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Research Article

Preliminary the Diagnosis and Recommendation Integrated System (DRIS) Norms for Evaluating the Nutrient Status of Apple

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Abstract: The Diagnosis and Recommendation Integrated System (DRIS) is an important tool for increasing fruit yield and fruit quality. There are still no studies on the use of DRIS for nutritional diagnosis of the apple tree for China conditions. The objectives of this study were to establish norms for apple, to compare mean yield, leaf nutrient contents and variance of nutrient ratios of low- and high-yielding subpopulations. The study covered the apple producing areas of the Wei-bei Loess Plateau in the northwest of China, in 164 orchards selected for their high productivity and employment of excellent management techniques. The concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese and zinc were determined in leaf samples. The data were divided into high-yielding (>45 t/ha) and low-yielding (<45 t/ha) subpopulations and norms were computed using standard DRIS procedures and a preliminary DRIS norms for apple growing in the Wei-bei Loess Plateau are selected. These norms were developed with data from only one region, so data from future surveys and field trials may subsequently be used to enlarge the database allowing the refinement of model parameters. The results elucidate that the DRIS model for apple, developed in this study, is a diagnostic tool that may be used to predict if insufficiencies or imbalances in N, P, K Ca, Mg, Fe, Mn and Zn supplies are occurring in apple production area in the Wei-bei Loess Plateau, China and indeed elsewhere in the other apple production areas with similar c1imatic and soil conditions.

Keywords: Apple, DRIS norms, high-yielding, leaf diagnosis, low-yielding, weibei loess plateau

INTRODUCTION

China apple production and export volume rank the first in the world (FAO, 2010). Almost 4.7 million ha of apple are grown around the world and about 44% of those areas are located in China (FAO, 2010). The Wei-bei Loess Plateau, with advantaged apple producing conditions, is an important apple production area in China. Apple is grown extensively in this area with an average 601,520 ha in production and annual yield reaches nearly 8.6 million ton (SPBS, 2010). In this area, improper use of fertilizers is likely to be the major factors contributing to declining yield and quality, though no local nutrition guidelines are available. The foliar analysis has frequently been used to be an important tool to monitor the nutrient status of plants.

The Diagnosis and Recommendation Integrated System (DRIS) is claimed to have certain advantages over other conventional interpretation tools (Beverly, 1987; Malavolta *et al*., 1993; Srivastava and Shyam, 2008). DRIS firstly developed for *Hevea brasiliensis* by Beaufils (1956, 1973). It is a method to evaluate plant nutritional through indexes, which provides a means of simultaneously identifying imbalances, deficiencies and excesses in plant nutrients and ranking them in order of importance (Walworth and Sumner, 1986). DRIS uses a comparison of the leaf tissue nutrient concentration ratios of nutrient pairs with norms from a high-yielding group (Soltanpour *et al*., 1995), different from the traditional methods of leaf diagnosis like the critical level and sufficiency range.

DRIS norms have been used successfully to interpret the results of leaf analyses for both annual crops and perennial crops, such as potato (Meldal-Johnson and Sumner, 1980; Mackay *et al*., 1987; Parent *et al*., 1994), tomato (Caron and Parent, 1989; Hartz *et al*., 1998; Mayfield *et al*., 2002), grassland swards (Bailey *et al*., 1997a, b), lettuce (Sanchez *et al*., 1991), onion (Caldwell *et al*., 1994), cucumber (Mayfield *et al*., 2002), rice (Singh and Agrawal, 2007), corn (Soltanpour *et al*., 1995), pineapple (Teixeira *et al*., 2009), apple (Goh and Malakouti, 1992; Singh *et al*., 2000), mango (Schaffer *et al*., 1988; Raghupathi and Bhargava, 1999; Raj and Rao, 2006), peach (Beverly and Worley, 1992; Sanz, 1999; Awasthi *et al*., 2000) and sapota (Appa Rao *et al*., 2006). However none have been developed for apple in the Wei-bei Loess Plateau of the northwestern China.

The objective of this study was to establish appropriate DRIS norms for apple in China, seeking to

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use the DRIS method for its nutritional diagnosis. A survey of apple was conducted to provide a broad database of foliar nutrient concentrations in low- and high-yielding plants from which to ca1culate DRIS norms.

MATERIALS AND METHODS

The research was carried out in the Wei-beiLoess Plateau which is one of the main apple producing areas in China. The Wei-beiLoess Plateau is located in between 34° 36' and 36° 20' North latitude, 106°20' and 110°40' East longitude and the altitude from 800 to 1200 m. The Wei-bei Loess Plateau belongs to Warm and semi-humid continental monsoon climate. The annual rainfall varies between 525 and 730 mm. Mean maximum temperatures range from 34 to 40°C and mean minimum temperatures from -16 to -25°C. The sunshine duration is between 2,300 to 2,500 h. The frost-free period is 170D.

In 2007, a questionnaire was filled out by the farmer of the orchard, including rootstock, spacing, year of planting, pest management, fertilizer management and corrective measures. One hundred and sixty four apple orchards, 19 from Cultivated loessial soils, 68 from Huangshan soils, 22 from Dark loessial soils, 44 from Lou soils, 4 from red soils, 5 from Cinnamon soils, 2 from Skeletol soils, were selected for survey. According to fruit leaf sample standard in China (Gangli *et al*., 1985), the collection of leaves was accomplished between July and August. Each orchard 25 plants were random selected for their uniformity.

Leaf samples were washed with deionized water, dried at 65°C weighed, milled to 20 mesh for mineral analysis. Total Nitrogen (N) was analyzed by the Nessler procedure (Chapman and Pratt, 1961). Phosphorus (P) was analyzed by the molybdenum yellow method. Potassium (K) was measured by the flame photometer. Calcium (Ca), Magnesium (Mg), Copper (Cu), iron (Fe), Manganese (Mn) and Zinc (Zn) were measured by atomic absorption spectrophotometer.

According to Beaufils (1973) and Walworth and Sumner (1986), the DRIS norms selection was made along the following priorities:

- Yield and leaf nutrient concentrations built a databank, which was divided into high- (>45 t/ha) and low-yielding (<45 t/ha) subpopulations.
- Calculate the mean, standard deviation, variance and skew for each leaf nutrient concentration for the two subpopulations.
- Calculate a variance ratio (V_{low} for low-yielding sub-population/V_{high} for high-yielding sub-population) for each nutrient concentration and of two ratios involving each pair of nutrients.
- Make sure that the leaf nutrient concentration data for the high-yielding sub-population were relatively symmetrical or un-skewed, so that they provided realistic approximations of the likely range of interactive influences of different nutrients on crop productivity (Ramakrishna *et al*., 2009).
- Select nutrient ratio expressions that had relatively un-skewed distributions in the high-yielding sub-population (skewness values <1.0).
- Select nutrient expressions for which the variance ratios (V_{low}/V_{high}) were relatively large.
- Select equal numbers of expressions for each of the n elements (A, B, C, …… and X) to meet an absolute (orthogonal) requirement of the mathematical model.
- The following equations were developed for the calculation of DRIS indexes based on leaf analysis:

$$\text{X index} = \frac{f(X/A)+f(X/B)+\cdots\cdots-f(E/X)-f(F/X)-\cdots\cdots}{n-1}$$

where,

$$f(X/A) = \left(\frac{X/A}{x/a} - 1\right) \times \frac{1000}{CV} \text{ when } X/A > x/a$$

or,

$$f(X/A) = \left(1 - \frac{X/A}{x/a}\right) \times \frac{1000}{CV} \text{ when } X/A < x/a$$

where, X/A is the actual value of the ratio of X and A in the plant under diagnosis, x/a the value of the norm (the mean value of high-yielding orchards) and CV the coefficient of variation for population of high-yielding orchards.

It was considered that plants present nutritional balance for a given nutrient when the values of the indices, defined for the DRIS methods, are close to zero (Walworth and Sumner, 1987). When nutrients are in a state of imbalance, the negative DRIS index values mean that are undersupplied and positive DRIS index values mean that are oversupplied. The greater negative DRIS index values of the indices the greater the nutrient undersupply and the greater positive DRIS index values of the indices the greater the nutrient oversupply.

RESULTS

The yield of apple from the sampling apple orchards in 2007 ranged from 9.9 to 112.5 t/ha in Fig. 1. The mean productivity of the apple trees correspond end to 13.6 t/ha (SPBS, 2004, 2005, 2006) in the last three harvests in the Wei-bei Loess Plateau. It is evident that the average of yield of the sampling apple orchards used in this study (35.8 t/ha) was much superior to the overall average of the area, but the data were highly skewed in favor of very low yields. This meant that

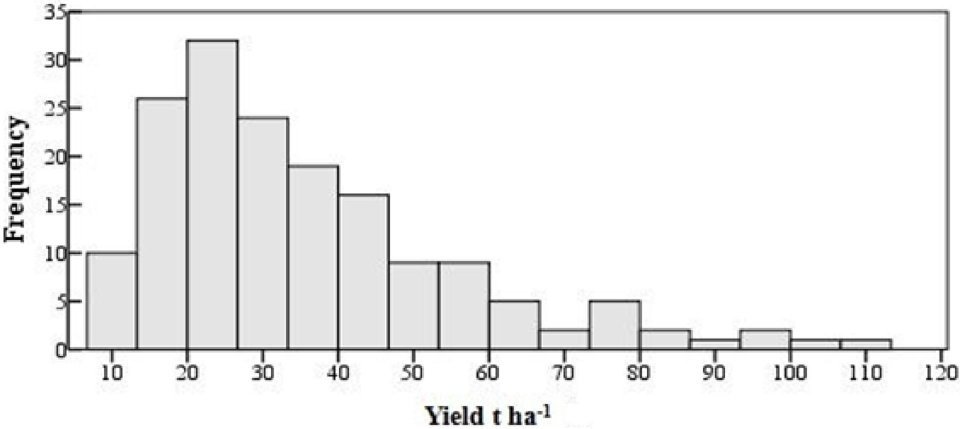

Fig. 1: Frequency distribution of the yield of apple trees (t/ha) in fruits, for the harvests of 2007 of 164 orchards in the Wei-bei loess plateau, China

Table 1: Summary statistics for apple tree yield and leaf nutrient concentration data for total yielding population (n = 164)

Nutrient	Min.	Max.	Median	Mean	C.V. (%)	S.D.	Skewness
N (g/kg)	22.20	31.90	26.87	26.99	6.71	1.81	0.26
P (g/kg)	1.32	3.40	2.35	2.38	15.22	0.36	0.06
K (g/kg)	3.44	17.69	9.48	9.79	30.94	3.03	0.36
Ca (g/kg)	5.97	40.44	13.30	13.95	35.64	4.97	1.53
Mg (g/kg)	1.29	8.15	3.54	3.66	32.63	1.19	0.94
Cu (mg/kg)	1.55	39.55	5.15	6.88	97.32	6.70	3.18
Fe (mg/kg)	96.50	441.83	202.77	211.26	29.65	62.64	1.18
Mn (mg/kg)	48.95	160.96	84.64	87.24	27.92	24.36	0.75
Zn (mg/kg)	12.01	68.47	25.11	27.95	39.11	10.93	1.35
Yield (t/ha)	9.90	112.50	30.50	35.83	56.24	20.15	1.36

C.V.: Coefficient of variation; S.D.: Standard deviation; Min.: Minimum; Max.: Maximum

Table 2: Summary statistics for apple tree yield and leaf nutrient concentration data for high-yielding (n = 36) and low-yielding (n = 127) sub-populations

	High-yielding subpopulation≥45 t/ha (n = 37)					Low-yielding subpopulation≥45 t/ha (n = 127)				
Parameter	Min.	Max.	Mean	C.V. (%)	Skewness	Min.	Max.	Mean	C.V. (%)	Skewness
N (g/kg)	24.57	31.49	27.58	6.680	0.36	22.20	31.90	26.82	6.60	0.22
P (g/kg)	1.65	3.23	2.38	15.11	0.41	1.32	3.40	2.37	15.31	-0.03
K (g/kg)	4.02	17.69	10.43	29.14	0.51	3.44	17.17	9.60	31.37	0.33
Ca (g/kg)	7.77	24.04	14.56	26.91	0.50	5.97	40.44	13.78	38.05	1.69
Mg (g/kg)	2.27	6.80	4.06	25.61	0.44	1.29	8.15	3.54	34.28	1.15
Cu (mg/kg)	2.47	20.38	6.69	66.32	1.92	1.55	39.55	6.94	104.34	3.13
Fe (mg/kg)	111.74	441.83	226.88	30.62	0.85	96.50	438.54	206.70	29.04	1.31
Mn (mg/kg)	50.63	147.89	92.28	25.99	0.83	48.95	160.96	85.77	28.40	0.77
Zn (mg/kg)	13.21	67.96	29.06	36.62	1.31	12.01	68.47	27.63	39.94	1.39
Yield (t/ha)	48.60	112.50	66.80	24.57	1.12	9.90	44.60	26.80	34.36	0.11

C.V.: Coefficient of variation; Min.: Minimum; Max.: Maximum

only 37 of the 164 data points were assigned to the high-yielding subpopulation (≥45 t/ha).

Summary statistics for the apple yield and leaf nutrient concentration data available from the total apple orchard survey are listed in Table 1. The leaf nutrient concentration for the macronutrients N, P, K, Ca and Mg for total population ranged from 22.2 to 31.9, 1.32 to 3.40, 3.44 to 17.69, 5.97 to 40.44 and 1.29 to 8.15 g/kg, respectively. The leaf nutrient concentration for the micronutrients Cu, Fe, Mn and Zn varied from 1.55 to 39.55, 96.5 to 441.83, 48.95 to 160.93 and 12.01 to 68.47 mg/kg dry weight tissue respectively. The mean leaf nutrient concentrations of N, P, K, Ca and Mg were 26.99, 2.38, 9.79, 13.95 and 3.66 g/kg, respectively. The mean leaf nutrient concentrations of Cu, Fe, Mn and Zn were 6.88, 211.26, 87.24 and 27.95 mg/kg, respectively.

In order to verify differences between mean leaf concentrations from high-yielding subpopulation and low-yielding subpopulation, the minimum, the maximum, the mean leaf nutrient concentrations, coefficient of variation and skewness are shown in the Table 2. In the high-yielding subpopulation, the data for the macronutrients N, P, K, Ca and Mg were relatively symmetrical, with having skewness values less than 0.6. The data for the micronutrients, Fe, Mn and Zn were also relatively symmetrical, with having values marginally less than 1.4. Only Cu was highly skewed

Table 3: Mean, Coefficients of Variance (C.V.'s), skewness values and variances (V_{low} and V_{high}) for high and low-yielding subpopulations and the variance ratios, V_{low}/V_{high}

	High-yielding subpopulation				Low-yielding subpopulation				
Nutrient ratio	Mean	C.V. (%)	Skewness	V_{high}	Mean	C.V. (%)	Skewness	V_{low}	V_{low}/V_{high}
N/P	11.810	14.16	-0.103	2.796000	11.570	17.14	0.999	3.930000	1.406
P/N	0.087	15.10	0.804	0.000170	0.089	16.45	0.313	0.000210	1.251
N/K	2.886	32.12	1.310	0.859000	3.123	38.36	1.653	1.435000	1.671
K/N	0.380	29.78	0.597	0.013000	0.359	31.61	0.278	0.013000	1.008
N/Fe	0.133	31.56	0.843	0.001800	0.140	28.12	0.919	0.001500	0.873
Fe/N	8.286	32.93	1.278	7.446000	7.725	28.74	1.132	4.929000	0.662
N/Mn	0.319	25.63	0.035	0.006700	0.338	28.15	0.382	0.009000	1.353
Mn/N	3.377	28.73	0.885	0.941000	3.215	29.74	0.828	0.914000	0.971
N/Zn	1.066	35.11	1.026	0.140000	1.103	34.24	0.514	0.143000	1.018
Zn/N	1.053	35.28	0.977	0.138000	1.034	40.53	1.437	0.176000	1.273
N/Ca	2.036	28.76	0.968	0.343000	2.207	36.13	0.662	0.636000	1.854
Ca/N	0.530	27.50	0.563	0.021000	0.518	39.64	1.704	0.042000	1.980
N/Mg	7.214	25.21	0.678	3.309000	8.458	36.02	1.358	9.280000	2.805
Mg/N	0.147	24.15	0.307	0.001300	0.133	35.42	1.270	0.002200	1.751
P/K	0.245	30.09	1.719	0.005400	0.273	37.43	1.783	0.010000	1.922
K/P	4.400	26.52	0.528	1.362000	4.101	32.72	0.582	1.801000	1.323
P/Fe	0.011	30.97	0.198	0.000013	0.012	29.91	0.825	0.000014	1.083
Fe/P	97.600	36.23	1.202	1250.190000	88.950	32.95	1.442	859.190000	0.687
P/Mn	0.028	30.84	0.793	0.000072	0.030	30.76	0.799	0.000084	1.157
Mn/P	39.880	32.65	1.216	169.590000	36.860	31.30	0.891	133.120000	0.785
P/Zn	0.092	34.90	0.577	0.001000	0.097	36.00	0.597	0.001200	1.197
Zn/P	12.410	39.05	1.630	23.494000	11.860	42.44	1.647	25.340000	1.079
P/Ca	0.174	26.70	0.680	0.002100	0.191	32.39	0.786	0.003800	1.779
Ca/P	6.175	26.23	0.454	2.623000	5.821	34.54	1.339	4.042000	1.541
P/Mg	0.622	27.74	0.479	0.030000	0.749	37.06	0.833	0.077000	2.580
Mg/P	1.738	28.99	0.864	0.254000	1.539	41.84	1.893	0.415000	1.634
K/Fe	0.051	46.90	1.582	0.000560	0.051	48.72	1.181	0.000630	1.116
Fe/K	23.570	39.83	0.784	88.130000	24.870	58.90	2.396	214.610000	2.435
K/Mn	0.123	47.37	1.674	0.003400	0.121	42.24	0.762	0.002600	0.771
Mn/K	9.723	40.08	0.850	15.190000	9.972	46.52	1.324	21.520000	1.417
K/Zn	0.392	37.02	0.989	0.021000	0.395	48.73	1.370	0.037000	1.762
Zn/K	2.956	43.03	1.772	1.617000	3.187	51.37	1.287	2.680000	1.657
K/Ca	0.757	34.38	0.495	0.068000	0.763	40.80	0.918	0.097000	1.430
Ca/K	1.508	40.06	1.296	0.365000	1.543	41.73	0.887	0.414000	1.136
K/Mg	2.785	44.22	1.264	1.517000	2.975	42.05	0.726	1.565000	1.032
Mg/K	0.432	45.47	1.240	0.039000	0.407	47.69	1.243	0.038000	0.974
Fe/Mn	2.581	34.18	0.365	0.778000	2.601	40.56	0.980	1.113000	1.430
Mn/Fe	0.442	39.74	1.377	0.031000	0.446	37.87	0.575	0.029000	0.926
Fe/Zn	8.852	49.04	1.421	18.840000	8.487	43.51	0.612	13.630000	0.724
Zn/Fe	0.141	52.99	2.228	0.005600	0.143	46.15	0.955	0.004400	0.780
Fe/Ca	16.850	45.08	1.518	57.690000	17.130	50.37	1.718	74.480000	1.291
Ca/Fe	0.070	38.69	0.450	0.000740	0.072	49.87	1.919	0.001300	1.769
Fe/Mg	58.880	42.46	2.948	625.100000	65.560	48.50	2.086	1010.960000	1.617
Mg/Fe	0.019	33.43	0.956	0.000041	0.019	49.20	1.797	0.000084	2.052
Mn/Zn	3.491	36.22	0.661	1.599000	3.392	33.28	0.388	1.274000	0.797
Zn/Mn	0.327	37.12	0.863	0.015000	0.334	39.60	1.497	0.018000	1.191
Mn/Ca	6.859	38.57	0.874	6.999000	6.957	43.09	1.260	8.985000	1.284
Ca/Mn	0.170	41.68	1.204	0.005000	0.172	45.92	1.626	0.006200	1.238
Mn/Mg	24.460	41.59	1.381	103.490000	27.450	51.46	1.622	199.500000	1.928
Mg/Mn	0.047	33.59	0.219	0.000250	0.045	44.17	0.874	0.000390	1.588
Zn/Ca	2.153	53.10	2.584	1.307000	2.201	45.29	0.929	0.994000	0.760
Ca/Zn	0.559	40.10	1.044	0.050000	0.554	47.22	1.393	0.069000	1.365
Zn/Mg	7.659	46.84	1.831	12.870000	8.725	53.77	1.390	22.010000	1.710
Mg/Zn	0.159	48.12	1.797	0.005800	0.146	48.87	0.997	0.005100	0.875
Ca/Mg	3.716	28.39	0.542	1.113000	4.046	32.07	1.061	1.684000	1.513
Mg/Ca	0.291	27.29	0.262	0.006300	0.271	30.33	0.552	0.006800	1.075

C.V.: Coefficient of variation

with skewness values greater than 2.0 in the low-yielding subpopulation and skewness values nearly 2.0 in the high-yielding subpopulation. This mean Cu was deemed unsuitable for DRIS model development. Then Mean Coefficients of Variance (C.V.'s), skewness values and variances (V_{low} and V_{high}) for high and low-yielding subpopulations and the variance ratios, V_{low}/V_{high} were calculated in Table 3.

There were four priorities for nutrient ratio expression selection. The first was to ensure (by visual

Table 4: DRIS norms, mean values, Coefficient of Variation (C.V.'s) and variance ratios (V_{low}/V_{high}) for selected nutrient ratio expressions in apple

Nutrient ratio	Mean	C.V. (%)	V_{low}/V_{high}
N/P	11.810	14.16	1.406
N/Fe	0.133	31.56	0.873
Zn/N	1.053	35.28	1.273
N/Mg	7.214	25.21	2.805
P/Zn	0.092	34.90	1.197
P/Ca	0.174	26.70	1.779
P/Mg	0.622	27.74	2.580
Fe/K	23.570	39.83	2.435
Mn/K	9.723	40.08	1.417
K/Zn	0.392	37.02	1.762
K/Ca	0.757	34.38	1.430
Fe/Mn	2.581	34.18	1.430
Mg/Fe	0.019	33.43	2.052
Zn/Mn	0.327	37.12	1.191
Mn/Ca	6.859	38.57	1.284
Ca/Mg	3.716	28.39	1.513

C.V.: Coefficient of variation

assessment) that norms were based on Gaussian distributions of yield versus nutrient expression values, otherwise calculated means (norms) for nutrient expressions might differ from the true values at maximum crop yield (Walworth and Sumner, 1986); The second was to ensure that the skewness values in the high-yielding subpopulation were less than 1.0. The third was to select nutrient ratio expressions which the variance ratios (V_{low}/V_{high}) were relatively large, thereby maximizing the potential for such expressions to differentiate between healthy and unhealthy plants (Walworth and Sumner, 1987). The forth was to select equal numbers of expressions for each of the eight elements (N, P, K, Ca, Mg, Fe, Mn and Zn) to meet an absolute (orthogonal) requirement of the mathematical model.

The mean values (norms) for the chosen ratios (for the high-yielding population) and their associated CVs were adopted as the DRIS (diagnostic) parameters for apple and are showed in Table 4. The selected nutrient ratio expressions were duly in compliance with the four priorities for nutrient ratio expression selection. A total of 16 nutrient ratio expressions, four for each nutrient (N, P, K, Ca, Mg, Fe, Mn and Zn), were finally selected. Some expressions with high variance ratios were omitted, because five suitable nutrient ratio expressions could not be identified for each nutrient, so four were selected instead.

CONCLUSION

In this study, the leaf nutrient concentration in the high-yielding subpopulation had relatively symmetrical distribution, so that they provided realistic approximations of the likely range of interactive influences of different nutrients on crop productivity (Ramakrishna *et al*., 2009). Additionally, the selected nutrient ratios had relatively large variance ratios (V_{low}/V_{high}) and, therefore, these nutrient ratios got the maximum potential to differentiate between "healthy" and "unhealthy" plants (Walworth and Sumner, 1987). The selected nutrient ratios also had small C.V.'s in keeping with their diagnostic importance (Walworth and Sumner, 1986). These were given credibility both to the database and to the DRIS model. The useful parameters in DRIS diagnosis selected on apple nutrition based on different researchers were showed in Table 5 (Parent and Granger, 1989; Zhu *et al*., 1990; Goh and Malakouti, 1992; Jiang Yuanmao and Shu, 1995). Most of the selected ratios as DRIS norms in this study are significantly like to the norms provided for these researches (Table 5). So the DRIS model for apple, developed in this study, is a diagnostic tool that may be used to predict if insufficiencies or imbalances in N, P, K Ca, Mg, Fe, Mn and Zn supplies are occurring in apple production area in the Wei-bei Loess Plateau, China.

However, the calculation procedures for the norms and DRIS indexes are still in developing stage. Most research results have indicated that the more specific is the database for DRIS norms derivation, the more effective the method application is. The criteria for the reference subpopulation definition also demand further studies. There are several ways to select the reference population, but there is no common and standard. Further investigation and field experiments are necessary, to enlarge the model database and allow the refinement of DRIS parameters. As it stands, though, this preliminary DRIS model for apple is one of the best diagnostic tools currently available for simultaneously evaluating the N, P, K Ca, Mg, Fe, Mn and Zn statuses of apple in the Wei-bei Loess Plateau, China and indeed elsewhere in the other apple production areas with similar climatic and soil conditions.

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Table 5: The useful parameters in DRIS diagnosis selected on apple nutrition based on different researchers

Researchers	DRIS norms
Goh and Malakouti (1992)	N/P, N/K, N/Ca, N/Mg, P/K, P/Ca, P/Mg, K/Ca, K/Mg, Ca/Mg
Parent and Granger (1989)	N/P, K/N, N/Ca, N/Mg, K/P, P/Ca, P/Mg+, K/Ca, K/Mg, Ca/Mg
Zhu *et al*. (1990)	N/P, N/K, N/Ca, N/Mg, N/Mn, N/Zn, N/Cu, N/Fe, K/P, Ca/P, P/Mn, P/Zn, P/Cu, P/Fe, Ca/K, Mg/K, K/Mn, Zn/K, K/Cu, Fe/K, Mg/Ca, Mn/Ca, Zn/Ca, Cu/Ca, Fe/Ca, Mn/Mg, Zn/Mg, Mg/Cu, Fe/Mg, Mn/Cu, Zn/Mn, Fe/Mn, Zn/Cu, Zn/Fe, Fe/Cu
Jiang Yuanmao and Shu (1995)	N/P, K/N, N/Ca, N/Mg, N/B, N/Zn, N/Fe, Mn/N, K/P, P/Ca, P/Mg, P/B, P/Zn, P/Fe, Mn/P, K/Ca, K/Mg, K/B, K/Zn, K/Fe, K/Mn, Ca/Mg, Ca/B, Zn/Ca, Ca/Fe, Mn/Ca, B/Mg, Zn/Mg, Fe/Mg, Zn/B, Fe/B, Mn/B, Zn/Fe, Mn/Zn, Mn/Fe

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REFERENCES

Appa Rao, V.V., S. Singh, B.D. Sharma *et al*., 2006. DRIS norms for sapota (*Manilkara achras* M.) in western plains of India. Indian J. Hortic., 63(2): 145-147.

Awasthi, R.P., S.K. Sharma and V.P. Bhutani, 2000. Diagnosis and Recommendation Integrated System (DRIS) norms for peach (*Prunus persica* L.) CV. Indian J. Hortic., 57(4): 277-280.

Bailey, J.S., J.A.M. Beattie and D.J. Kilpatrick, 1997a. The Diagnosis and Recommendation Integrated System (DRIS) for diagnosing the nutrient status of grassland swards: I. Model establishment. Plant Soil, 197: 127-135.

Bailey, J.S., A. Cushnahan and J.A.M. Beattie, 1997b. The Diagnosis and Recommendation Integrated System (DRIS) for diagnosing the nutrient status of grassland swards: II. Model calibration and validation. Plant Soil, 197: 137-147.

Beaufils, E.R., 1956. Mineral equilibrium in the foliage and latex of *Hevea brasiliensis*. Ann. Agron., 2: 205-218.

Beaufils, E.R., 1973. Diagnosis and Recommendation Integrated System (DRIS). A General Scheme for Experimentation and Calibration Based on Principles Developed from Research in Plant Nutrition. Soil Sci. Bulletin No. 1, University of Natal, Pietermaritzburg, S. Africa.

Beverly, R.B., 1987. Modified DRIS method for simplified nutrient diagnosis of ‘valencia’ oranges. J. Plant Nutr., 10: 1401-1408.

Beverly, R.B. and R.E. Worley, 1992. Preliminary DRIS diagnostic norms for Pecan. HortScience, 27: 217-272.

Caldwell, J.O., M.E. Sumner and C.S. Vavrina, 1994. Development and testing of preliminary foliar DRIS norms for onions. HortScience, 29: 1501-1504.

Caron, J. and L.E. Parent, 1989. Derivation and assessment of DRIS norms for greenhouse tomatoes. Can. J. Plant Sci., 69: 1027-1035.

Chapman, H.D. and P.F. Pratt, 1961. Methods of Analysis for Soils, Plants and Waters. University of California, Division of Agricultural Science, Berkeley, CA.

FAO, 2010. FAOSTAT. Retrieved from: http://faostat3.fao.org/home/index.html (Accessed on: November 30, 2012).

Gangli, L.R., X.S. Su and W. Jinsui, 1985. Studies on the standard sample of fruit leaf samples. J. Acta Hortic. Sinca, 12: 217-223.

Goh, K.M. and M.J. Malakouti, 1992. Preliminary nitrogen, phosphorus, potassium, calcium and magnesium DRIS norms and indexes for apple orchards in Canterbury, New Zealand. Commun. Soil Sci. Plan., 23: 1371-1385.

Hartz, T.K., E.M. Miyao and J.G. Valencia, 1998. DRIS evaluation of the nutritional status of processing tomato. HortScience, 33: 830-832.

Jiang Yuanmao, G. and H. Shu, 1995. Nutrient diagnosis of 'starking delicious' apple. Acta Hortic. Sinica, 22(3): 215-220.

Mackay, D.C., J.M. Carefoot and T. Entz, 1987. Evaluation of the DRIS procedure for assessing the nutritional status of potato (*Solanum tuberosum* L.). Commun. Soil Sci. Plan., 18: 1331-1353.

Malavolta, E., S.A. Oliveika and G.C. Vitti, 1993. The use of Diagnosis Recommendation Integrated System (DRIS) to evaluate the nutritional status of healthy and blight affected citrus trees. In: Fragoso, M.A.C. and M.L. van Beusichem (Eds.), Proceeding of the 8th International Colloquium on Optimization of Plant Nutrition. Kluwer Academic Publishers, Dordrecht, Netherlands, pp: 157-159.

Mayfield, J.L., E.H. Simonne, C.C. Mitchell, J.L. Sibley, R.T. Boozer and E.L. Vinson III, 2002. Effect of current fertilization practices on the foliar nutrition status of double-cropped tomato and cucumber produced with plasticulture. J. Plant Nutr., 25(1): 1-15.

Meldal-Johnson, A. and M.E. Sumner, 1980. Foliar diagnostic norms for potatoes. J. Plant Nutr., 2: 569-576.

Parent, L.E. and R.L. Granger, 1989. Derivation of DRIS norms from a high-density apple orchard established in the Quebec Appalachian Mountains [J]. J. Am. Soc. Hortic. Sci., 114(6): 915-919.

Parent, L.E., A.N. Cambouris and A. Muhawenimama, 1994. Multivariate diagnosis of nutrient imbalance in potato crop. Soil Sci. Soc. Am. J., 58: 1432-1438.

Raghupathi, H.B. and B.S. Bhargava, 1999. Preliminary nutrient norms for ‘Alphonso’ mango using diagnosis and recommendation integrated system. Indian J. Agr. Sci., 69: 648-650.

Raj, G.B. and A.P. Rao, 2006. Identification of yield-limiting nutrients in mango through DRIS indices. Commun. Soil Sci. Plan., 37(11): 1761-1774.

Ramakrishna, A., J.S. Bailey and G. Kirchhof, 2009. A preliminary Diagnosis and Recommendation Integrated System (DRIS) model for diagnosing the nutrient status of sweet potato (*Ipomoea batatas*). Plant Soil, 316: 107-116.

Sanchez, C.A., G.H. Snyder and H.W. Burdine, 1991. DRIS evaluation of the nutritional status of crisphead lettuce. HortScience, 26: 274-276.

Sanz, M., 1999. Evaluation of interpretation of DRIS system during growing season of the peach tree: Comparison with DOP method. Commnn. Soil. Sci. Plan., 30: 1025-1036.

Schaffer, B., K.D. Larson, G.H. Snyder and C.A. Sanchez, 1988. Identification of mineral deficiencies associated with mango decline by DRIS. HortScience, 23: 617-619.

Singh, V.K. and H.P. Agrawal, 2007. Development of DRIS norms for evaluating nitrogen, phosphorus, potassium and sulphur requirements of rice crop. J. Indian Soc. Soil Sci., 55(3): 294-303.

Singh, N.P., R.P. Awasthi and A. Sud, 2000. Diagnosis and Recommendation Integrated System (DRIS) norms for apple (Malus × *Domestica borkh*. L. CV. starking delicious) in Himachal Pradesh. Indian J. Hortic., 57(3): 196-204.

Soltanpour, P.N., M.J. Malakouti and A. Ronaghi, 1995. Comparison of diagnosis and recommendation integrated system and nutrient sufficient range of corn. Soil Sci. Soc. Am. J., 59: 133-139.

SPBS (Shaanxi Provence Bureau of Statistic), 2004. Statistical Communique of the Fruit Development in Shaanxi Province in 2004. Retrieved from: http://www.stats.gov.cn/tjgb/qttjgb/dfqttjgb/t20050323_402309004.htm (Accessed on: November 30, 2012).

SPBS (Shaanxi Provence Bureau of Statistic), 2005. Statistical Communique of the Fruit Development in Shaanxi Province in 2005. Retrieved from: http://www.stats.gov.cn/tjgb/qttjgb/dfqttjgb/t20060306_402309003.htm (Accessed on: November 30, 2012).

SPBS (Shaanxi Provence Bureau of Statistic), 2006. Statistical Communique of the fruit Development in Shaanxi Province in 2006. Retrieved from: http://shaanxi.mofcom.gov.cn/aarticle/sjgongzuody/200703/20070304490354.html (Accessed on: November 30, 2012).

SPBS (Shaanxi Provence Bureau of Statistic), 2010. Statistical Communique of fruit in Shaanxi Province. Retrieved from: http://www.sn.stats.gov.cn/news/qsgb/201132390305.htm (Accessed on: November 30, 2012).

Srivastava, A.K. and S. Shyam, 2008. DRIS norms and their field validation in Nagpur mandarin. J. Plant Nutr., 31(6): 1091-1107.

Teixeira, L.A.J., J.A. Quaggio and F.C.B. Zambrosi, 2009. Preliminary DRIS norms for ‘Smooth Cayenne’ pineapple and derivation of critical levels of leaf nutrient concentrations. Acta Hortic., 822: 131-138.

Walworth, J.L. and M.E. Sumner, 1986. Foliar diagnosis: A review. Adv. Plant Nutr., 3: 193-241.

Walworth, J.L. and M.E. Sumner, 1987. The Diagnosis and Recommendation Integrated System (DRIS). Adv. Soil Sci., 6: 149-188.

Zhu, W., Z. Duan and X. Xue, 1990. Apple tree nutrition diagnosis and correction technology research. Proceeding of the China Horticultural Society 60th Anniversary of the Founding and 6th Annual Meeting Proceedings I Fruit Trees. Wanguo Academic Press, Beijing, pp: 42-46.