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Identification of the productivity-limiting nutrients of Xuxiang kiwifruit (*Actiniadia chinensis*) in China's central Shaanxi province by analyzing soil fertility and leaf elements

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ABSTRACT

A survey was initiated to identify the productivity-limiting nutrients of Xuxiang kiwifruit (*Actiniadia chinensis* Lindl.) orchards in central Shaanxi province in China during 2016-2017. For this purpose 149 kiwifruit orchards were selected for leaf sampling and 59 of them were randomly selected for soil analysis. These investigated orchards were divided into two subpopulations: high-productivity subpopulation (21 orchards) and low-productivity subpopulation (128 orchards) according to the fruit yield and appearance as well as vine growth performance. The nutrient concentrations in leaves of high-productivity subpopulation were used to compute the norms of the diagnosis and recommendation integrated system (DRIS), and in low-productivity orchards the order of nutrient requirement was found to be Zn>Mn>K>Fe>Cl>P>B>Ca>Mg>Cu>N. Among them, the deficient nutrients were Zn, Mn and K, while the excessive ones were N, Cu and Mg. However, the limiting elements in various locations and orchard ages differed. These results obtained from leaf analysis were further validated by soil fertility evaluation using sufficiency range, 94.9%, 83.1%, 76.3%, 32.2% and 23.7% of the orchards were high in pH, Ca, Mg, nitrate N and Cu respectively. By contrast, approximately 70% of the soils were low in Fe, Mn, Zn and Cl, and over 30% low in K, P and OM. Results obtained could be used for guiding the sustainably-integrated nutrient management for kiwifruit orchards in central Shaanxi and other regions with similar environmental conditions.

Key words: *Actiniadia*, DRIS, Leaf nutrient, Nutritional diagnosis, Soil fertility, Sufficiency range

Kiwifruit (*Actiniadia chinensis* Lindl.) is one of the most important recently domesticated fruit crops in the world. In 2015, the kiwifruit yield and harvested area in China represented 2187867 tons and 181900 ha, and accounted for 52.7% and 69.0% of the world's yield and area respectively (FAO 2018). Among them, 47.1% and 24.3% of China's yield and area come from central Shaanxi (Zhang 2016, FAO 2018). However, the average yield of kiwifruit is much lower in China (12.0 tonnes/ha) than the whole world (15.7 ton/ha), especially in the second and third largest kiwifruit-producing countries, Italy (21.9 tonnes/ha) and New Zealand (34.0 tonnes/ha, FAO 2018). The poor yield is often attributed to inadequate information on plant nutrition and soil fertility (Liu *et al.* 2002, Song *et al.* 2003, Wang 2008). Indeed, nutrient disorders of kiwifruit orchards in central Shaanxi province (e.g. N excess and hidden hunger of Fe, K, Cl and P) occur frequently, and result in a substantial loss of fruit quantity and quality (Zhang *et al.* 2001, Lai 2011, Tran *et al.* 2012, Lu *et al.* 2016a).

Nutritional diagnosis is an important tool for increasing the fruit yield and quality as well as improving the plant growth through efficient fertilization. Several approaches for interpreting the results of leaf nutrient analysis have been proposed, such as critical values (CV) or sufficiency ranges (SR) (Bates 1971), diagnosis and recommendation integrated system (DRIS; Beaufils 1973), deviation from optimum percentage (DOP; Montañes *et al.* 1993), and compositional nutrient diagnosis (CND; Parent and Dafir 1992). Compared with the former two methods, the latter two were less employed due to the lack of useful references and field trials to ensure validity and accuracy. SR method is widely used for plant nutrient diagnosis owing to its easy assess and practice. Another widespread method is DRIS, and this method possesses some additional advantages over SR: (1) to reflect the nutrient balance or interaction, (2) to identify the order of nutrient requirements or limiting nutrients, and (3) to reduce the effects of sampling time and plant position (Walworth and Sumner 1987). Thus, DRIS has sightly higher diagnostic precision than SR in many cases (Walworth and Sumner 1987). To date, DRIS has been used

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successfully for a wide range of cash crops, such as orange (Srivastava and Singh 2008), apple (Nachtigall and Dechen 2007), banana (Wairegi and Asten 2011), guava (Hundal *et al.* 2007), sugarcane (Barłóg 2016) and oil palm (Behera *et al.* 2016). Nevertheless, the DRIS norms for 'Xuxiang', the currently predominant kiwifruit cultivar in central Shaanxi, have not been developed.

The objectives of this study were: (i) to develop the DRIS norms of leaf nutrients for 'Xuxiang' kiwifruit in central Shaanxi province, and (ii) to evaluate the nutritional status of these kiwifruit orchards through leaf analysis and soil testing.

MATERIALS AND METHODS

Site description

The research was performed in the central region of Shaanxi province, China (34°7'~35°10'N, 106°12'~108°58'E, evaluation 451~831 m). This area has sufficient sunshine and a warm temperate continental monsoon climate with hot, wet summers, and cold, dry winters. The average annual temperature and precipitation are 11 to 13°C and 500 to 800 mm, respectively. About 60% of the precipitation is received between June and September. The majority of the studied soils are classified as earth-cumuli-orthic anthrosols or cultivated loessial soils according to China Soil Taxonomy (Xiong and Li 1987).

Sampling and analysis

A total of 149 leaf samples were collected from kiwifruit (*Actinidia chinensis* var. *deliciosa* 'Xuxiang') orchards in late August and early September during 2016-2017. Among them, 109 orchards were from Meixian, 5 from Qishan, 5 from Wugong, 6 from Yangling and 24 from Zhouzhi. Leaf samples were taken from the second leaf past the final fruit cluster on a fruiting lateral, and each sample consisted of 40 leaves (blade plus petiole) from 20 vines with 2 leaves per vine (Sher 2008). The samples were washed in sequence with tap water, 0.5% detergent solution, 0.1% hydrochloric acid (HCl) solution and deionized water. Then, the leaf samples were oven-dried at 65°C to a constant weight, ground in a mill to pass through a 20-mesh sieve, and stored in sealed plastic bags for analysis. The concentration of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and boron (B) in plant leaves was determined by an inductively coupled plasma optical emission spectrometry (ICP-OES, IRIS-Advan type, Thermo, USA), and chlorine (Cl) by a discontinuous analyzer after dry-ashed (with the addition of CaO only for Cl measurement) and dissolved in 0.5 mol/L HNO_3 solution (Zhou *et al.* 2014). The nitrogen (N) concentration in leaf tissue was quantified using Kjeldahl methods (Bao 2000).

A total of 59 soil samples were taken from the randomly selected leaf-sampling orchards. Among them, 35 orchards were from Meixian, 5 from Qishan, 5 from Wugong, 6 from Yangling and 8 from Zhouzhi. Soil samples were taken at a depth of 0 to 30 cm and a distance of 1.0 to 1.2 m from the main vines with a soil auger of 5 cm interior diameter. Each soil sample was composed of five random soil cores per orchard, stored in double-lined plastic bags, and brought into the laboratory for soil property analysis. The samples were air-dried, ground by a rolling pin to pass through a 1.00-mm sieve (half of the soil sub-samples were passed through a 0.15-mm sieve for organic matter analysis), and stored in sealed plastic bags until analysis. Soil chemical properties (i.e. pH, organic matter (OM), salt, sodium (Na), P, K, Ca, Mg, Fe, Mn, Cu, Zn, B and Cl) were analyzed according to the methods described by Bao (2000), and N was determined according to the method described by Mohammed *et al.* (2017). Briefly, soil pH was measured with a glass electrode in a 1:5 suspension of soil to water by mass, and electrical conductivity (EC) was measured in the same extract and the total salt concentration was calculated by EC. OM content was determined by the potassium dichromate volumetric method of external heating. Mineral N (including ammonium N and nitrate N) was extracted with 1.0 mol/L KCl and determined using a continuous flowing analyzer. Available soil P was determined with the molybdate blue method after extraction with $NaHCO_3$. Exchangeable cations (K^+, Ca^{2+}, Mg^{2+}, and Na^+) were extracted with 1.0 mol/L NH_4OAc, and most available micronutrients (Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+}) were extracted with 0.05 mol/L diethylenetriaminepentaacetic acid (DTPA) reagent, and all determined by atomic absorption spectrophotometer (AAS). Available B was extracted by boiling water and determined by ICP-OES. Soil Cl was extracted from a 1:2.5 soil-water mixture and determined with a discontinuous analyzer.

When taking leaf and soil samples, data on the yield and cultivation-related information of each orchard were obtained from the growers and reassessed by local kiwifruit experts to guarantee the reliability of the orchard information.

Procedure of DRIS norms

To establish DRIS norms, the population was divided into two subpopulations: high-productivity subpopulation and low-productivity subpopulation. The high-productivity subpopulation was defined as those orchards with a fruit yield equal to or above 2000 kg/667m^2 (fruit quantity), uniform and large-sized fruits (fruit quality), and healthy green leaves (the capability to successively bear fruits in following years) at harvest stage. The mean value, standard deviation (SDs) and coefficient of variation (CVs) of leaf nutrient concentrations and ratios in high-productivity subpopulation were considered nutritionally balanced or a reference for diagnostic norms and listed in Table S1. The subpopulation with high productivity was represented by 21 orchards (14.1% of the orchards) and low productivity by 128 orchards (85.9% of the orchards).

The DRIS provides a means of ordering nutrient ratios into a meaningful expression referred as the DRIS index (Walworth and Sumner 1987). The values of nutrient ratios with relatively large variance ratios (variance of low productivity subpopulation (S^2_l)/variance of high productivity subpopulation (S^2_h); i.e. F value) were selected to calculate the DRIS indices (Serra *et al.* 2013). The DRIS indices for nutrient A through N were computed using the following equations (Beaufils 1973, Walworth and Sumner 1987):

Index A = 1/z[f(A/B)+f(A/C)+f(A/D)+…+f(A/N)]

Index B = 1/z[-f(A/B)+f(B/C)+f(B/D)+…+f(B/N)]

Index N = 1/z[-f(A/N)-f(B/N)+f(N/C)+…-f(M/N)]

where when A/B is larger or equal to a/b,

f(A/B) = [(A/B)/(a/b)-1]×1000/CV

or when A/B is smaller than a/b,

f(A/B) = [1-(a/b)/(A/B)]×1000/CV

where Index A, DRIS index; f(A/B), DRIS functions; z, the number of DRIS functions; A/B, nutrient ratio of the samples diagnosed in low productivity subpopulation; a/b, mean value of nutrient ratio in high-productivity subpopulation; CV, coefficient of variation of nutrient ratio in high-productivity subpopulation.

The more negative the DRIS index, the more shortage would be the nutrient relative to others; and *vice versa*. The DRIS indices were assessed by comparing DRIS indices with the mean value of nutrient imbalance index (NIIm), which was equal to the sum of the absolute value of each DRIS index divided by the number of DRIS indices (Nachtigall and Dechen 2007):

Deficient = Ix<0 and |Ix|>NIIm,

Normal = |Ix|≤NIIm, and

Excessive = Ix>0 and |Ix|>NIIm.

All data were computed using Microsoft Office Excel 2007.

RESULTS AND DISCUSSION

Leaf nutrient status of kiwifruit orchards

We assessed the nutritional status of kiwifruit leaves in low-productivity subpopulation according to the DRIS norms established by high-productivity subpopulation (Table 3), and found that the nutrient requirement of Xuxiang kiwifruit in central Shaanxi followed the order: Zn>Mn>K>Fe>Cl>P>B>Ca>Mg>Cu>N (Table 1). Among them, the deficient elements were recorded for Zn, Mn and K while the excessive ones for N, Cu and Mg (Table 1). However, the limiting nutrients in various locations differed. Leaf samples from both Meixian and Zhouzhi were deficient in Zn and Mn, Qishan deficient in P, Wugong deficient in K, and Yangling deficient in Cl, P and Mn (Table 1). By contrast, the orchards in Meixian were excessive in N and Mg, Zhouzhi excessive in N, Ca and B, Qishan and Yangling excessive in Cu, and Wugong excessive in Mg, Cu and Fe (Table 1). Moreover, kiwifruit nutrient requirement varied considerably with plant age (Table 1). Mn deficiency occurred across all orchard ages, and other deficiency elements shifted from Zn and K through Zn to Mg and Cl with increasing kiwi-vine age (Table 1). The orchards older than 12 years were excessive in Ca, Zn and K, whereas those equal to or younger than 12 years were

Table 1 DRIS indices of leaf nutrients in different sites and orchard ages for kiwifruit orchards

Site	DRIS indices											NIIm	Yield (kg/667m^2)	Order of requirement
	N	P	K	Ca	Mg	Cl	Fe	Mn	Cu	Zn	B			
All sites	2.33	-0.53	-1.68	1.60	2.08	-0.69	-0.74	-2.48	2.32	-2.96	0.75	1.65	1967	**Zn***>**Mn***>**K***>Fe>Cl>P>B>Ca>**Mg***>**Cu***>**N***
Meixian	1.85	0.43	-0.84	1.21	1.74	-0.37	-1.15	-1.98	0.63	-2.52	1.01	1.25	2124	**Zn***>**Mn***>Fe>K>Cl>P>Cu>B>Ca>**Mg***>**N***
Qishan	-2.02	-6.29	-2.67	1.79	-1.23	-4.03	0.84	-3.92	25.75	-3.47	-4.76	5.16	1583	**P***>B>Cl>Mn>Zn>K>N>Mg>Fe>Ca>**Cu***
Wugong	-5.23	-3.29	-12.70	-2.48	16.55	-2.95	11.32	-6.46	13.11	-2.76	-5.13	7.45	850	**K***>Mn>N>B>P>Cl>Zn>Ca>**Fe***>**Cu***>**Mg***
Yangling	0.04	-5.77	-2.91	-3.00	2.45	-8.33	3.07	-5.43	19.33	4.03	-3.47	5.26	1300	**Cl***>**P***>**Mn***>B>Ca>K>N>Mg>Fe>Zn>**Cu***
Zhouzhi	7.39	-2.20	-2.66	4.65	-0.66	0.90	-2.86	-3.11	0.71	-5.47	3.30	3.08	1725	**Zn***>**Mn***>Fe>K>P>Mg>Cu>Cl>**B***>**Ca***>**N***
Plant age (year)														
<8	3.04	-0.27	-2.87	1.62	2.72	-0.48	-0.74	-2.67	3.18	-3.71	0.19	1.95	1711	**Zn***>**K***>**Mn***>Fe>Cl>P>B>Ca>**Mg***>**N***>**Cu***
8-12	1.46	-0.94	-0.55	1.18	2.09	-1.14	-0.88	-1.76	1.93	-2.26	0.87	1.37	2240	**Zn**>**Mn**>Cl>P>Fe>K>B>Ca>**N***>**Cu***>**Mg***
>12	1.52	-0.23	1.84	3.01	-3.52	-1.86	-0.12	-3.40	-0.63	2.05	1.34	1.78	2219	**Mg***>**Mn***>**Cl**>Cu>P>Fe>B>N>**K***>**Zn***>**Ca***

The sample numbers for 'All sites', 'Meixian', 'Qishan', 'Wugong', 'Yangling', and 'Zhouzhi' are 128, 95, 3, 5, 5, and 20 respectively; the sample numbers for '<8', '8-12', and '>12' are 67, 48, and 12 respectively. NIIm, mean value of nutrient imbalance index. *Indicate significantly imbalanced nutrients because the absolute values of these nutrient DRIS indices are larger than NIIm.

excessive in Cu, N and Mg (Table 1). This may be due to the nutritional status of fruit crops influenced by a variety of factors, such as soil type, climate, cultivar, and plant age as well as nutrient reserves in plant tissues (Mourão Filho 2004, Vajari *et al.* 2018). Additionally, the kiwifruit yield decreased with NIIm increased (Table 1), indicating that NIIm is able to reflect the nutrient balance well.

Soil fertility status of kiwifruit orchards

To validate the DRIS results from kiwifruit leaves, we further randomly selected 59 orchards from the investigated orchards to assess soil fertility. 94.9% and 83.1% of the orchards were excessive in pH and Ca respectively (Table 2), indicating that the soils are calcareous. Moreover, 76.3%, 32.2% and 23.7% of the soil samples were high in Mg, nitrate N and Cu (Table 2). On the other hand, approximately 70% of the kiwifruit orchards were low in Fe, Mn, Zn and Cl (Table 2). Over 30% of the soils were low in K, P and OM (Table 2). Additionally, more than 70% of the orchards were in optimum range for soil B, Na and salt (Table 2). These results agreed well with the DRIS results from leaf analysis (Table 1 and Table 2). Taken together, our results showed that both nutrient deficiency and excess existed in kiwifruit orchards in central Shaanxi, and a better soil management is highly needed to improve soil fertility and thus to enhance the kiwifruit productivity (Lago *et al.* 2015, Peticila *et al.* 2015, Zhao *et al.* 2017).

Noteworthy, the excessive percentages of soil nitrate N and Cu were not as high as soil Ca and Mg (Table 2), but those of leaf N and Cu seemed to be higher than leaf Ca and Mg (Table 1). This may be associated with (1) frequent leaf spray of Cu-containing fungicides or N-containing foliar fertilizers and (2) ionic selective absorption by plant roots (Marschner 2012). In addition, Lu *et al.* (2016a, 2016b) reported that N overfertilization was found in the Yujiahe catchments of Zhouzhi and changing arable crops to kiwifruit orchards increased the environmental burden of this region, and thus was unfavorable to the sustainability of kiwifruit industry (Müller *et al.* 2015, Cui *et al.* 2018). Consequently, rational N fertilization is necessary for high-productivity kiwifruit orchards in central Shaanxi.

Nutrient disorders are commonly observed in kiwifruit cultivation (Smith *et al.* 1987a, Liu *et al.* 2002, Tran *et al.* 2012). Results indicate that the investigated region was hidden-hungry in Fe and Cl, besides Zn, Mn and K (Table 1 and Table 2). Fe deficiency is generally related to the phenomenon of kiwifruit leaf chlorosis (Tran *et al.* 2012), which may be induced by several factors, such as high soil pH, high $CaCO_3$ content, excessive fruit loading in previous year, and damages to root system (Tagliavini and Rombolà 2001). Here we suggested that Fe deficiency in central Shaanxi was mainly caused by high pH and Ca in calcareous soils (Table 2), and leaf chlorosis might be a combined effect of several chlorophyll-related nutrient deficiencies, such as Fe, Zn and Mn (Table 1 and Table 2). In central Shaanxi, Cl deficiency has been well documented 17 year ago (Zhang *et al.* 2001), and the increasing kiwifruit yield by applying Cl-containing fertilizers was reported recently (Yang 2016). However, the increase of kiwifruit yield diminished with increasing the amount of Cl-containing fertilizers (Yang 2016). Therefore, Cl in central Shaanxi may be in hidden hunger. The reasons leading to potential Cl

Table 2 Soil fertility status for kiwifruit orchards in central Shaanxi province (n=59)

	Mean	CV (%)	Sample range	Optimum range	Deficient frequency (%)	Excessive frequency (%)
pH	7.67	8.1	4.87-8.28	5.5-6.5	1.7	94.9
OM (%)	1.61	14.3	1.10-2.15	1.5-4.0	30.5	0.0
Salt (g/kg)	0.71	32.4	0.32-1.34	0-1.0		11.9
Na(mg/kg)	26.42	75.7	5.29-106.86	0-92		5.1
N (mg/kg)	39.47	65.2	12.87-109.63			
NH_4^+-N (mg/kg)	10.81	55.0	1.70-43.58			
NO_3^--N (mg/kg)	28.81	82.3	3.95-98.35	11-28	20.3	32.2
P (mg/kg)	42.76	81.3	5.04-167.52	30-60	42.4	18.6
K (mg/kg)	247.26	46.6	108.91-715.52	235-470	55.9	8.5
Ca (g/kg)	6.20	19.5	1.03-7.51	2.8-5.6	3.4	83.1
Cl (mg/kg)	10.28	106.4	3.42-86.05	10-30	69.5	1.7
Mg (mg/kg)	240.08	31.1	99.85-419.46	120-180	3.4	76.3
Fe (mg/kg)	4.88	301.8	0.78-108.97	4.5-10	94.9	5.1
Mn (mg/kg)	4.63	119.0	0.93-36.48	7-12	89.8	5.1
Cu (mg/kg)	0.87	37.8	0.37-2.02	0.5-1.0	5.1	23.7
Zn (mg/kg)	0.69	112.4	0.14-4.27	1.0-2.0	83.1	5.1
B (mg/kg)	0.70	35.2	0.38-1.45	0.5-1.0	18.6	10.2

Optimum range is summed from Li *et al.* (1996), Bao (2000), Sher (2008), Tong (2011), Huang *et al.* (2014) and Yu (2017).

Table 3 Descriptive data of nutritional status of kiwifruit leaves for high-productivity orchards (n=21)

	Mean	CV (%)	Variance		Mean	CV (%)	Variance		Mean	CV (%)	Variance
N	20.4543	6.9	1.99543	P/Mn	0.01226	46.6	0.000033	Fe/Mg	29.9210	40.7	148.622
P	1.55947	36.5	0.32353	Mn/P	109.467	67.4	5443.04	Mg/Mn	0.05948	56.0	0.00111
K	11.6072	33.3	14.9824	P/Cu	0.12275	67.0	0.00676	Mn/Mg	29.1365	110.5	1036.78
Ca	42.6811	9.5	16.3188	Cu/P	11.9520	61.9	54.8052	Mg/Cu	0.52309	49.0	0.06559
Mg	6.87128	24.7	2.88762	P/Zn	0.05494	48.1	0.00070	Cu/Mg	2.67214	67.8	3.28358
Cl	4.94283	36.6	3.27071	Zn/P	22.0093	43.3	90.7469	Mg/Zn	0.24295	41.9	0.01037
Fe	190.849	25.8	2429.64	P/B	0.02507	39.3	0.00010	Zn/Mg	4.96956	47.6	5.59706
Mn	167.226	69.9	13657.0	B/P	46.8331	42.4	394.179	Mg/B	0.10960	36.6	0.00161
Cu	17.8845	65.2	136.00	K/Ca	0.27666	37.7	0.01090	B/Mg	10.2084	31.5	10.3587
Zn	32.8938	46.5	233.46	Ca/K	4.22703	45.5	3.69697	Cl/Fe	0.02803	47.5	0.00018
B	67.0856	29.5	392.97	K/Mg	1.91900	66.9	1.64784	Fe/Cl	44.3455	51.4	519.631
N/P	14.1141	22.8	10.3143	Mg/K	0.69922	56.4	0.15540	Cl/Mn	0.04046	57.2	0.00053
P/N	0.07617	35.3	0.00072	K/Cl	2.57678	40.3	1.07935	Mn/Cl	37.5653	88.7	1110.81
N/K	1.99775	40.5	0.65307	Cl/K	0.48234	56.7	0.07467	Cl/Cu	0.42358	69.8	0.08741
K/N	0.56822	33.6	0.03639	K/Fe	0.06260	33.9	0.00045	Cu/Cl	4.42211	84.7	14.0405
N/Ca	0.48398	12.8	0.00383	Fe/K	18.1702	42.0	58.1012	Cl/Zn	0.18818	65.0	0.01498
Ca/N	2.09958	13.1	0.07619	K/Mn	0.09320	56.7	0.00279	Zn/Cl	7.63165	58.7	20.0557
N/Mg	3.19723	33.1	1.11972	Mn/K	15.1811	67.4	104.773	Cl/B	0.07973	46.6	0.00138
Mg/N	0.33664	24.6	0.00687	K/Cu	0.89980	58.4	0.27649	B/Cl	15.1256	46.4	49.1689
N/Cl	4.63629	34.4	2.54669	Cu/K	1.70005	76.2	1.67676	Fe/Mn	1.57215	54.1	0.72421
Cl/N	0.24333	37.1	0.00815	K/Zn	0.42494	52.0	0.04878	Mn/Fe	0.89198	65.0	0.33565
N/Fe	0.11417	29.4	0.00113	Zn/K	3.29697	69.5	5.24465	Fe/Cu	14.3540	46.2	44.0665
Fe/N	9.39084	27.1	6.45489	K/B	0.19512	57.7	0.01267	Cu/Fe	0.09384	63.2	0.00352
N/Mn	0.17352	52.9	0.00842	B/K	6.74965	57.8	15.2283	Fe/Zn	6.93484	44.0	9.30982
Mn/N	8.23202	70.1	33.2896	Ca/Mg	6.67890	31.9	4.53611	Zn/Fe	0.18805	66.5	0.01564
N/Cu	1.61999	48.7	0.62286	Mg/Ca	0.16270	28.0	0.00207	Fe/B	3.15659	48.0	2.29174
Cu/N	0.87617	65.3	0.32686	Ca/Cl	9.57903	30.9	8.77064	B/Fe	0.37544	37.8	0.02018
N/Zn	0.73819	39.5	0.08504	Cl/Ca	0.11622	36.1	0.00176	Mn/Cu	12.3164	85.3	110.386
Zn/N	1.59840	43.8	0.49038	Ca/Fe	0.23887	30.0	0.00515	Cu/Mn	0.13722	76.9	0.01112
N/B	0.33086	29.7	0.00968	Fe/Ca	4.53625	29.5	1.79023	Mn/Zn	5.91109	78.5	21.5042
B/N	3.28544	29.3	0.92846	Ca/Mn	0.36404	55.4	0.04071	Zn/Mn	0.26898	67.1	0.03260
P/K	0.14861	43.7	0.00422	Mn/Ca	3.98940	73.7	8.65155	Mn/B	3.04091	99.3	9.12725
K/P	7.93568	39.4	9.79868	Ca/Cu	3.42507	51.3	3.08139	B/Mn	0.60394	66.4	0.16079
P/Ca	0.03686	36.0	0.00018	Cu/Ca	0.42864	68.8	0.08701	Cu/Zn	0.58190	61.7	0.12881
Ca/P	29.7748	29.8	78.8255	Ca/Zn	1.57093	44.2	0.48155	Zn/Cu	2.42213	69.4	2.82190
P/Mg	0.24167	44.6	0.01161	Zn/Ca	0.78751	50.8	0.15988	Cu/B	0.31921	80.6	0.06621
Mg/P	4.73555	33.2	2.46602	Ca/B	0.68883	29.6	0.04151	B/Cu	5.79602	65.1	14.2479
P/Cl	0.36420	61.6	0.05029	B/Ca	1.57776	29.7	0.22031	Zn/B	0.54894	55.9	0.09414
Cl/P	3.48179	44.4	2.39377	Mg/Cl	1.60101	47.1	0.56775	B/Zn	2.54721	58.6	2.22529
P/Fe	0.00861	41.1	0.000012	Cl/Mg	0.80506	59.4	0.22902				
Fe/P	131.579	32.6	1841.13	Mg/Fe	0.03837	38.3	0.00022				

The unit of 'N', 'P', 'K', 'Ca', 'Mg', and 'Cl' is g/kg; the unit of 'Fe', 'Mn', 'Cu', 'Zn', and 'B' is mg/kg.

deficiency include (1) low Cl content in soils (Table 2), (2) high Cl requirement of kiwifruit plant (Smith *et al.* 1987b), and (3) the large amount of Cl removal by harvested fruit, summer and winter prunings, and fallen leaves (Wang 2008, Vajari *et al.* 2018).

In sum, the nutritional status of 'Xuxiang' kiwifruit orchards in central Shaanxi was characterized by Zn, Mn and K deficiency, as well as N, Cu and Mg excess. Moreover, the limiting nutrients varied across locations and orchard ages. These results provide a useful reference for rational fertilization of kiwifruit orchards in calcareous soils.

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