Research Article
Nutritional Diagnosis for Apple by DRIS, CND and DOP

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Abstract: This study derived and compared norms for apple, using the Diagnosis and Recommendation Integrated System (DRIS), Compositional Nutrient Diagnosis (CND) and deviation form optimum percentage (DOP) diagnose methods in the Wei Bei Loess Plateau, Shaanxi Province, China. A total of 68 leaf samples were collected from apple trees grown in Huashan soils. The nutritional status was diagnosed by the DRIS, CND and DOP methods. The CND norms expressed as row-centered log ratios (mean±standard deviation) for d = 5 nutrients for the high-yield subpopulation (producing more than 46.67 t/ha) were: VN = 0.998±0.066, VP = -1.499±0.124,VK = -0.189±0.283, VCa = 0.217±0.213, VMg = -1.035±0.267, VR5 = 1.508±0.144. The optimum ranges for leaf nutrient concentrations were: N = 27.23±1.79 g/kg, P = 2.26±0.32 g/kg, K = 8.63±2.50 g/kg, Ca = 12.73±2.66 g/kg, Mg = 3.71±1.12 g/kg, R5 = 45.44±3.95 g/kg. The regression relating CND to DRIS and DOP indices were significant linear. There was a multinomial regression equation between CND r2 and DRIS NBI, also between CND r2 and ∑DOP. This study showed that the differences in CND, DRIS and DOP approaches did not lead to large differences in identified deficiencies. So, CND may in practice still be the preferred approach since multivariate methods could be further explored to assess nutrient status in plants, but people can choose any approach they want use since they had the similar evaluation result.

Keywords: Apple, CND, DOP, DRIS, leaf diagnosis, weibei loess plateau

INTRODUCTION

China apple production and export volume rank the first in the world (FAO, 2010). Almost 4.7 million hectares 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 (Shaanxi Provence Bureau of Statistic), 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 correlation between soil and plant nutrient status is often poor (Hanson, 1987), so the foliar analysis has frequently been used to be an important tool to monitor the nutrient status of plants. There were several approaches can be used to diagnose foliar nutrient status, i.e., Critical Value Approach (CVA) (Bates, 1971), Diagnosis and Recommendation Integrated System (DRIS) (Beaufils, 1973), Compositional Nutrient Diagnosis (CND) (Parent and Dafir, 1992), Deviation form Optimum Percentage (DOP) (Montañésa, 1993).

The DRIS is a bivariate diagnosis method; and the CND expands the DRIS concept from a bivariate to a multivariable method. DRIS is based on dual ratios of nutrients, while CND is based on row-centered log ratios. Both DRIS and CND take nutrient interactions into consideration. Different from DRIS and CND, the DOP is a unary analysis method which quantifies the difference between a single nutrient concentration and its reference value using a percentage expression (Montañésa et al., 1993).

The Diagnosis and Recommendation Integrated System (DRIS) firstly developed for Hevea brasiliensis by Beaufils (1956, 1973). Many researchers considered DRIS was claimed to have certain advantages over other conventional interpretation tools (Beverly, 1987; Malavolta et al., 1993; Srivastava and Singh, 2008). DRIS norms have been used successfully to interpret the results of leaf analyses for both annual crops and perennial crops, such as tomato (Caron and Parent, 1989; Hartz et al., 1998; Mayfield et al., 2002), apple (Goh and Malakouti, 1992; Singh et al., 2000) and mango (Schaffer et al., 1988; Raghupathi and Bhargava, 1999; Raj and Rao, 2006). The CND has been developed for Potato (Parent et al., 1994; Khiari et al., 2001b), banana (Raghupathi et al., 2002) and curcuma longa (Kumar et al., 2003). However, the
The objective of this study was to derive and compare DRIS, CND and DOP Norms for apple, in the Wei-bei Loess Plateau of the northwestern China.

**METHODS AND MATERIALS**

**Experimental data:** The research was carried out in the Wei-bei Loess Plateau which is one of the main apple producing areas in China. The Wei-bei Loess 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 170 D.

According to fruit leaf sample standard in China (Gangli et al., 1987), the collection of leaves was accomplished between July and August. Each orchard 25 plants were random selected for their uniformity. A total of 68 leaf samples were collected from apple trees grown in Huangshan soils.

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) and magnesium (Mg) were measured by atomic absorption spectrophotometer.

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

- Yield and leaf nutrient concentrations built a databank, which is divided into high- (>45 t/ha) and low-yielding (<45 t/ha) subpopulations
- Calculate the mean, standard deviation and variance 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
- Select nutrient expressions for which the variance ratios (V\_low/V\_high) are 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 are developed for the calculation of DRIS indexes based on leaf analysis:

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

where,

\[
f(X/A) = \left(\frac{X/A}{x/a} - 1\right) \times \frac{1000}{cv} \quad \text{when } X/A > x/a
\]

Or,

\[
f(X/A) = \left(1 - \frac{X/A}{x/a}\right) \times \frac{1000}{cv} \quad \text{when } X/A < x/a
\]

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 this ratio for a high-yielding orchards) and CV the coefficient of variation of this ratio 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, 1986). 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. The absolute sum values of the nutrient indices generate an additional index called Nutritional Balance Index (NBI). The greater the NBI values the greater the nutrient imbalance:

\[
NBI = |A \text{ index}| + |B \text{ index}| + |C \text{ index}| + \cdots + |X \text{ index}|
\]

According to Khiari et al. (2001a), Compositional Nutrient Diagnosis (CND) method was developed by the following equations. Plant tissue composition forms a d-dimensional nutrient arrangement; i.e., simplex (S\(d\)) made of \(d+1\) nutrient proportions including \(d\) nutrients and a filling value (\(R_{d}\)) defined as (Parent and Dafir, 1992):

\[
S^d = \left[\begin{array}{c} N > 0, P > 0, K > 0, \ldots, R_d > 0, \\ N + P + K + \cdots + R_d = 100 \end{array}\right]
\]

where,

\[100 = \text{The dry matter concentration (\%)}\]

\[N, P, K, \ldots = \text{Nutrient proportions (\%)}\]

\[R_d = \text{The filling value computed as}\]

\[R_d = 100 - (N + P + K + \cdots) \ldots \]

A Geometric mean (G) is computed as:

\[
G = \left(\frac{1}{d+1} \right) \left(\frac{N \times P \times K \times \cdots \times R_d}{d+1}\right)
\]

Row-centered log ratio is computed as:
where, \( V_x \) is the CND row-centered log ratio expression for nutrient \( X \).

The observations are sequenced in a decreasing yield order, after the observations are divided into two subpopulations using the Cate-Nelson procedure (Khiari et al., 2001a). In the first partition, the two highest yield values constitute one group (c) and the remainder of the yield values constitute another group (group Low); thereafter, the three highest yield values constitute group High and the remainder of the yield values constitute the group Low. This process is repeated until the two lowest yield values constitute group Low and the remainder of the yield values constitute group High. Each iteration, the numbers of observations were \( n_1 \) and \( n_2 \) for the group High and group Low (\( n_1+n_2 = n \), \( n \) is the number of whole observations). For the two subpopulations obtained in iteration, the variances of the row-centered log ratios were computed. The variance ratio of component \( X \) was then computed as:

\[
\text{Variance ratio of component } X = \frac{\text{Variance of } V_x, n_1 \text{ observations}}{\text{Variance of } V_x, n_2 \text{ observations}}
\]

where, \( f_i(V_x) \) is the ratio function between two subpopulations for nutrient \( X \) at the \( i \)th iteration; \( V_x \) is the CND row-centered log ratio expression for nutrient \( X \). The cumulative variance ratio function, which is the sum of the variance ratios at the \( i \)th iteration from the top, is computed as follows:

\[
F_i^c(V_x) = \frac{\sum_{i=1}^{n_1-1} f_i(V_x)}{\sum_{i=1}^{n_2} f_i(V_x)} \times 100
\]

The relationship between the cumulative function and yield (Y) is showed as:

\[
F_i^c(V_x) = aY^3 + bY^2 + cY + h
\]

The inflection point is obtained by equating the second derivative of Eq. (12) to zero. Therefore, the yield cutoff value is \(-\frac{b}{3a}\). CND norms are computed using means and standard deviations corresponding to the row-centered log ratios \( V_x \) of \( d \) nutrients for high-yield subpopulation, that is, \( V_x^* \) and \( SD_x^* \). The CND indices, denoted as \( I_x \), are calculated as:

\[
I_x = \frac{V_x - V_x^*}{SD_x^*}
\]

The nutrient imbalance index of a diagnosed specimen, namely CND \( r^2 \), is calculated as:

\[
r^2 = I_i^2 + I_j^2 + I_k^2 + \ldots + I_d^2
\]

Deviation from Optimum Percentage (DOP) (Montañés et al., 1993) index is defined as the percentage deviation of the concentration of an element with respect to the optimum content taken as the reference value. The DOP index is calculated as:

\[
\text{DOP} = \left[ \frac{C}{C_{ref}} \right] - 100
\]

where, \( C \) is the concentration of a given nutrient; and \( C_{ref} \) is the optimal nutrient concentration. Like the DRIS index, the DOP index can be positive, zero, or negative, the negative DOP index values mean that are undersupplied and positive DOP index values mean that are oversupplied. The sum of the absolute values of the DOP indexes (\( \Sigma \text{DOP} \)) is just like the NBI. If the sample is near to an adequate nutritional status, the \( \Sigma \text{DOP} \) will be near zero (Montañes et al., 1993).

RESULTS

The \( S^3 \), i.e., six-dimensional (\( d+1 \)) apple simplex comprised the five nutrients N, P, K, Ca and Mg and the filling value \( R_5 \). \( R_5 \) values were calculated by Eq. (6). Summary statistics for the apple yield and leaf nutrient concentration data available from the apple orchard survey are listed in Table 1. The leaf nutrient concentration for N, P, K, Ca, Mg and \( R_5 \) ranged from 23.28 to 31.49, 1.65 to 3.40, 4.08 to 16.62, 6.71 to 40.44, 1.78 to 8.15 and 11.56 to 59.18 g/kg, respectively. The mean leaf nutrient concentrations of N, P, K, Ca, Mg and \( R_5 \) were 26.59, 2.41, 9.34, 14.25, 3.78 and 43.62 g/kg, respectively. Yield ranged from 9.9 to 100.4 t/ha and mean was 37.07 t/ha.

CND row-centered log ratios \( V_N, V_P, V_K, V_Ca, V_Mg \) and \( V_R5 \) were compute using Eq. (7-9). The cumulative variance ratio function was estimated by Eq. (10) and Eq. (11). According to Eq. (12), the relationship between the cumulative function and apple yield (Y)
Table 2: Relationship between the cumulative variance function \( F_i^c(V_i) \) and apple yield in S5 and yield at point of inflection

| \( V_N \) | \( y = -0.0002x^4 + 0.0419x^3 - 3.4116x + 95.865 \) | 0.9976 | 69.83 |
| \( V_P \) | \( y = 0.0002x^4 - 0.028x^3 + 0.3305x^2 + 99.879 \) | 0.9994 | 46.67 |
| \( V_K \) | \( y = -0.0002x^4 - 0.0233x^3 - 2.2483x + 101.01 \) | 0.9988 | 38.83 |
| \( V_{Ca} \) | \( y = -0.0002x^4 + 0.0309x^2 - 2.6174x + 100.33 \) | 0.9968 | 51.50 |
| \( V_{Mg} \) | \( y = 0.0001x^4 - 0.0188x^3 - 0.8626x^2 + 99.323 \) | 0.9994 | 62.67 |
| \( V_{Rs} \) | \( y = -0.0004x^4 + 0.066x^3 - 4.1116x + 93.048 \) | 0.9847 | 55.00 |

Yield at inflection point (-\( b/3a \))

- \( V_N_y = -0.0002x^3 + 0.0419x^2 - 3.4116x + 95.865 \) with \( R^2 = 0.9976 \), yield at inflection point 69.83 t/ha
- \( V_P_y = 0.0002x^3 - 0.028x^2 + 0.3305x^2 + 99.879 \) with \( R^2 = 0.9994 \), yield at inflection point 46.67 t/ha
- \( V_K_y = -0.0002x^3 - 0.0233x^2 - 2.2483x + 101.01 \) with \( R^2 = 0.9988 \), yield at inflection point 38.83 t/ha
- \( V_{Ca}_y = -0.0002x^3 + 0.0309x^2 - 2.6174x + 100.33 \) with \( R^2 = 0.9968 \), yield at inflection point 51.50 t/ha
- \( V_{Mg}_y = 0.0001x^3 - 0.0188x^2 - 0.8626x^2 + 99.323 \) with \( R^2 = 0.9994 \), yield at inflection point 62.67 t/ha
- \( V_{Rs}_y = -0.0004x^3 + 0.066x^3 - 4.1116x + 93.048 \) with \( R^2 = 0.9847 \), yield at inflection point 55.00 t/ha

Fig. 1: Relationship between CND and DRIS indices

was showed in Table 2. Yield cutoff values (inflection points at -\( b/3a \)) were 69.83 t/ha for, 46.67 for, 38.83 for, 51.50 for, 62.67 for and 55.00 for. All six relationships showed a cubic pattern (Fig. 1). The theory of the CND approach recommends that the highest yield cutoff value must be used to partition the low-yielding subpopulation from the high-yielding subpopulation. However, in apple production in China, 45 t/ha was used to divide the high-yielding subpopulation and low-yielding subpopulation. In this study, 46.67 t/ha was chosen to define the high-yielding subpopulation. This result implied that 23.5% of the population was considered as the high-yielding subpopulation (Fig. 2).

The CND norms, as means and standard deviations (\( V^*_N \) and SD\( N^*_N \)) of the CND row-centered log ratios for the high-yield subpopulation (producing more than 46.67 t/ha) were: \( V^*_N = 0.998\pm0.066 \), \( V^*_P = 0.998\pm0.0124 \), \( V^*_K = 0.998\pm0.283 \), \( V^*_Ca = 0.998\pm0.066 \), \( V^*_Mg = 0.998\pm0.0124 \), \( V^*_Rs = 0.998\pm0.283 \).
Table 3: The CND norms for \( d = 5 \) nutrients in a high-yielding subpopulation producing more than 46.67 t/ha of apple and their corresponding optimum ranges of leaf nutrient concentrations

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Mean</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>27.23</td>
<td>1.79</td>
</tr>
<tr>
<td>P</td>
<td>2.26</td>
<td>0.32</td>
</tr>
<tr>
<td>K</td>
<td>8.63</td>
<td>2.50</td>
</tr>
<tr>
<td>Ca</td>
<td>12.73</td>
<td>2.66</td>
</tr>
<tr>
<td>Mg</td>
<td>3.71</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Table 4: DRIS norms, mean values and Coefficient of Variation (CV) for selected nutrient ratio expressions in apple

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Mean</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P/N</td>
<td>0.08</td>
<td>13.57</td>
</tr>
<tr>
<td>K/N</td>
<td>0.32</td>
<td>29.18</td>
</tr>
<tr>
<td>Ca/N</td>
<td>0.47</td>
<td>22.30</td>
</tr>
<tr>
<td>Mg/N</td>
<td>0.14</td>
<td>27.71</td>
</tr>
<tr>
<td>K/P</td>
<td>3.88</td>
<td>30.86</td>
</tr>
<tr>
<td>P/Ca</td>
<td>0.19</td>
<td>24.21</td>
</tr>
<tr>
<td>P/Mg</td>
<td>0.66</td>
<td>34.13</td>
</tr>
<tr>
<td>K/Ca</td>
<td>2.60</td>
<td>48.00</td>
</tr>
<tr>
<td>K/Mg</td>
<td>3.72</td>
<td>36.56</td>
</tr>
</tbody>
</table>

The DRIS norms, as well as mean values and Coefficient of Variation (CV) were showed in Table 4. These DRIS norms were used to calculate the DRIS indices for N, P, K, Ca, Mg and R₅ Nutritional Balance Index (NBI) by Eq. (1-4). Relationship between CND and DRIS indices were showed in Fig. 1. The regression relating CND to DRIS indices for N, K, Ca and Mg were significant linear and the \( R^2 \) were 0.8839, 0.8153, 0.9615 and 0.9235, respectively. The regression relating CND to DRIS indices for P was significant linear, the \( R^2 \) was only 0.3229. There was a multinomial regression equation between CND \( r^2 \) and DRIS NBI with \( R^2 \) of 0.9102 (Fig. 3).

The Deviation form Optimum Percentage (DOP) indices were computed by Eq. (15). Relationship between CND and DOP indices were showed in Fig. 4. The regression relating CND to DOP indices for K, Ca and Mg were significant linear and the \( R^2 \) were 0.8993, 0.8885 and 0.875, respectively. The regression relating CND to DRIS indices for N and P were not significant linear, the \( R^2 \) were both less than 0.5. here was a multinomial regression equation between CND \( r^2 \) and \( \sum DOP \) with \( R^2 \) of 0.9091 (Fig. 5).

**DISCUSSION**

According to Gangli et al. (1987), the standard of apple leaf nutrient concentrations for whole China was: N 20–26 g/kg, P 1.5–2.3 g/kg, K 10–20 g/kg, Ca 10–20 g/kg and Mg 2.2–3.5 g/kg. The standard for apple leaf nutrient concentrations in Shaanxi province was N 23.1–25 kg¹, P 1.38–1.66 kg¹, K 7.3–9.8 kg¹, Ca 17.3–22.4 kg¹ and Mg 3.7–4.3 kg¹ (An, 2004). Compare with them, this research had the same optimum leaf nutrient concentrations ranges for K, Ca and Mg which were computed by CND, N and P were...
The fact that CND and DRIS norms were closely related was in line in earlier studies (Parent et al., 1993; Parent et al., 1994; Khiari et al., 2001c). In this study, the regressions relating CND to DRIS had high $R^2$ for all nutrients except P and showed similar trends (Fig. 1). The regression relating CND to DOP indices for K, Ca and Mg were significant linear and the $R^2$ were 0.8993, 0.8885 and 0.875, respectively (Fig. 4). Some orders of imbalances were showed in Table 5. Although the order differed between DRIS, CND and DOP, all methods identified the same most deficient nutrient and the least deficient nutrient. This suggests that the differences among the methods may be minimal. This is further supported by the fact that all three approaches did not seem to differ in categorizing of observations as either deficient or excess (Fig. 1 and 4).

The closeness in relationships between CND to DRIS or DOP suggests that both DRIS and DOP
methods give similar diagnosis. On the other hand, the fact that the $R^2$ relationship between DRIS and CND $r^2$ had a slightly higher adjusted $R^2$ (0.9102) compared to the relationship between CND $r^2$ and DOP (0.9091) (Fig. 3 and 5) suggests that the DRIS may be superior. Nonetheless, the DRIS is a bivariate diagnosis method; the CND is a multivariable method; both of them are more complex calculations than DOP. This study showed that the differences in CND, DRIS and DOP approaches did not lead to large differences in identified deficiencies. So, CND may in practice still be the preferred approach since multivariate methods could be further explored to assess nutrient status in plants, but people can choose any approach they want use since they had the similar evaluation result.

CONCLUSION

The CND norms expressed as row-centered log ratios (mean±standard deviation) for $d = 5$ nutrients for the high-yield subpopulation (producing more than 46.67 t/ha) were: $N = 0.998±0.066$, $P = -1.499±0.124$, $K = -0.189±0.283$, $Ca = 0.217±0.213$, $Mg = -1.035±0.267$, $\Sigma DOP = 1.508±0.144$.

The optimum ranges for leaf nutrient concentrations were: $N = 27.23±1.79$ g/kg, $P = 2.26±0.32$ g/kg, $K = 8.63±2.50$ g/kg, $Ca = 12.73±2.66$ g/kg, $Mg = 3.71±1.12$ g/kg, $R_5 = 45.44±3.95$ g/kg.

The regression relating CND to DRIS and DOP indices were significant linear. There was a multinomial regression equation between CND $r^2$ and DRIS NBI, also between CND $r^2$ and $\Sigma DOP$.

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