartz)、早熟禾(*Poa annua* L.)、荠菜(*Capsella bursa-pastoris* (Linn.) Medic.)等良性杂草,它们的特点为须根多、矮生、耗水较少,这些草种每年都能在土壤中留下大量死根,腐烂后既增加土壤有机质,又能在土壤中留下许多空隙,增加土壤通透性。刈割覆盖后也能增加土壤肥力,改善土壤结构。

1.2 生草对果园非生物环境因子的影响

1.2.1 物理因子 生草覆盖可调节果园土壤温度。

果园生草可增加地表覆盖度,在高温时可减少光照对地表的直接辐射,减缓热量向深层土壤的传递,缓解地表温度上升,减少土壤水分蒸发。在低温时,可对地面起到保温效果,有助于减小果园土壤的温差^[8]。研究发现果园生草可降低高温季节的土壤温度^[9~11]。张义等^[10]研究表明,果园生草能降低土壤极端最高温度,提高土壤CO₂释放速率,并且其土壤CO₂释放速率的提高效果较地膜、秸秆、砂石覆盖均显著。

生草对土壤含水量影响的相关研究得出了不同的结果,一些学者认为,果园实施生草栽培后,增加了园区草被地表覆盖,加强了对降雨的拦截,减少了地表径流,减缓了土壤水分的蒸散作用,并能够优化土壤组成,提高深层土壤的储水量,故能显著提高果园土壤含水量。Palese等^[12]指出,生草使雨季过后橄榄园100~200 cm的土壤水分提高17%~45%。孙霞等^[13]在苹果园株间间作紫花苜蓿试验中发现间作牧草在0~20 cm和20~40 cm土层均较免耕和清耕提高了土壤含水量。但也有研究表明了相反的结论。赵政阳等^[14]在渭北地区苹果园发现,在高温季节,果园草与果树之间存在水分竞争,降低了土壤含水量。邹亚丽等^[15]在樱桃(*Cerasus pseudocerasus*)园间作白三叶草的试验表明间作牧草显著降低土壤含水量,20~40 cm土层土壤含水量降低25.27%,出现与果树争水的矛盾。在果园种植的筛选优良的草种比自然生草在保持土壤含水量方面的作用更明显^[9]。

土壤容重的值高说明土壤紧实,孔隙数量较少,土壤的通气性差,对果树生长不利。Oliveira等^[16]研究发现紫羊茅草(*Festuca rubra*)使油橄榄园土壤的容重高于硬木树皮覆盖;土壤孔隙度和饱和水力传导率跟除草剂的处理无显著差异。果园生草有压实土壤和减少渗透的效应,可能是在刈割时的割草机碾压。Palese等^[12]在意大利雨养区橄榄园试验中表明,在生草覆盖土壤中,总孔隙率沿着土壤均匀分布,有利于垂直水运动到更深层;在秋冬季能更好地储水,特别是在山顶位置陡峭区的深层土壤,这有利于夏季干早期橄榄根系伸长从深层土吸水。在果园生草可以改善土壤结构,提升其保水蓄水能力^[17]。Rosa等^[18]发现葡萄园间作生草的土壤物理性质与天然林相似,土壤结构质量良好,行间大孔隙率、总孔隙率减少,土壤密度增加,与表面土层的压实有关;与用除草剂系统相比,机械割青增加了土

壤团聚体的稳定性。Taguas 等^[19]在山地油橄榄园试验表明,适量播量的生草能增加地表透水面积从而增加降水下渗量,降低径流系数,蓄水能力增强,保护了果园土壤。孙计平等^[20]研究表明生草处理使土壤容重显著降低,土壤孔隙度、土壤含水量和排水能力显著增加,对0~10 cm 土层物理特性的影响最大,生草处理显著降低了0~10 cm 土层粒径>5 mm 机械稳定性团聚体和粒径>2 mm 水稳定性团聚体含量,生草8 a 显著增加了0~30 cm 土层粒径0.25~2 mm 水稳定性团聚体含量。随着生草年限的增加,梨园土壤物理性状愈趋改善。李洪兵等^[21]研究表明,生草能提高土壤孔隙度、降低土壤容重,有效改善土壤物理结构,白三叶生草处理土壤水分蓄持能力和比水容量高于清耕,在高吸力阶段差异更为明显;与清耕处理相比,生草处理土壤饱和含水量、田间持水量、凋萎系数均有提高。

1.2.2 化学因子 土壤有机质包括各种动植物的残体、微生物体及其微生物分解和合成的各种有机物质,为果树的生长发育提供了丰富碳源,因此果园土壤需要保持较高的有机质含量水平。Palese 等^[22]研究表明果园生草能提高土壤表土层中有机质含量,随着土层的加深土壤有机质的增加量有所降低。李会科等^[23]在渭北苹果园生草土壤性状测定结果中表明,生草能显著提高0~20 cm 土层有机质含量。生草对株间和行间各层土壤有机质含量的提高效应与生草年限有关,梁博文等^[24]在梨园研究表明在生草4年后,行间有机质含量比清耕处理土壤提高64.6%,有机质含量随生草年限的增加逐年提高。Liu 等^[25]研究表明生草栽培显著增强亚热带果园土壤中的土壤碳汇,生草栽培管理有提高土壤碳汇的潜力。孙计平等^[26]研究表明,生草可以显著提高0~10 cm 土层胡敏酸含量,且随着生草年限增加,胡敏酸含量升高,生草8 a 0~20 cm 土层胡敏酸与富里酸比值显著高于清耕,土壤稳定性好。长期果园生草可以有效增加土壤腐殖酸含量,使土壤腐殖质品质朝好的方向转化。

N、P、K 含量高低直接影响果树的生长发育及果实品质。无机态N、P、K 可以直接吸收利用。孙计平等^[26]研究表明生草8 a 后,0~10 cm 土层碱解氮、速效磷和速效钾质量分数分别达到148.97、144.99 和682.39 mg·kg⁻¹的较高水平,且随土层深度增加呈减少趋势,可能是由于生草吸收下层土壤矿质营养,刈

割后积累到表层土壤的缘故。有研究表明与清耕相比,生草使不同土层土壤有机质、碱解 N、有效 P 含量增加^[27]。李会科等^[28]研究表明生草具有活化有机态N、P、K 的功能,有利于果树对N、P、K 营养元素的吸收利用。梁博文等^[23]报道了在梨园间作生草后各层土壤碱解 N、速效 P、速效 K 含量均升高,且随生草年限的增加逐年升高。豆科牧草还可通过生物固氮作用提高氮素利用。总体而言,果园多年种植牧草对土壤养分的积累具有正效应^[9]。

Engel 等^[29]针对于生草刈割后的果园覆盖阶段发现,草覆盖区较未覆盖区增加果树每片叶子的N、K 含量;在总体上有25%~50%的草地干物质(在2 cm 高度上割下)转移到树盘,即用刈割青草转移生物质,每 hm² 草覆盖物转移10~25 kg N, 2~4 kg P, 15~25 kg K, 3~5 kg Ca 和1~2 kg Mg 到树盘。Shui 等^[30]在柑橘园中间作生草试验表明生草使地表径流减少了38.8%,增加了7.1%的土壤肥力(N、P、K 和有机质的年累积)。Heo 等^[31]在有机苹果园间作 *Glechoma hederacea*、*Thymus magnus* 和 *Ixeris stolonifera* 发现,间作对土壤化学性质具有积极意义; *G. hederacea* 使土壤中可用的P₂O₄ 含量显著增加,在土壤中的Ca 增加39%,Mg 增加6%,K 增加11%。Gillespie 等^[32]利用³²P 标记的羟基磷灰石发现,在核桃树(*Juglans nigra*)园间作苜蓿,其幼苗表现出更大的磷摄取。溶解的磷灰石-P 扩散在核桃-苜蓿根交界点可能是吸收机制之一。果园生草后土壤的微生物数量增加,从而促进土壤有机碳的分解和有机氮矿化,增加土壤矿质养分含量^[33]。俞立恒^[9]报道了果园实施不同生草栽培2 a 后对提高土壤营养成分的效果,较间种前相比,在0~10 cm 土层,白三叶、杂三叶(*Trifolium hybridum*)、鸭茅效果较好,在20~30 cm 土层,苜蓿较好。Xu 等^[34]在三峡库区柑橘园试验表明生草梯田园是较斜坡果园、加植物篱斜坡园、梯田园改善土壤肥力最有效的措施。也有研究发现生草能减少土壤中N、P、K 养分含量。李华等^[35]报道了葡萄园行间种植苜蓿和黑麦草可使0~60 cm 土层土壤速效 K、速效 P 及碱解 N 含量降低,并认为该现象可能与当地的试验条件、生草类型及树种有关。此外,在果园生草措施中由于牧草和果树的生长吸收,土壤速效养分的降低是正常土壤性征变化(表1)。

土壤 pH 值影响多种营养元素的转化方向、转化

表1 生草对果园土壤非生物环境因子的影响

Table 1 Effects of sod-culture on soil abiotic factors in orchard

果树类型 Fruiter types	草种 Forage variety	种植地区 Planting area	树龄 Tree age /a	生草效应 The effect of sod-culture	参考文献 References
苹果 <i>Malus domestica</i>	白三叶 <i>Trifolium repens</i> 杂三叶 <i>Trifolium hybridum</i> 鸭茅 <i>Dactylis glomerata</i>	北京市通州区 Tongzhou, Beijing	10(苹果) 10(Apple)	高温下明显降低地下5 cm和15 cm土层土温;寒冷季节15 cm土层的土温可平均提升0.8 ℃。 The 5 cm and 15 cm underground soil temperature reduced obviously in the high temperature season, the 15 cm soil temperature enhanced equally 0.8 ℃ in the cold season.	[9]
梨 <i>Pyrus pyrifolia</i>	多年生黑麦草 <i>Lolium perenne</i> 苜蓿 <i>Medicago sativa</i>	北京市顺义区 Shunyi, Beijing	5(梨) 5(Pear)		
苹果 <i>Malus domestica</i>	白三叶草 <i>Trifolium repens</i>	陕西长武县 Changwu, Shaanxi	9	土壤CO ₂ 释放速率较秸秆、砂石及地膜覆盖均高。 The soil CO ₂ release rate higher than straw mulch, gravel mulch and plastic film mulch.	[10]
闽楠 <i>Phoebe bournei</i>	杂草 Weeds	湖南桃源县 Taoyuan, Hunan		提高地表湿度。 Increased land humidity.	[11]
橄榄 <i>Olea europaea</i>	杂类草 Spontaneous grass	意大利南部 Southern Italy	7	对山坡地土壤能更好地储水,特别是在秋冬季节。 Able to better store water, received during the autumn-winter period, especially in the steep area .	[12]
葡萄 <i>Vitis vinifera</i>	白三叶 <i>Trifolium repens</i> 红三叶 <i>Trifolium pretense</i> 一年生黑麦草 <i>Lolium multiflorum</i>	巴西南部 Southern Brazil		改善土壤结构,增加了土壤团聚体的稳定性。 Improve the soil structure and increased the soil aggregates stability.	[18]
苹果 <i>Malus domestica</i>	白三叶 <i>Trifolium repens</i> 多年生黑麦草 <i>Lolium perenne</i>	陕西洛川县 Luochuan, Shaanxi	10~12	显著提高0~20 cm土层有机质含量。 The content of organic matter in the 0~20 cm soil layer significantly increased.	[28]
苹果 <i>Malus domestica</i>	Glechoma hederacea, <i>Thymus magnus</i> , <i>Ixeris stolonifera</i>	韩国江原道 Gangwon Provincial, Korea	8	增加土壤中矿质元素的有效性。 Increase the effectiveness of mineral elements in the soil.	[31]
柑橘 <i>Citrus reticulata</i>	多年生黑麦草 <i>Lolium perenne</i>	湖北秭归县 Zigui, Hubei		增加土壤有机物质和有效N、P、K含量,减少容重。 Soil organic matter and available N,P,K significantly increased, decreased bulk density.	[34]

进程及养分的有效性,对果树营养有重要作用。梁博文等^[23]报道梨园生草可以显著降低各土层土壤pH值,株间土壤pH值降低了1.2%~3.4%,行间土壤pH值降低了0.6%~4.08%,且随生草年限的增加逐年降低。杨奉霞^[36]对南方梨园的研究结果表明果园生草区的土壤pH值呈下降趋势,不同草种在不同地区的效应不同。关于土壤pH值降低的现象,需要区别酸性土壤和碱性土壤,对酸性土壤来说是不利的。李华等^[35]研究发现在生草葡萄园种植的3种牧草可使土壤pH升高。果园生草不仅削弱了水分蒸发引起的盐、碱迁移,而且对盐、碱离子具有一定降解效应。因而探究生草对土壤盐、碱性的影响对盐碱地果园土壤改良非常具有意义。研究发现,在盐碱地梨园,自然生草能有效地减弱土壤的盐碱性^[23, 37~38],如生草7 a后,与清耕相比,0~20和20~40 cm土层的土壤水溶性总盐分别下降了21.8%和29.7%;说明生草对土壤的盐碱性具有一定调节效应,这也为改良盐碱化土壤打开了独特的角度^[39]。

1.3 生草对果园土壤微生物及肥力相关酶的影响

土壤有机碳和微生物活性的增加是重要的土壤

肥力提高的指标。果园生草可增加土壤微生物的多样性和肥力相关酶活性^[9]。研究^[40~41]表明间作牧草土壤的肥力相关酶活性显著提高,刘广勤等^[42]在梨园间作鼠茅(*Vulpia myuros*)的研究还表明,种植鼠茅后控制了禾本科杂草的发生,土壤中放线菌数量大大增加,为对照的5倍。

Shishido等^[43]认为果园土地的不同利用方式,可改变果园土壤微生物群落结构,Laurent等^[44]的研究也证明果园生草有助于增加土壤微生物的数量。Yao等^[45]苹果园内发现,生草处理有较大的可培养真菌群体,变性梯度凝胶电泳的结果显示芽后施除草剂处理和果园生草处理在土壤微生物群落方面无明显差别(表2)。果园生草通过改变土壤微生物群落丰度、活性和组成从而影响苹果树生长和产量。司鹏等^[46]研究表明,生草处理的微平板每孔颜色平均变化率和多样性指数均显著高于清耕,清耕对照和生草处理土壤微生物存在一定的代谢差异性,生草显著改变了土壤微生物群落功能,并对土壤微生物代谢羧酸类化合物、碳水化合物和酚

表2 生草对果园土壤微生物及肥力相关酶的影响效应

Table 2 Effects of sod-culture on soil microorganisms fertility-related enzymes in orchard

果树类型 Fruiter types	草种 Forage variety	种植地区 Planting area	树龄 Tree age/a	影响效应 The effect of sod-culture	参考文献 References
梨 <i>Pyrus pyrifolia</i>	自然生草 Herbiferous naturally	山东省东营市 Dongying, Shandong	17	明显提高土壤微生物呼吸、活性、活跃微生物量、微生物磷酯脂肪酸总量。 Microbial activity and respiration, active microbes and total phospholipid fatty acids significantly improved.	[38]
葡萄 <i>Vitis vinifera</i>	紫花苜蓿 <i>Medicago sativa</i>	陕西杨凌区 Yangling, Shaanxi	4	提高土壤的蔗糖酶、脲酶、磷酸酶、纤维素酶活性。 Improved the activities of SaA, UrA, Phosphatase, Cellulose.	[40]
梨 <i>Pyrus pyrifolia</i>	白三叶 <i>Trifolium repens</i>	陕西杨凌区 Yangling, Shaanxi	6	提高土壤碱性磷酸酶、蔗糖酶和过氧化氢酶活性。 Soil alkaline phosphatase, invertase, and catalase activities significantly improved.	[41]
梨 <i>Pyrus pyrifolia</i>	鼠茅 <i>Vulpia myuros</i>	江苏省常熟市 Changshu, Jiangsu	3	增加土壤中放线菌数量,显著提高土壤酸性磷酸酶和脲酶的活性。 Increase the quantity of actinomycetes, UrA and acid phosphatase activities significantly increased.	[42]
苹果 <i>Malus domestica</i>	羊茅 Red festuca rubra 混合生草 Mixture of grass	美国纽约 New York, United States		有较大的可培养真菌群体。 Had the largest population of culturable fungi.	[45]

酸类化合物3类碳源的影响最为明显。生草有利于葡萄园土壤微生物群落结构的改善。王艳廷等^[38]报道多年自然生草梨园土壤微生物呼吸、活性、活跃微生物量、微生物磷酯脂肪酸总量提高效果明显。

丛枝菌根真菌(Arbuscular Mycorrhizal Fungi, AMF)是一类重要的土壤真菌,能够与陆地上80%以上的植物根系建立共生关系,形成丛枝菌根(Arbuscular Mycorrhiza, AM)这种互惠共生体结构。AMF在土壤中分布广泛,寄主具有广谱性^[47],在植物营养和土壤保持中发挥重要作用。AMF对改善植物吸收水分和养分、增强抗逆性、促进生长发育有一定作用,从而可以提高植物的产量和品质,AMF生态适应性强^[48]。边秀举等^[49]研究表明,AMF能够促进宿主植物对矿质营养的吸收;增强植株对水分、盐分和重金属等非生物胁迫的抗性^[50]。由AMF的菌丝和孢子壁分泌的特殊糖蛋白球囊霉素(glomalin)可防止土壤团聚体中的水和营养物损失。Zou等^[51]报道在多年生果园中球囊霉素相关土壤蛋白(glomalin related soil protein, gRSP)质量浓度高达1 mg·g⁻¹,可稳定土壤团聚体,作为多年生果园中土壤有机物的部分之一。杨雅婷等^[52]研究发现三叶草生草栽培的梨园根际系统中,通过AMF菌丝桥的联接,促进了梨根系矿质营养和水分的吸收运转,促进梨苗的生长发育。Zou等^[51]在柑橘园间作白三叶试验中发现生草可刺激土壤菌丝生长,显著增加GRSP和土壤有

机碳的浓度、水稳定性聚集体、土壤过氧化物酶和磷酸酶的活性,刺激菌根发展,潜在地改善果园土壤性质。

AMF定殖反映宿主植物根系被丛枝菌根真菌所侵染的状况,常用“丛枝菌根真菌定殖率”来描述丛枝菌根真菌定殖状况,AMF定殖率按照酸性品红乳酸染液或者台盼蓝染液染色宿主植物根系,光学显微镜观察AM真菌不同结构的着生状况来计算。计算公式:

$$\text{定殖率} \% = \text{AM 真菌感染根段数} / \text{检查总根段数} \times 100$$

还可以采用定殖强度来描述丛枝菌根真菌定殖状况。

Wang等^[53]在柑橘园间作牧草,结果表明AMF繁殖体和GRSP的含量在生草果园中比在清耕园显著增加。丰富的AM共生体可能有助于保持土壤质量,特别是在生草果园。Wang等^[54]发现间作牧草柑橘园土壤中AMF群落的总定殖率、菌丝长度较秸秆覆盖、除草剂处理和免耕都高。生草能显著提高果园AMF物种丰富度和多样性指数,可提高AMF效益。Cruz等^[55]在梅(*Prunus mume*)园种植鼠茅的试验中发现生草增加了土壤中AMF繁殖体的数量,有一些与AMF相关的细菌可用作磷增溶剂。通过间作牧草调节微生物群落结构是提高果园植物保护水平的有效措施之一(表3)。

表3 生草对果园土壤AMF生长的影响

Table 3 Effects of sod-culture on arbuscular mycorrhizal fungi growth in orchard

果树类型 Fruiter types	草种 Forage variety	种植地区 Planting area	树龄 Tree age/a	影响效应 The effect of sod-culture	参考文献 References
柑橘 <i>Citrus reticulata</i>	白三叶 <i>Trifolium repens</i>	浙江台州市	10	AMF繁殖体和GRSP的量在免耕和植草果园中比在清洁耕作果园显著更高 AM colonization, AM fungal propagules, and GRSP were significantly higher in both clean cultivation and grass-planted orchards than in clean tillage orchards.	[52]
柑橘 <i>Citrus reticulata</i>	百喜草 <i>Paspalum notatum</i>	湖北武汉市	15~17	显著提高果园AMF物种丰富度和多样性指数。 Significantly increased species richness and Shannon-Wiener index of AMF	[54]
梅 <i>Prunus mume</i>	鼠茅 <i>Vulpia myuros</i>	Tanabe city, Wakayama, Japan		增加土壤中AMF繁殖体的数量,一些与AMF相关的细菌可用作磷增溶剂 Increased the number of AMF propagules in soil, some bacteria associated to AMF were useful as phosphorus solubilizers bacteria.	[55]

2 生草对果树根系发育及丛枝菌根(AM)的影响

2.1 生草对果树根系发育的影响

根系是生草栽培中水肥竞争的作用部位。根系的空间分布可反映生草对根系生长发育的影响,一般认为,生草限制根系发育,促进根系下扎,但也有相反的报道。李华等^[56]在干旱区幼龄‘赤霞珠’葡萄园行间种植牧草试验中发现行间牧草可使葡萄根系向土壤深处发展,有利于对土壤养分和水分的吸收利用。李会科^[57]研究表明行间生草可使苹果有效根系向土壤深处发展,其中20~60 cm土层提高幅度较大,白三叶区、黑麦草区苹果树平均有效根长密度高于清耕区,生草促进了果树<2 mm径级根系的发育。Monteiro等^[58]认为葡萄园生草由于土壤表层水分的降低,使土壤上层根系受损,而下层根系向更深土层发展以探索深层土壤。但Coker^[59]研究发现桃和梨(*Pyrus pyrifolia*)在白三叶处理区较清耕区的根接近地表,表层土壤根密度较清耕大,认为生草改善了浅根和侧根的发育。李华等^[56]研究报道,幼龄‘赤霞珠’葡萄园行间生草降低了植株根系的数量,尤其是小于2 mm细根,生草区根系平均密度是清耕区的71.5%。李发林等^[60]发现果园生草显著降低了蜜柚的根系活力。可见,试验条件不同,生草对果树根系发育与分布的影响表现出不同的特点。

2.2 生草对果树AM的影响

AMF在同种和不同种植物根系间均可以形成菌丝桥,菌丝桥可使邻近的不同种的植株之间进行养分的运输和传递^[61]。AMF在土壤生态系统中延伸出的根外菌丝可通过菌丝融合的方式形成丛枝菌根网络(arbuscular mycorrhizal network, AMN)^[62]。Cruz

等^[63]在三隔室根箱试验中观察到通过丛枝菌根菌丝在两种或多种不同植物之间可形成AMN,在植物之间交换营养物并维持植物系统中的营养物;百喜草根部分泌物可在体外刺激菌丝的生长,该网络可用于果园生草技术。百喜草间作果园系统在柑橘(*Citrus reticulata*)果园中已经显示出效率。Zhang等^[64]在两室根箱种植枳苗和白三叶接种AMF的研究发现AM定殖促进受体植物的生长、根葡萄糖积累。

生草能够促进AM的形成,并提高其侵染率。马永甫^[48]通过对奉节脐橙(*Citrus sinensis*)园菌根资源状况调查发现:自然生草果园的AM侵染率高于清耕果园,自然生草的AMF孢子密度最高。张锦娟^[65]在试验中表明生草处理更有利于提高柑橘根际土壤中AMF的多样性,生草处理泡囊侵染率、丛枝侵染率、总侵染率与孢子密度均显著优于免耕。曾明等^[47]报道百喜草和白三叶草生草区土壤AMF孢子数和柑桔根系菌根侵染率显著高于清耕区和其他生草区。百喜草和白三叶栽培在促进土壤AMF生长的同时,增强了对柑橘根系的侵染能力,AMF根外的菌丝在土壤中伸展,当和柑橘(*Citrus*)等果树根系接触时,易侵染果树根系,并通过这种菌丝的桥梁作用,促进养分向果树的转移。

在干旱季节,土壤水分胁迫一定程度上抑制了土壤AMF孢子的形成,但高菌根侵染率的生草自身可解除这种抑制^[47, 66],自身促进了土壤中AMF的生长和根系菌根的形成,并促进根系对水分和磷素营养的吸收利用,改善果树生理代谢,提高果实品质。Zou等^[67]在柑橘园间作白三叶试验中发现生草可刺激菌根定殖,生草显著增加了土壤磷酸酶的活性,并刺激菌根发展,通过菌根化促进了果树生长(表4)。

故菌根侵染率将作为果园生草草种的筛选指标

表4 生草对果树AM形成的影响

Table 4 Effects of sod-culture on arbuscular mycorrhiza formation in orchard

果树类型 Fruiter types	草种 Forage variety	种植地区 Planting area	树龄 Tree age/a	影响效应 The effect of sod-culture	参考文献 References
脐橙 <i>Citrus sinensis</i>	自然生草 Herbiferous naturally	重庆奉节县 Fengjie, Chongqing	15~20	提高AM侵染率;提高AM菌孢子密度。 Improve the AM colonization rate, improved the spore density.	[48]
梨 <i>Pyrus pyrifolia</i>	百喜草 <i>Paspalum notatum</i> 白三叶 <i>Trifolium repens</i>	重庆涪陵区 Fuling, Chongqing	5	在干旱季节可提高土壤AMF孢子数和梨根系菌根侵染率 Significantly increased the AMF spore number and the infection rates.	[65]
温州蜜柑 <i>Citrus unshiu</i>	百喜草 <i>Paspalum notatum</i>	华中农业大学 果树标本园		提高根际土壤中AMF的多样性;提高泡囊侵染率、丛枝侵染率、总侵染率与孢子密度。 Improving the AMF diversity in the rhizosphere soil, increased the vesicles, arbuscules and total colonization rate and spore density.	[66]
枳 <i>Poncirus trifoliata</i>		Fruiter Herbarium, Huazhong Agricultural University			
枳 <i>Poncirus trifoliata</i>	白三叶 <i>Trifolium repens</i>	长江大学校园 Yangtze University campus		刺激AM定殖和土壤菌丝生长,显著增加GRSP含量 Stimulated AM colonization and soil hyphal growth, significantly increased the concetnt of GRSP.	[67]

之一。

3 生草对果树生长发育的影响

3.1 生草对果树树体生长的影响

果园生草可通过改善果园温湿度影响光合作用。生草条件下苹果树叶片变厚,叶面积变大,叶绿素含量升高,光合作用效率增强。在夏季高温期间,番荔枝(*Annona squamosa*)果园套种柱花草(*Stylosanthes guianensis*)、百喜草和丰花草(*Borreria stricta*)均可使其光合速率增加^[68]。林利^[69]研究表明生草可以截持降雨量,减少土壤中水分的蒸发,较高的土壤含水量可较为明显地提高板栗(*Castanea mollissima Blume*)的净光合速率;同时在树下生草起到遮阴效果,使树下温度较低,加之高的土壤含水量,可以有效地降低板栗的蒸腾速率。

葡萄(*Vitis vinifera*)园生草可明显降低树体生长势^[58],新定植的幼树尤其敏感,全园生草使葡萄树体生长的减弱是由于草对水分的过度竞争,但当水分供应充足时,这种竞争就会减弱。Forey等^[70]在幼龄桃(*Amygdalus persica*)园的试验说明长时间的水分亏缺下种植牧草,由于草的竞争果树生长显著降低。果园生草可以明显减少树体的营养生长,这在苹果园^[14,71~72]、葡萄园^[73]、李园^[74]、山核桃园^[5]研究中已得到证实。

李华等^[56]研究结果表明,在‘赤霞珠’葡萄园行间播种多年生黑麦草、紫花苜蓿和白三叶可有效控制植株的长势,增大基径,降低新梢生长量。Du等^[75]在黄土丘陵沟壑区试验表明间作造成沙打旺(*Astragalus adsurgens*)和杏(*Armeniaca vulgaris*)的水

肥竞争,降低了土壤水分和土壤养分,降低了产量;但用割青的沙打旺覆盖可增加0~60 cm土层中的土壤水分;在0~20 cm土层增加土壤有机物,增加杏的产量。Glenn等^[76]研究了生草对桃树的长期效应,结果表明,生草的前4~7 a, Autumnglo桃生长量降低,而对随后几年桃树生长无大的影响;生草当年,树干横截面积年增长量降低,以后则无显著影响。Monteiro等^[58]认为生草对土壤水分竞争造成果树水分胁迫是抑制果树营养生长的原因之一,但在树体新梢旺盛时,这种效应可达到控制树体营养生长、促进生殖生长的效果。邓丰产等^[71]研究表明生草第6年,白三叶草和高羊茅(*Festucu arundinacea*)处理使苹果树干周减小,高羊茅处理使新梢量较少;并且促进了果树中、短枝比例,有利于生殖生长。不同草种抑制作用不一,因此可通过试验筛选一些浅根性的草种,减弱其对果树体生长的抑制效应。

Thomas等^[77]试验表明具有大和深根系的牧草比浅根草系牧草消耗更多的水分,并且当停止灌溉时,间作深根系牧草比间作浅根系的苹果(*Malus pumila*)树更快地降低叶片水势,具有浅根系的生草较适宜在苹果树下生长。Medrano等^[73]认为果树和牧草生育期的重叠时间同样值得关注,以避免对果树过度的干旱胁迫造成坐果减少甚至过早落叶。生草可能会在春季后发生水竞争导致严重的果树干旱胁迫,对果树生长和果实发育产生负面影响。

也有研究者指出生草以病虫害的方式影响树势,如生草可通过影响致病微生物和线虫的增殖、寄宿不同的病原菌、影响昆虫等来影响树势,化感自毒也是因素之一^[78],间作白三叶和百喜草对树莓

(*Ruhus occidentalis*)^[79]和枳苗(*Poncirus trifoliata*)^[80]的生长发育存在化感效应,白三叶水浸提液中存在影响树苗生长发育的化感物质且表现出低促高抑的效应,上述生草对果树生长的负面影响需要在果园生草栽培中高度注意。

3.2 生草对果树生理的影响

新梢生长量、叶绿素含量和根系活力能反映果树的生长势和生长潜力,徐雄等^[74]研究表明李(*Prunus salicina*)园生草采用的刈割覆盖、刈割压埋后上述指标较清耕都有极显著地增加。杨文权等^[81]在行间种植白三叶的桃园研究表明生草减轻了干旱对桃树光合作用的影响,使其光合中心保持较高的活性,有效缓解了高温干旱导致的伤害。杨宏伟等^[82]在油橄榄(*Olea europaea*)园的试验发现间作百喜草后,提高了油橄榄光合色素含量和细胞膜稳定指数,抑制了自由基积累,增加了渗透调节物质含量,增强了抗氧化物酶活性,提高了根系活力,改善油橄榄自身的抗氧化能力,从而在整体上增强了油橄榄的抗旱性。Monteiro等^[58]在限水区葡萄园发现,在生育早期由于生草与葡萄的竞争,减少果树的冠层叶面积,并因此减少后来的蒸腾损失。

此外,Lopes等^[83]指出生草减少了葡萄植株的营养活性,生草与葡萄的根系竞争引起葡萄深层根营养活性增加。Lopes等^[84]在葡萄牙的非灌溉葡萄园中的试验发现,与土壤耕作相比,从开花到中期成熟生草处理显示较低的叶水势;但在生育后期,生草处处理营养生长显著减少,减少可滴定酸度,增加浆果总酚和花青素,对葡萄组成具有积极影响,这些差异也在葡萄酒中发现。

李芳东等^[85]在试验中表明,与清耕处理相比,果园生草处理提高了苹果叶片衰老过程中叶片部分过氧化物酶的活性,使自由基含量保持相对较低的水平,延缓了叶绿素的降解,从而延缓了叶片衰老,提高了其净光合速率。阳淑等^[86]发现生草促进了枳苗生长发育,增加了枳苗N、P、K含量(黑麦草除外),提高了枳苗叶片中渗透调节物质含量、抗氧化酶活性,降低了叶片中MDA的含量。

3.3 生草对果实品质的影响

果实发育是以光合作用产物积累为基础的,生草能提供良好的水肥气热条件,提高了叶片的光合效率,一定程度上促进了果树的生长发育,提高果实产量和品质,如吴玉森等^[37]在梨园的试验中发现自

然生草4 a及7 a的果实脆度、可溶性固形物含量、香气总量、总糖含量及糖酸比均明显升高;颜晓捷等^[27]报道生草可通过提升土壤有机质含量而使杨梅果实产量和品质提高。

Thomas等^[87]研究发现,种植鸭茅(*Dactylis glomerata*)可使洛林桃和红港桃产量降低,而国内报道显示,生草可以提高桃树产量。毛培春等^[88]研究发现,与对照相比,种植白三叶的桃果实维生素C、可溶性糖和可溶性固形物含量显著提高,可滴定酸含量降低,糖酸比提高。生草能减缓果实的裂果,提高果实商品率^[80]。邱燕萍等^[89]在研究中得出:间作牧草的荔枝(*Litchi chinensis*)园果实纵、横径及单果质量增长曲线均近似呈直线型,并且坐果率和产量较大棚覆盖均有显著提高。李会科^[57]研究表明生草提高了苹果百叶质量、中短枝比例、成花率、坐果率,随着生草年限增加,上述作用效果趋于提高,特别以间作白三叶效果最为显著。

4 存在问题及发展方向

综上所述,生草具有提高果园土壤有机质含量、促进丛植菌根真菌定殖、提高果实产量、改善果实品质、保护生态环境的显著优点,果园生草已成功应用到多种果园中,但是由于该模式目前还存在一些问题和人们对该问题认识不足,影响了生草在果园栽培中的大范围推广。

4.1 目前存在的问题

(1)草与果树的争水争肥问题:因草与果树生活于同一片区域,2者对资源的竞争是不容忽视的重要问题;(2)草的种植年限问题:多年生牧草会逐渐老化,草在土壤表面盘根错节,影响土壤通透性。

4.2 以后研究的侧重点

针对上述问题,可侧重从以下角度进行研究:

(1)根据果树及果园的具体条件,选择适宜的生草模式并选择一些浅根性、菌根侵染率高的草种。理想的生草草种应提供足够的地面覆盖,与果树的水肥竞争力相对较弱,较少与果树竞争水肥,并能促进果树根系的吸收功能。

(2)选择适宜生草的播期、播深及播量:适宜的播期可以使牧草与果树的水分临界期错开,使2者对水肥需求的高峰期交叉时间减少;播深的研究意义与选择浅根性草种一致,在空间上错开牧草与果树对水肥资源需求的重叠;播量的多少会影响草与

果树竞争的强弱。

(3)生草年限:通过牧草的及时更新解决生草多年后草的老化问题。

(4)割青周期和割青方式:刈割可抑制草根系功能,降低其对水肥的吸收,且刈割的青草覆盖树盘对提高土壤肥力有着重要意义。不合理的割青方式可能会破坏土壤结构,所以应针对不同牧草草种采取恰当的管理措施。

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