果 树 学 报 2019,36(12):1658-1666
Journal of Fruit Science

DOI:10.13925/j.cnki.gsxb.20190240

云南玉溪柑橘园土壤养分水平和叶片营养状况相关性分析

朱攀攀[1],李有芳[1],邱洁雅[1],王 敏[1],张超博[1],凌丽俐[1],施云庭[2],胡军华[1],张 蓉[2],李永奇[2],资丽玲[2],彭良志[1*]

([1]西南大学柑桔研究所•国家柑桔工程技术研究中心,重庆 400712;[2]云南省玉溪市柑桔研究所,云南华宁 652801)

摘 要:【目的】对云南省玉溪市柑橘土壤养分水平和叶片营养状况及其相关性进行分析,为柑橘的合理施肥提供科学依据。【方法】对玉溪市华宁南盘江河谷区、华宁山地区、元江干热河谷区和新平山地区4个生态区101个柑橘园土壤和叶片样品的10种营养元素进行测定分析。【结果】南盘江河谷区、华宁山地区、元江干热河谷区和新平山地区4个生态区橘园土壤碱解N含量不足(缺乏和低量)的比例分别为77.08%、63.64%、91.67%、80.00%;华宁山地区土壤速效P不足最为严重,达到100%,其余3个生态区土壤速效P主要在适宜水平;4个生态区土壤速效K适宜水平的比例分别达到93.75%、100%、83.33%、96.67%;土壤交换性钙Ca含量以适宜水平为主,但交换性Mg含量以不足水平为主;各生态区土壤速效Fe、Mn、Cu含量丰富(适宜及以上),土壤速效B不足,而元江干热河谷区和新平山地区速效Zn含量主要不足;土壤速效B主要是不足水平。华宁山地区柑橘叶片N、K不足比例较高,分别达到45.45%和36.36%,其余3个生态区的N、P、K均处于丰富水平;叶片Ca含量丰富;元江干热河谷区叶片Mg不足比例66.67%,其余3个生态区叶片Mg均在丰富水平;各生态区叶片Fe、Mn、B含量均丰富;叶片Zn均在不足水平;新平山地区30.00%橘园叶片Cu含量不足。对4个生态区分别进行相关性分析,结果显示南盘江河谷区橘园土壤有效Mn、Zn、Cu、B及新平山地区橘园土壤有效Mg、Mn、Zn与其叶片相应元素含量显著($p < 0.05$)或极显著($p < 0.01$)相关,元江干热河谷区橘园土壤有效Mg与叶片Mg含量极显著相关,华宁山地区土壤全部营养元素有效态含量与叶片对应元素含量未达显著正相关水平;整体相关性分析结果则显示,橘园土壤有效Mn、Cu、B与叶片相应元素含量显著或极显著相关。【结论】玉溪不同柑橘生态区土壤与叶片营养元素含量丰缺并存,生产上需重视补充与平衡。整个玉溪产区橘园土壤与叶片营养元素含量相关性规律不强;玉溪橘园测土不能良好反映树体的实际营养状况,需要探索改进测土方法,或结合叶片营养诊断制定施肥方案。

关键词:柑橘;玉溪;土壤养分;叶片营养;相关性

中图分类号:S666 **文献标志码:**A **文章编号:**1009-9980(2019)12-1658-09

Correlation between soil and leaf nutrient element contents in citrus orchards of Yuxi city, Yunnan province

ZHU Panpan[1], LI Youfang[1], QIU Jieya[1], WANG Min[1], ZHANG Chaobo[1], LING Lili[1], SHI Yunting[2], HU Junhua[1], ZHANG Rong[2], LI Yongqi[2] , ZI Liling[2], PENG Liangzhi[1*]

(*[1]Citrus Research Institute, Southwest University/National Citrus Engineering Research Center, Chongqing 400712, China; [2]Citrus Research Institute of Yuxi City, Yunnan Province, Huaning 652801, Yunnan, China*)

Abstract:【Objective】In recent years, benefiting from its natural advantages and climatic conditions, Yuxi city of Yunnan province has become an important citrus production area with plateau characteristics in China. In 2017, there were 147 700 hm^2 citrus planting areas in Yuxi with a yield of 280 000 tons, accounting for 33% and 39% of the total fruit planting area and yield of the city, respectively. For a long time, fertilization in citrus production in Yunnan has mainly relied on farmers' experience, and N, P, K were mainly applied, neglecting the supplement of Ca, Mg and Zn fertilizers and organic ma-

收稿日期:2019-05-27 接受日期:2019-09-02

基金项目:国家重点研发计划专项课题(2017YFD0202006);国家现代农业(柑橘)产业技术体系建设专项(CARS-26-01A)

作者简介:朱攀攀,女,在读硕士研究生,主要从事果树栽培与生理研究。Tel:15523843199,E-mail:1376927586@qq.com

*通信作者 Author for correspondence. Tel:023-68247009,E-mail:pengliangzhi@cric.cn

(C)1994-2020 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

nures. The differences in soil physical and chemical properties and nutrients in Yuxi citrus production area directly affected the absorption and distribution of soil nutrients by trees, and also affected the yield and fruit quality. Therefore, in this study, both soil and leaf samples were collected and their nutrient elements were quantitatively determined in the main citrus production areas of Yuxi city. The aim was to study the relationship between soil and leaf nutrient elements and to provide a theoretical basis for citrus rational fertilization. 【Methods】Both soil and leaf samples of Satsuma mandarin, Bingtang sweet orange and Orah mandarin were selected and collected from 101 orchards in four representative main producing areas: Huaning Nanpanjiang river valley area(HNRV), Huaning mountain area(HNM), Yuanjiang river dry-heat valley area (YJRV) and Xinping mountain area(XPM). Ten essential mineral elements in soils and leaves were determined and analyzed. 【Results】The proportions of soil alkaline hydrolytic N in an insufficient level in HNRV，HNM, YJRV and XPM reached 77.08%, 63.64%, 91.67% and 80.00%, respectively. The insufficiency of soil available P in HNM was the severest, which accounted for 100%; and in other three ecological areas the soil available P was mainly in an adequate level (≥ optimum range). The proportions of soil available K in an adequate level in the four areas reached 93.75%, 100%, 83.33% and 96.67%, respectively. The content of soil exchangeable Ca was mainly in an adequate level, but exchangeable Mg was mainly in an inadequate level (＜optimum range). The contents of soil available Fe, Mn and Cu in all ecological areas were adequate, but available Zn in YJRV and XPM was mainly in an inadequate level. The proportion of soil available B was mainly in an inadequate level. Except that the proportion of leaf N and K in an inadequate level was slightly higher in HNM，the contents of leaf N, P and K were adequate in each ecological area, and a large proportion of leaf samples showed excessive contents of leaf N and K. All the citrus leaf samples were adequate in Ca content. However, the proportion of inadequate Mg content in leaves was high. The contents of leaf Fe, Mn, Cu and B were abundant, and a large proportion of leaf Fe, Mn and B were in excessive levels. Leaf Zn deficiency was common and severe, and about 90% leaf samples were in an inadequate level of Zn. Available Zn and Cu in soils of HNRV indicated an extremely significantly positive correlation with their corresponding elements in leaves（$p < 0.01$）, and there was a significantly positive correlation with Mn and B between soils and leaves（$p < 0.05$）. In YJRV, there was a significantly positive correlation between soil exchangeable Mg and leaf Mg contents. It had an extremely significantly positive correlation between soil exchangeable Mn and leaf Mn contents in XPM, and there was a significantly positive correlation in the contents of exchangeable Mg between soils and leaves. There was no significant positive correlation between lea f and soil contents of available nutrient elements in HNM. In addition, the contents of other nutrient elements in soil and leaves in other ecological areas had no significant positively correlation. However, the results showed that the contents of available Mn and B in soils had an extremely significantly positive correlation with their corresponding elements in leaves. And there was a significantly positive correlation between the contents of Cu between soils and leaves, but the remaining nutrients had no significantly positive correlation between soils and leaves. 【Conclusion】Most of the citrus orchards were characteristic of being both in rich and deficient in terms to some elements. Attention should be paid to the supplement and balance of elements in citrus production. There were significant differences in the correlation between soil and leaf nutrient element contents in different citrus ecological areas in Yuxi. The correlation between soil and leaf nutrient element contents in citrus orchards in Yuxi production area was not obvious. As for N, P, K and most of the medium and trace nutrient elements, there was no significant positive correlation between soils and leaves, and nearly half of these elements were negatively correlated for their contents between soils and leaves. Although soil nu-

(C)1994-2020 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

trient analysis in Yuxi citrus orchards can not reflect the actual nutrient status of citrus trees, it is necessary to explore and improve the methods for soil sampling and nutrient analysis, so as to formulate fertilization programs based on foliar nutrient diagnosis.

Key words: *Citrus*; Yuxi city; Soil nutrient elements；Leaf nutrient elements；Correlation

测土配方施肥广泛用于指导粮棉油蔬菜等大田作物生产[1-3]，成为我国农业生产的一项重要技术措施[4]。大田作物的耕作层土壤每年进行一至多次的翻耕耙耘，土壤中的养分分布均匀度好，土壤取样代表性强，土壤养分检测的结果能直接反映作物的营养状况，这是测土配方施肥的基础。柑橘等多年生果树的施肥以沟施、穴施或滴灌施为主，土壤难于进行翻耕耙耘，肥料在土壤中的分布均匀度差，土壤取样的代表性不强，致使土壤养分测定数据往往不能良好地反映树体的营养状况[5-8]，用测土配方来指导柑橘施肥效果较差。然而，不同产区的柑橘园，因地形、土壤种类和施肥习惯等的不同，土壤养分检测指标与树体营养指标的相关性会有很大的不同，如江西安远橘园土壤有效P、Zn含量与柑橘叶片P、Zn含量呈正相关，湖南湘中橘园土壤碱解N、有效K含量与柑橘叶片N、K含量呈正相关，桂西北橘园土壤碱解N和有效P、Mg含量与叶片N、P、Mg含量呈正相关，而土壤其他养分含量则与叶片对应营养元素含量相关性差[5-7]。因此，了解柑橘产区土壤和叶片营养元素相关性，有利于减少柑橘测土配方施肥的盲目性。

云南省玉溪市是我国重要的高原特色柑橘产区，2017年，玉溪柑橘面积达1.47万 hm^2，产量达28万t[9]。玉溪柑橘主要分布在华宁、新平、元江、易门4个县，生态类型可分为华宁南盘江河谷区、华宁山地区、元江干热河谷区、新平山地区4种类型[10-11]，笔者在对上述生态区域柑橘园进行土壤和叶片营养元素定量测定基础上，进行二者之间的相关性分析，以期为玉溪柑橘测土配方施肥的适应性提供依据。

1 材料和方法

1.1 样品采集

试验于2017年9—10月在云南玉溪华宁南盘江河谷区、华宁山地区、元江干热河谷区、新平山地区4种生态区域选择具有代表性、1个月内没有施肥的柑橘园101个，其中华宁南盘江低热河谷区48个，华宁山地区11个，元江干热河谷区12个，新平山地区30个，品种为‘温州蜜柑’‘冰糖橙’和‘沃柑’。

土壤样品采集：每个果园按“S”型选取采样树10~15株，在每株树冠滴水线（避开施肥沟、施肥穴）周围东、西、南、北4个方位采集距地表0~40 cm深土层的土壤300 g左右，除去石块、根系等杂质，10~15个采样点的土壤等量均匀混合，用4分法取约1 000 g土样装袋编号后带回试验室，阴干，粉碎，过2 mm尼龙网筛，置于干净的塑料袋内干燥、避光保存备用。

叶片样品采集：在对应的土壤采样树上，在每株树的东南西北4个方位、高1.5~2 m处，采当年春梢营养枝顶部向下的第3枚健康叶片，每株采8枚叶片，每个叶样约100枚叶片。采集的样品装入打有透气孔的干净塑料袋内，放入冰镇的保温泡沫箱中带回实验室，参照庄伊美[12]的方法，经过清洗、灭酶、75 ℃恒温烘干、粉碎、干燥、装瓶密封置于干燥器中保存待测。

1.2 营养元素的测定

1.2.1 土壤营养元素测定 土壤有效P、K、Cu、Fe、Mn、Zn采用ASI浸提剂浸提，交换性Ca、Mg采用乙酸浸提。有效P采用双光速紫外可见分光光度计（北京普析通用仪器有限责任公司生产）测定；有效K、Cu、Fe、Mn、Zn以及交换性Ca、Mg采用原子吸收分光光度计（Perkin Elmer公司生产）测定；碱解N采用扩散法测定；有效B采用沸水浸提—ICP—AES法测定[13]。

1.2.2 叶片营养元素测定 叶片N采用浓硫酸消解法，用凯氏定氮仪（北京通润源机电技术有限责任公司生产）测定；P、S用硝酸加高氯酸消解后，用双光速紫外可见分光光度计（北京普析通用仪器有限责任公司生产）分别在700 nm、440 nm波长下测定；K、Ca、Mg、Fe、Mn、Zn和Cu用硝酸加高氯酸消解后，用AA-800原子吸收分光光度计（Perkin Elmer公司生产）测定；B采用干灰化-甲亚胺比色法[14-15]测定。

1.3 营养元素含量分级

1.3.1 玉溪柑橘园土壤养分水平分级指标 柑橘园土壤养分水平分级指标以ASI法分析土壤速效养分的评价指标为主体，结合文献[12,16-17]的分级标准而定（表1）。

(C)1994-2020 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

表1　柑橘园土壤有效养分水平分级标准

Table 1 Standard for soil nutrient grading in citrus orchards

（mg·kg-1）

有效养分 Available nutrient	缺乏 Deficiency range	低量 Low range	适量 Optimum range	高量 High range	过量 Excess range
碱解氮 Alkaline hydrolytic N	<50	50~100	100~200	>200	-
有效磷 Available P	<5	5~15	15~80	>80	-
有效钾 Available K	<50	50~100	100~200	>200	-
交换性钙 Exchangeable Ca	<200	200~1 000	1 000~2 000	2 000~3 000	>3 000
交换性镁 Exchangeable Mg	<80	80~150	150~300	300~500	>500
有效铁 Available Fe	<5	5~10	10~20	20~50	>50
有效锰 Available Mn	<2	2~5	5~20	20~50	>50
有效锌 Available Zn	<0.5	0.5~2.0	2.0~5.0	5.0~10.0	>10
有效铜 Available Cu	<0.3	0.3~0.5	0.5~1.0	1.0~2.0	>2.0
有效硼 Available B	<0.25	0.25~0.50	0.50~1.00	1.00~2.00	>2.0

1.3.2　玉溪柑橘叶片营养状况分级指标　结合玉溪气候条件和柑橘品种特点，参考国内外柑橘叶片营养指标，将玉溪柑橘叶片营养元素丰缺划分为缺乏、低量、适量、高量、过量5个等级（表2）。

表2　柑橘叶片营养状况分级标准

Table 2 Standard for soil nutrient grading in citrus orchards

元素 Element	缺乏 Deficiency range	低量 Low range	适量 Optimum range	高量 High range	过量 Excess range
w(N)/%	<2.40	2.40~2.70	2.70~3.00	3.00~3.20	>3.20
w(P)/%	<0.10	0.10~0.12	0.12~0.16	0.16~0.30	>0.30
w(K)/%	<0.70	0.70~1.00	1.00~1.50	1.50~2.00	>2.00
w(Ca)/%	<1.60	1.60~3.00	3.00~5.00	5.00~7.00	>7.00
w(Mg)/%	<0.20	0.20~0.30	0.30~0.50	0.50~0.70	>0.70
w(Fe)/(mg·kg-1)	<35	35~60	60~120	120~200	>200
w(Mn)/(mg·kg-1)	<18	18~25	25~100	100~300	>300
w(Zn)/(mg·kg-1)	<18	18~25	25~100	100~200	>200
w(Cu)/(mg·kg-1)	<4	4~6	6~16	16~20	>20
w(B)/(mg·kg-1)	<20	20~35	35~100	100~200	>200

1.4　数据分析

试验数据采用Excel 2013和SPSS18.0统计软件进行分析。

2　结果与分析

2.1　玉溪柑橘园土壤养分状况

由表3可知，华宁南盘江河谷区77.08%橘园土壤碱解N含量不足（缺乏和低量，下同），有效P和有效K含量丰富（适宜或以上，下同）的橘园比例分别为79.17%和93.75%，交换性Ca和交换性Mg含量丰富的果园比例分别为100%和95.83%，85%以上橘园土壤有效Fe、Mn、Zn、Cu含量丰富，但有45.83%橘园土壤有效B含量处于低量水平。

华宁山地区63.64%橘园土壤碱解N含量不足，100%橘园有效P含量不足，100%橘园有效K含量丰富，100%橘园交换性Ca过量，63.6%橘园交换性Mg丰富，多数橘园微量元素含量丰富，但有36.36%橘园土壤有效B为低量。

元江干热河谷区91.67%橘园土壤碱解N含量不足，有效P、有效K、土壤交换性Ca含量丰富橘园分别占64.66%、83.33%和66.67%，但有50%橘园土壤交换性Mg含量不足，91.67%和100%橘园土壤有效Zn和B含量不足。

新平山地区80.00%橘园土壤碱解N不足，77.67%橘园土壤有效P和96.67%橘园有效K含量丰富，63.33%橘园交换性Ca和83.33%橘园交换性Mg含量不足，土壤Mn、Cu含量丰富，但土壤低Zn、低B比例高。

2.2　云南玉溪柑橘叶片营养状况

表4结果表明，华宁南盘江河谷区柑橘叶片N、P、K含量丰富的果园比例较高，分别占75.00%、95.84%和58.34%，其中叶片N超标（高量或过量，下同）橘园达37.5%。97.92%橘园叶片Ca在适宜水平，但Mg不足的橘园比例占66.67%。叶片微量元素主要是Zn不足（89.6%缺乏，10.4%低量）、Cu超标比例较大（87.5%）和B丰富比例占97.92%。

华宁山地区柑橘叶片N、K不足比例较高，分别为45.45%和36.36%；100%橘园叶片P、Ca丰富，但叶片Mg不足和缺Zn橘园比例均达100%，100%橘园叶片B含量丰富，其余元素以适量为主。

元江干热河谷区柑橘叶片N、P、K含量丰富，其中N超标橘园比例58.34%；Ca、Mg含量丰富的橘园比例分别达100%和66.66%；83.33%橘园叶片Zn不足，分别有100%和91.67%橘园叶片Fe和Mn超标。

新平山地区柑橘叶片N、P、K超标橘园比例分

(C)1994-2020 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.net

表3　玉溪柑橘园土壤营养元素养分状况

Table 3 The contents of soil available nutrient elements in citrus orchards inYuxi

地区 Area	营养元素 Element	平均值 Mean/（mg·kg⁻¹）	变异系数 Coefficient of variation/%	比例 Percentage/%				
				缺乏 Deficient range	低量 Low range	适量 Optimum range	高量 High range	过量 Excess range
华宁南盘江河谷区 Huaning Nanpanjiang river valley area	碱解氮 Alkaline hydrolytic N	85.22	0.62	12.50	64.58	20.83	2.09	0.00
	有效P Available P	72.09	1.49	4.17	16.67	54.16	25.00	0.00
	有效K Available K	305.94	0.61	0.00	6.25	25.00	68.75	0.00
	交换性Ca Exchangeable Ca	3 633.35	0.99	0.00	0.00	29.17	37.50	33.33
	交换性Mg Exchangeable Mg	325.81	0.36	0.00	4.17	37.50	50.00	8.33
	有效Fe Available Fe	26.01	0.66	2.08	8.33	33.33	47.92	8.33
	有效Mn Available Mn	41.23	1.00	0.00	0.00	52.08	16.67	31.25
	有效Zn Available Zn	9.55	1.03	0.00	12.50	31.25	22.92	33.33
	有效Cu Available Cu	2.55	0.78	0.00	4.17	14.58	31.25	50.00
	有效B Available B	0.68	0.68	0.00	45.83	41.67	10.42	2.08
华宁山地区 Huaning mountain area	碱解氮 Alkaline hydrolytic N	84.71	0.37	0.00	63.64	36.36	0.00	0.00
	有效P Available P	8.20	0.43	18.18	81.82	0.00	0.00	0.00
	有效K Available K	289.45	0.60	0.00	0.00	18.18	81.82	0.00
	交换性Ca Exchangeable Ca	9 445.06	0.64	0.00	0.00	0.00	0.00	100.00
	交换性Mg Exchangeable Mg	185.49	0.60	9.09	27.27	54.55	9.09	0.00
	有效Fe Available Fe	20.00	0.34	0.00	9.09	36.36	54.55	0.00
	有效Mn Available Mn	15.98	1.08	0.00	18.18	72.73	0.00	9.09
	有效Zn Available Zn	3.89	0.61	9.09	18.18	45.45	27.27	0.00
	有效Cu Available Cu	1.24	0.28	0.00	0.00	27.27	72.73	0.00
	有效B Available B	0.53	0.31	0.00	36.36	63.64	0.00	0.00
元江干热河谷区 Yuanjiang river dry-heat valley area	碱解氮 Alkaline hydrolytic N	53.03	0.42	50.00	41.67	8.33	0.00	0.00
	有效P Available P	30.07	1.07	0.00	33.33	58.33	8.34	0.00
	有效K Available K	183.13	0.52	0.00	16.67	58.33	25.00	0.00
	交换性Ca Exchangeable Ca	1 522.77	0.56	0.00	33.33	41.67	16.67	8.33
	交换性Mg Exchangeable Mg	265.92	0.87	25.00	25.00	8.33	25.00	16.67
	有效Fe Available Fe	8.05	1.00	33.33	41.67	16.67	8.33	0.00
	有效Mn Available Mn	46.11	0.47	0.00	0.00	16.67	33.33	50.00
	有效Zn Available Zn	1.08	0.67	16.67	75.00	8.33	0.00	0.00
	有效Cu Available Cu	4.52	0.43	0.00	8.33	8.33	0.00	83.33
	有效B Available B	0.24	0.13	50.00	50.00	0.00	0.00	0.00
新平山地区 Xinping mountain area	碱解氮 Alkaline hydrolytic N	76.14	0.31	13.33	66.67	20.00	0.00	0.00
	有效P Available P	51.26	0.82	3.33	20.00	56.67	20.00	0.00
	有效K Available K	250.74	0.41	0.00	3.33	30.00	66.67	0.00
	交换性Ca Exchangeable Ca	1 023.60	0.73	0.00	63.33	23.33	10.00	3.34
	交换性Mg Exchangeable Mg	90.08	0.48	43.33	40.00	16.67	0.00	0.00
	有效Fe Available Fe	25.98	1.37	6.67	26.67	30.00	23.33	13.33
	有效Mn Available Mn	57.27	0.69	0.00	0.00	23.33	23.33	53.33
	有效Zn Available Zn	1.97	0.58	0.00	70.00	26.67	3.33	0.00
	有效Cu Available Cu	3.38	0.38	0.00	0.00	10.00	6.67	83.33
	有效B Available B	0.31	0.40	33.33	63.33	3.34	0.00	0.00

(C)1994-2020 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

表4　玉溪橘园叶片营养元素含量状况

Table 4　The contents of leaf nutrient elements in citrus orchards in Yuxi

地区 Area	营养元素 Element	平均值 Mean	变异系数 Coefficient of Variation/%	比例 Percentage/% 缺乏 Deficient range	低量 Low range	适量 Optimum range	高量 High range	过量 Excess range
华宁南盘江河谷区 Huaning Nanpanjiang river valley area	w(N)/%	2.88	0.08	4.17	20.83	37.50	33.33	4.17
	w(P)/%	0.15	0.14	0.00	4.17	79.17	16.67	0.00
	w(K)/%	1.02	0.33	22.92	18.75	47.92	10.42	0.00
	w(Ca)/%	4.20	0.12	0.00	0.00	97.92	2.08	0.00
	w(Mg)/%	0.27	0.27	16.67	50.00	33.33	0.00	0.00
	w(Fe)/(mg·kg^{-1})	101.21	0.42	2.08	8.33	66.67	20.83	2.08
	w(Mn)/(mg·kg^{-1})	57.36	0.64	4.17	8.33	81.25	6.25	0.00
	w(Zn)/(mg·kg^{-1})	14.23	0.19	89.58	10.42	0.00	0.00	0.00
	w(Cu)/(mg·kg^{-1})	31.60	0.48	2.08	4.17	6.25	12.50	75.00
	w(B)/(mg·kg^{-1})	95.58	0.32	0.00	2.08	60.42	37.50	0.00
华宁山地区 Huaning mountain area	w(N)/%	2.66	0.08	27.27	18.18	54.55	0.00	0.00
	w(P)/%	0.15	0.11	0.00	0.00	72.73	27.27	0.00
	w(K)/%	1.19	0.23	0.00	36.36	45.45	18.18	0.00
	w(Ca)/%	4.57	0.07	0.00	0.00	90.91	9.09	0.00
	w(Mg)/%	0.13	0.37	90.91	9.09	0.00	0.00	0.00
	w(Fe)/(mg·kg^{-1})	104.15	0.25	0.00	0.00	81.82	18.18	0.00
	w(Mn)/(mg·kg^{-1})	27.27	0.21	9.09	9.09	81.82	0.00	0.00
	w(Zn)/(mg·kg^{-1})	14.30	0.16	100.00	0.00	0.00	0.00	0.00
	w(Cu)/(mg·kg^{-1})	8.13	0.50	9.09	18.18	63.64	9.09	0.00
	w(B)/(mg·kg^{-1})	93.90	0.33	0.00	0.00	54.55	45.45	0.00
元江干热河谷区 Yuanjiang river dry-heat valley area	w(N)/%	3.00	0.08	0.00	8.33	33.33	41.67	16.67
	w(P)/%	0.13	0.07	0.00	0.00	100.00	0.00	0.00
	w(K)/%	1.43	0.17	0.00	0.00	66.67	33.33	0.00
	w(Ca)/%	4.41	0.08	0.00	0.00	91.67	8.33	0.00
	w(Mg)/%	0.41	0.35	0.00	33.33	33.33	33.33	0.00
	w(Fe)/(mg·kg^{-1})	214.67	0.19	0.00	0.00	0.00	41.67	58.33
	w(Mn)/(mg·kg^{-1})	161.93	0.37	0.00	0.00	8.33	83.33	8.33
	w(Zn)/(mg·kg^{-1})	20.12	0.20	33.33	50.00	16.67	0.00	0.00
	w(Cu)/(mg·kg^{-1})	14.23	0.35	0.00	8.33	50.00	25.00	16.67
	w(B)/(mg·kg^{-1})	76.89	0.36	0.00	0.00	83.33	16.67	0.00
新平山地区 Xinping mountain area	w(N)/%	3.19	0.07	0.00	0.00	23.33	33.33	43.33
	w(P)/%	0.16	0.14	0.00	0.00	50.00	50.00	0.00
	w(K)/%	1.46	0.33	6.67	13.33	36.67	30.00	13.33
	w(Ca)/%	4.39	0.14	0.00	0.00	80.00	20.00	0.00
	w(Mg)/%	0.32	0.40	6.67	53.33	23.33	16.67	0.00
	w(Fe)/(mg·kg^{-1})	170.73	0.23	0.00	0.00	13.33	56.67	30.00
	w(Mn)/(mg·kg^{-1})	153.75	0.95	0.00	0.00	56.67	33.33	10.00
	w(Zn)/(mg·kg^{-1})	18.52	0.47	43.33	26.67	30.00	0.00	0.00
	w(Cu)/(mg·kg^{-1})	19.30	0.94	16.67	13.33	23.33	13.33	33.33
	w(B)/(mg·kg^{-1})	58.67	0.32	0.00	3.33	93.33	3.33	0.00

别为76.66%、50.00%和43.33%；100%橘园叶片Ca丰富，但60.00%橘园叶片Mg、70.00%橘园叶片Zn和30.00%橘园叶片Cu含量不足。

2.3　玉溪柑橘园土壤养分和叶片营养元素含量的相关性

对4个生态区柑橘园土壤有效营养元素含量与叶片相应的营养元素含量分别进行相关性分析，结果显示（表5），华宁南盘江河谷区橘园土壤有效Zn、Cu含量分别与叶片Zn、Cu含量呈极显著正相关（$p < 0.01$），土壤有效Mn、B含量分别与叶片Mn、B含量呈显著正相关（$p < 0.05$）；其余营养元素含量在土壤与叶片之间无显著相关性。元江干热河谷区橘园土壤交换性Mg含量与叶片Mg含量呈极显著正相关；其余营养元素含量在土壤与叶片之间无显著相关性。新平山地区橘园土壤有效Mn含量与叶片Mn含量呈极显著正相关，土壤交换性Mg含量与叶片Mg含量呈显著正相关，土壤有效Zn含量与叶片Zn含量呈显著负相关；其余营养元素含量在土壤与

(C)1994-2020 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.net

表5　玉溪不同生态区柑橘园土壤有效营养元素含量与叶片相应营养元素含量的相关性

Table 5　Correlation analysis between the contents of soil available elements and leaf elements for citrus orchards in different climatic regions in Yuxi

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
华宁南盘江河谷区 Huaning Nanpanjiang river valley area	−0.104	0.064	0.084	−0.027	−0.080	−0.095	0.310*	0.382**	0.451**	0.319*
华宁山地区 Huaning mountain area	−0.270	−0.153	−0.398	−0.516	0.306	−0.246	0.480	0.035	0.118	0.432
元江干热河谷区 Yuanjiang river dry-heat valley area	0.367	0.247	0.268	0.042	0.842**	−0.462	0.331	−0.147	0.076	0.514
新平山地区 Xinping mountain area	0.240	0.156	0.154	−0.329	0.382*	−0.316	0.579**	−0.446*	0.327	0.215

注：**表示相关性达极显著（$p < 0.01$）水平；*表示相关性达显著（$p < 0.05$）水平。下同。

Note：** Correlation was very significant（$p < 0.01$）；* Correlation was significant（$p < 0.05$）. The same below.

叶片之间无显著相关性。华宁山地区土壤全部营养元素有效态含量与叶片对应元素含量未达到显著相关性。

对玉溪4个生态区的土壤有效营养元素含量与叶片相应的营养元素含量进行整体相关性分析，结果则显示（表6），土壤有效Mn、B含量分别与叶片Mn、B含量呈极显著正相关，土壤有效Cu含量与叶片Cu含量呈显著正相关，土壤有效Fe含量与叶片Fe含量呈显著负相关；其余营养元素含量在土壤与叶片之间无显著相关性。

表6　玉溪柑橘园土壤有效营养元素含量与叶片相应营养元素含量的相关性

Table 6　Correlation analysis between the contents of soil available elements and leaf elements for citrus orchards in Yuxi

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
玉溪 Yuxi	−0.080	0.069	−0.053	−0.044	0.119	−0.245*	0.456**	−0.104	0.247*	0.438**

3　讨　论

从本研究结果看，云南玉溪4个不同生态区柑橘园土壤碱解N含量普遍不足，土壤有效P、有效K含量丰富，仅华宁山地橘园土壤有效P含量不足。土壤交换性Ca、交换性Mg、有效Zn不足主要出现在元江干热河谷和新平山地橘园，而土壤有效B含量不足在4个生态区都较普遍。土壤有效Cu含量丰富的区域为华宁南盘江河谷和新平山地。总体而言，玉溪橘园土壤最不缺的是有效Fe和有效Mn，这显然与当地红壤和黄壤类型有关，红黄壤为酸性土壤，有效Fe、Mn含量丰富[18-19]。

玉溪柑橘叶片营养状况则表现为N、P、K含量丰富或过量，仅华宁山地区橘园有稍高比例的N、K不足。绝大部分橘园的叶片Ca、Fe、Mn、Cu、B含量丰富，多数生态区有较高比例的叶片Fe、Mn、Cu、B过量。但叶片Mg和Zn含量普遍不足，仅元江干热河谷区有过半的橘园叶片Mg含量达到或超过适宜值，叶片Zn营养状况最好的新平山地区也只有30%橘园达到适宜值。

比较上述橘园土壤养分和叶片营养元素含量变化，可以发现二者之间的含量变化差异较大，有些营养元素在土壤和叶片中的含量变化还呈现相反趋势。例如，土壤碱解N和有效B普遍不足，但叶片N和B含量却普遍高量或过量。主要原因可能是9—10月采样时离施肥已间隔1个月以上，6—9月为玉溪雨季，施用的氮肥在土壤中易淋洗和挥发损失[20-21]，同时也易被柑橘吸收利用，另外，土壤取样时避开了施肥点。玉溪土壤本身有效B含量低，但近年来柑橘生产上普遍叶面施用B肥[22]，导致土壤和叶片B含量变化不同。把各个生态区的橘园土壤和叶片营养元素含量变化进行相关性分析，可以发现同一种营养元素在不同生态区土壤和叶片中的含量变化相关性有很大不同，相关系数的数值差异大，多数元素还有正负值的不同，在4个生态区共计40个相关系数中，仅有7个相关系数达到了显著正相关。进一步把整个玉溪橘园土壤和叶片营养元素含量变化进行相关性分析，其结果又有所不同，相关系数达到显著正相关的只有Mn、Cu、B 3种元素。由此看来，玉溪的柑橘园土壤检测难于良好反映树体

(C)1994-2020 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.net

的营养状况，这与前人在江西[5]、湖南[6]和广西[7]等地的研究结论基本相同。

柑橘园土壤养分水平和叶片营养状况的相关性与否，是衡量测土配方施肥是否适应于指导柑橘施肥的主要依据。然而，柑橘等多年生果树除了土壤管理和施肥方法与大田作物差异大外，果树的养分吸收、贮藏和消耗与大田作物也有很大不同。果树根系发达，只要在根系分布范围内少数几个点（穴）施肥或滴灌施肥[23-25]，就能满足全株养分需求；柑橘枝叶和根系能贮存大量养分，每年的养分消耗主要是果实带走和部分枯枝落叶和残根，通常每年养分消耗不到当年树体总矿质养分的40%[26]，测定叶片养分能准确直接反映树体的营养水平和需求[24]。所以，美国等发达国家柑橘施肥主要以叶片营养诊断为基础[25,27-31]，适度配合土壤分析。但是，叶片营养诊断的样品前处理要求高，分析速度慢、耗时长、费用高，不适合我国这种家庭为主的微小果园，测土配方施肥仍然是目前我国橘园应用最多的方法[32]。但从现有研究结果看，基于测土的施肥配方并不能良好符合柑橘对养分的实际需求。因此，需要改进方法，重点是改进橘园土壤取样方法，对有机肥为主、化肥为主，穴施为主、撒施为主、滴灌施肥为主等不同施肥方案的果园，探索不同的土壤取样方法，找到土壤养分和叶片营养相关性好的土壤取样方案，方能实现柑橘的科学测土配方施肥。

4　结　论

云南玉溪4个不同生态区橘园土壤和叶片营养元素含量差异较大，柑橘园土壤碱解N含量普遍不足，有效P、有效K含量丰富，土壤交换性Ca含量以适宜水平为主，但交换性Mg含量以不足水平为主；各生态区土壤速效Fe、Mn、Cu含量丰富，土壤速效B主要为不足，元江干热河谷区和新平山地区有效Zn含量不足。柑橘园叶片N、P、K、Ca主要处于丰富水平，元江干热河谷区叶片Mg不足比例高，各生态区叶片Fe、Mn、Cu、B含量主要在丰富水平，叶片Zn均在不足水平。华宁南盘江河谷区橘园土壤有效Mn、Zn、Cu、B及新平山地区橘园土壤有效Mg、Mn、Zn与其叶片相应元素含量显著或极显著相关，元江干热河谷区橘园有效Mg与叶片Mg含量极显著相关；除此之外，其他生态区和元素在土壤与叶片中含量无显著相关性，有些甚至为负相关。对4个生态区土壤和叶片样品进行整体分析，只有土壤有效Mn、Cu、B与叶片相应元素含量显著或极显著正相关。橘园测土不能良好反映树体的实际营养状况，需要探索改进土壤取样方法，找到土壤养分和叶片营养相关性好的土壤取样方案，方能实现柑橘的科学测土配方施肥。玉溪柑橘生产上需重视营养元素补充与平衡，有条件的果园可以叶片营养诊断为主，结合测土制定橘园施肥方案。

参考文献 References：

[1] 吴泳泽．蔬菜生产中的土壤肥料问题与测土配方施肥技术应用[J]. 农业与技术，2019，39（4）：6-7.
WU Yongze. Soil and fertilizer problems in vegetable production and application of formulated fertilization by soil testing[J]. Agriculture and Technology，2019，39（4）: 6-7.

[2] 宋志伟，杨净云．果树测土配方施肥技术[M]. 中国农业科学技术出版社，2011.
SONG Zhiwei，YANG Jingyun. Fruit fertilization and fertilization technology for fruit tree[M]. China Agricultural Science and Technology Press，2011.

[3] 孙义祥，郭跃升，于舜章，蒋庆功，程琳琳，崔振岭，陈新平，江荣风，张福锁．应用“3414”试验建立冬小麦测土配方施肥指标体系[J]. 植物营养与肥料学报，2009，15（1）：197-203.
SUN Yixiang，GUO Yuesheng，YU Shunzhang，JIANG Qinggong，CHENG Linlin，CUI Zhenling，CHEN Xinping，JIANG Rongfen，ZHANG Fusuo. Establishing phosphorus and potassium fertilization recommendation index based on the“3414”field experiments[J]. Plant Nutrition and Fertilizer Science，2009，15（1）: 197-203.

[4] 黄安驹．测土配方施肥对农业增产增收的影响[J]. 农家参谋，2019（1）：36.
HUANG Anju. Effect of formula fertilization on increasing agricultural yield and income[J]. The Farmers Consultant，2019（1）: 36.

[5] 唐玉琴，彭良志，淳长品，凌丽俐，方贻文，严翔．红壤甜橙园土壤和叶片营养元素相关性分析[J]. 园艺学报，2013，40（4）：623-632.
TANG Yuqin，PENG Liangzhi，CHUN Changpin，LING Lili，FANG Yiwen，YAN Xiang. Correlation analysis on nutrient element contents in orchard soils and sweet orange leaves in southern Jiangxi province of China[J]. Acta Horticulturae Sinica，2013，40（4）: 623-632.

[6] 马小川，卢晓鹏，张子木，熊江，潘斌，刘恋，李泽航，唐超兰，谢深喜．湖南省不同纬度温州蜜柑园土壤和叶片营养及果实品质分析[J]. 果树学报，2018，35（4）：423-432.
MA Xiaochuan，LU Xiaopeng，ZHANG Zimu，XIONG Jiang，PAN Bin，LIU Lian，LI Zehang，TANG Chaolan，XIE Shenxi. Analyses of the soil and tree nutrition and fruit quality of Satsuma mandarin in orchards at different latitudes in Hunan province[J]. Journal of Fruit Science，2018，35（4）: 423-432.

[7] 余红兵，王仁才，肖润林，杨知建．桂西北环境移民示范区柑橘

(C)1994-2020 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.net

园土壤和叶片营养状况[J]. 湖南农业大学学报(自然科学版),2007(3):341-344.
YU Hongbing,WANG Rencai,XIAO Runlin,YANG Zhijian. Soil and leaf nutrient status of citrus orchards in environmental immigrant demonstration area of Northwest Guangxi[J]. Journal of Hunan Agricultural University (Natural Sciences),2007,33(3): 341-344.
[8] 刘秀红 . 南丰和衢州柑橘园土壤与树体营养状况的分析[D]. 武汉:华中农业大学,2014.
LIU Xiuhong. Analysis on soil and leaf nutrient element contents in orchards in the Nanfeng and Quzhou[D]. Wuhan: Huazhong Agricultural University,2014.
[9] 柏斌 . 云南:玉溪柑桔产业发展欣欣向荣[J]. 中国果业信息,2018,35(3):40.
BO Bin. Yunnan: Citrus industry is thriving in Yuxi[J]. China Fruit News,2018,35(3): 40.
[10] 张翠英 . 新平县柑橘产业发展现状及思路对策[J]. 南方农业,2013,7(10):64-68.
ZHANG Cuiying. Current situation of citrus industry development and countermeasures in Xinping County[J]. South China Agriculture,2013,7(10): 64-68.
[11] 罗世俊 . 华宁县柑桔产区的生态条件[J]. 云南农业科技,1998(5):5-6.
LUO Shijun. Ecological conditions of citrus production areas in Huaning County[J]. Yunnan Agricultural Science and Technology,1998(5): 5-6.
[12] 庄伊美 . 柑橘营养与施肥[M]. 北京:中国农业出版社,1997.
ZHUANG Yimei. Citrus nutrition and fertilization [M]. Beijing: China Agriculture Press,1997.
[13] 加拿大钾肥研究所北京办事处. 土壤养分状况系统研究法[M]. 北京:中国农业科学技术出版社,1992.
Beijing Office of Potassium and Phosphate Institute of Canada. Systematical and comprehensive evaluation approaches of soil nutrients[M] . Beijing:China Agricultural Science and Technology Press,1992.
[14] 国家林业局 . 森林土壤分析方法:中华人民共和国林业行业标准(LY/T 1210-1275-1999)[S]. 北京:中国标准出版社,1999.
Forestry Administration of P. R. China. Forest soil analysis methods: Forestry industry standard in The People's Republic of China (LY/T 1210-1275-1999)[S]. Beijing: Standard Press of China,1999.
[15] 鲍士旦 . 土壤农化分析 3 版[M]. 中国农业出版社,2000.
BAO Shidan. Soil Agrochemical Analysis[M]. 3rd Edition. China Agriculture Press,2000.
[16] 金继运,白由路,杨俐苹 . 高效土壤养分测试技术与设备[M]. 北京:中国农业出版社,2006
JIN Jiyun,BAI Youlu,YANG Liping. Efficient soil testing technology and equipment[M]. Beijing: China Agriculture Press,2006.
[17] 何天富 . 柑橘学[M]. 北京:中国农业出版社,1999.
HE Tianfu. Citrus science[M]. China Agriculture Press,1999.
[18] 王昌全,李叔南,夏建国,伍钧 . 西南红、黄壤粘粒组成及土壤保肥性能的研究[J]. 四川农业大学学报,1996(2:):211-214.
WANG Changquan,LI Shunan,XIA Jianguo,WU Jun. Study on clay composition and fertilizer conservation properitity of red and yellow soils in the southwest[J]. Journal of Sichuan Agricultural University,1996(2): 211-214.
[19] 王利民,卜晓莉,林新坚,黄东风,邱孝煊,罗涛 . 红黄壤区土壤改良利用技术研究进展[J]. 江西农业学报,2013,25(12):96-100.
WANG Limin,BU Xiaoli,LIN Xinjian,HUANG Dongfeng,QIU Xiaoxuan,LUO Tao. Research progress in improvement and utilization of soil in red-yellow soil region[J]. Acta Agriculturae Jiangxi,2013,25(12): 96-100.
[20] 普发贵,普靖茜 . 玉溪市降水化学特征及变化趋势分析[J]. 环境科学导刊,2015,34(1):50-54.
PU Fagui,PU Jingxi. Chemical characteristic and trend analysis of precipitation of Yuxi City[J]. Environmental Science Survey,2015,34(1): 50-54.
[21] JING G H,YU X X,LIU Q J,LI Z W. Characteristics of soil nitrogen loss under different intense rainfalls in Yimeng mountainous area[J]. Transactions of the Chinese Society of Agricultural Engineering,2012,28(6): 120-125.
[22] 王南南,彭抒昂,刘永忠 . 柑橘硼营养研究现状与展望[J]. 华中农业大学学报,2015,34(4):137-143.
WANG Nannan,PENG Shu'ang,LIU Yongzhong. Advances on boron nutrition of citrus[J]. Journal of Huazhong Agricultural University,2015,34(4): 137-143.
[23] WLRTH A E A . Fruit tree fertilization[J]. Schweizerische Zeitschrift fur Obst- und Weinbau,1970.
[24] ATKINSON D. The growth,activity and distribution of the fruit tree root system[J]. Plant and Soil,1983,71(1): 23-35.
[25] MALAVOLTA E,VIOLANTE N A. Mineral nutrition,liming,application of gypsum and fertilization of citrus[J]. 1989.
[26] 王男麒 . 柑橘花果脱落规律及其矿质养分损耗[D]. 重庆:西南大学,2014.
WANG Nanqi. Flower and young fruit drop characteristics and its nutrient element loss in citrus[D]. Chongqing: Xinan University,2014.
[27] ALVA A K,PARAMASIVAM S,OBREZA T A,SCHUMANN A W. Nitrogen best management practice for citrus trees : I. Fruit yield,quality,and leaf nutritional status[J]. Scientia Horticulturae,2006,107(3): 233-244.
[28] CHAPMAN H D,KELLEY W P. The mineral nutrition of citrus [M]//Ex The Citrus industry Volume I: history,botany,and breeding. First edition. Mineral Nutrition of Citrus Ex the Citrus Industry,1943.
[29] REUTHER W,REUTHER G W,KLOTZ L,CALAVAN E C,CARMAN G J. The citrus industry[M]. 1973.
[30] MENINO R. Leaf analysis in citrus: interpretation tools[M]. Advances in Citrus Nutrition,2012.
[31] HERNANDES A,DE SOUZA H A,DE AMORIM D A,NATALE W,LAVRES J,BOARETTO A E,CAMACHO M A. Dris norms for pêra orange[J]. Communications in Soil Science and Plant Analysis,2014,45(22): 2853-2867.
[32] 储成兵 . 农户测土配方施肥技术的持续采用意愿分析[J]. 湖北工程学院学报,2019(2):122-128.
CHU Chengbing. An analysis on farmers' durable adoption willingness of formula fertilization technology[J]. Journal of Hubei Engineering University,2019(2): 122-128.

(C)1994-2020 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net