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DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS) NORMS FOR APPLE CV. STARKING DELICIOUS

S. K. ATTAR[1]* AND N. K. JOOLKA[2]
[1]Agriculture Experimental Station, Paria, Navsari Agricultural University, Navsari - 396 145, Gujarat
[2]Department of Pomology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Solan - 173 230
e-mail: sanjayattar@gmail.com

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***Corresponding author**

ABSTRACT

The Diagnosis and Recommendation Integrated System (DRIS) is an important tool for diagnosing the nutrient balance of the fruit trees and recommending fertilizer schedule for increasing fruit yield and fruit quality. The objectives of this study were to establish DRIS norms for apple (*Malus x Domestica* Borkh.) and to compare them with norms derived from average of published sufficiency ranges. The study covered the major apple growing belts *viz.*Jubbal-Kotkhai, Karsog, Kalpa, Kotgarh and Naggar areas of Himachal Pradesh and the orchards were selected for their high productivity and employment of excellent management techniques. The concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, copper and zinc were determined in leaf samples. The data were divided into high-yielding (>150kg/tree) and low-yielding (<150kg/tree) subpopulations and norms were computed using standard DRIS procedures. 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, Cu and Zn supplies are occurring in apple production areas in the Western Himalayas and indeed elsewhere with similar c1imatic and soil conditions.

INTRODUCTION

Apple (*Malus x Domestica* Borkh.) is an important fruit crop cultivated in temperate regions of the world with immense nutritional value and advised on daily basis in diet. In India, it is cultivated in high reaches of Himalayan region mainly in the states of Jammu and Kashmir, Himachal Pradesh, Uttaranchal and Arunachal Pradesh with 8.0 MT/ha productivity (NHB, 2014). The low productivity as compared to 15.9 MT/ha on world basis (FAO, 2015) has been ascribed mainly to the nutritional health of the plantations which is utmost concern among farmers. Traditionally, to determine the optimum fertilizer doses the most appropriate method was to apply fertilizer on the basis of soil test and crop response studies (Regar and Singh, 2014) which defied the synergistic and antagonistic effects in relative availability of different essential nutrients from soil. The foliar nutrient concentration is now considered most pertinent and reliable method to judge the well being of a tree as it represents the*in situ* condition in a holistic way andis a very powerful tool for nutritional diagnosis to assess deficiency symptoms and make fertilizer recommendations (Filho, 2004). Because of the dynamic nature of the leaf tissue composition, strongly influenced by leaf age, maturation stage, and the interactions involving nutrient absorption and translocation, the tissue diagnosis may be a practice of difficult understanding and utilization (Walworth and Sumner, 1987). Several methods for nutritional diagnosis using leaf tissue analysis have been proposed and used, including the critical value (CV), the sufficiency range approach (SRA), and the diagnosis and recommendation integrated system (DRIS).DRIS developed by Beaufils (1973), expresses the result of foliar analysis through indices, which represent in a continuous numeric scale, the effect of each nutrient in the nutritional balance of plant. DRIS is advantageous as it presents continuous scale and easy interpretation; allows nutrient classification (from the most deficient up to the most excessive); can detect cases of yield limiting due to nutrient imbalance, even when none of the nutrient is below the critical level; and finally, allows to diagnose the plant nutritional balance through an imbalance index (Baldock and Schulte, 1996). Several DRIS norms have been developed for fruit crops *viz.* 'Valencia' orange (Beverly, 1984), sweet cherries (Righetti *et al.*, 1988), grapevine (Kumar *et al.*, 2003; Sharma *et al.*, 2005), peach (Sanz *et al.*, 1999), mango (Raghupathi *et al.*, 2005; Hundal *et al.*, 2005; Bhupal Raj and Prasad Rao, 2006). In the present study, DRIS norms have been developed for apple (cv. Starking Delicious) and compared with SRA in evaluating the nutritional status of apple orchards in Himachal Pradesh.

MATERIALS AND METHODS

The present studies were undertaken in major apple growing areas of Himachal Pradesh namely Jubbal-Kotkhai, Karsog, Kalpa, Kotgarh and Naggar which contributes to more than 80% of states production. Starking Delicious, which has a characteristic conical shape with deep red blush, is the main variety grown by farmers, hence was chosen for the study. At each location, five orchards (15-20 years old) were selected and in each orchard, twenty uniform and healthy trees were observed for two years. Leaf samples were collected from middle of terminal shoots of current year growth in the periphery of tree from 15th July to 15th August as suggested by Kenworthy (1964). Leaf samples were washed in detergent followed by tap water and distilled water. Leaves were shade dried and then dried in hot air oven at 70°C for 48 hours. The dried leaves were grounded to fine powder by using mixer and stored in air tight butter paper bags for nutrient analysis in accordance with Lalithya *et al.* (2014). Micro-Kjeldahl method was followed for estimation of total nitrogen and for estimation of other elements the samples were digested in di-acid (nitric and perchloric acid in the ratio 4:1). Phosphorus was estimated by vanado-molybdophosphoric yellow colour method using spectronic 21, while potassium was estimated by flame photometric method. Calcium, magnesium, iron, manganese, copper and zinc content were determined by atomic absorption spectrophotometer ECIL model AAS 4129. The following equations were developed for the calculation of DRIS indices based on leaf analysis (Walworth and Sumner, 1987):

$$\text{Index A} = [f(A/B) + f(A/C) + f(A/D) \ldots + f(A/N)]/Z$$

$$\text{Index B} = [-f(A/B) + f(B/C) + f(B/D) \ldots + f(B/N)]/Z$$

$$\text{Index N} = [-f(A/N) - f(B/N) + f(C/N) \ldots - f(M/N)]/Z$$

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, $f(A/B) = [(1 - (a/b)/(A/B)]\ 1000/CV$.

In these equations, A/B is the tissue nutrient ratio of the plant to be diagnosed; a/b is the optimum value or norm for that given ratio; CV is the coefficient of variation associated with the norm; and Z is the number of functions in the nutrient index composition. Values for other functions, such as *f*(A/C) and *f*(A/D) were calculated in the same way, using appropriate norms and CV.

RESULTS AND DISCUSSION

Diagnosis and recommendation integrated system (DRIS) norms

Table 1: Variability of various nutrient expressions for macro[y] and micronutrients[z] in low and high yielding population of apple trees

Form ofexpression	Low yielding population (A)			High yielding population (B)			F value (V_{low}/V_{high})
	Mean	C.V. (%)	Variance (V_{low})	Mean	C.V. (%)	Variance (V_{high})	
N/P	8.073	20.22	2.665E+00	9.926	15.61	2.401E+00	1.11
P/N	0.132	21.91	8.393E-04	0.102	17.35	3.132E-04	2.68**
NxP	0.561	26.98	2.294E-02	0.452	24.57	1.233E-02	1.86**
N/K	1.097	14.12	2.398E-02	1.199	9.82	1.386E-02	1.73**
K/N	0.556	16.18	8.099E-03	0.868	11.18	9.417E-03	0.86
NxK	3.069	20.82	4.082E-01	3.761	16.82	4.002E-01	1.02
N/Ca	1.047	14.57	2.326E-02	1.301	9.98	1.686E-02	1.38**
Ca/N	0.880	11.11	9.548E-03	0.821	10.52	7.460E-03	1.28*
NxCa	2.993	15.62	2.185E-01	3.718	13.18	2.401E-01	0.91
N/Mg	5.376	18.88	1.030E+00	6.552	15.49	1.030E+00	1.00
Mg/N	0.109	18.62	4.140E-04	0.159	14.49	5.308E-04	0.78
NxMg	0.856	28.49	5.946E-02	0.701	24.12	2.859E-02	2.08**
N/Fe	0.007	40.35	7.574E-06	0.007	37.15	6.763E-06	1.12
Fe/N	115.217	42.82	2.434E+03	145.940	40.12	3.428E+03	0.71
NxFe	525.611	23.01	1.463E+04	640.784	20.12	1.662E+04	0.88
N/Mn	0.020	39.15	6.280E-05	0.018	34.59	3.877E-05	1.62**
Mn/N	63.736	32.82	4.376E+02	64.123	27.28	3.060E+02	1.43*.
NxMn	311.013	33.15	1.063E+04	288.269	30.12	7.539E+03	1.41**
N/Cu	0.309	28.12	7.563E-03	0.216	30.61	4.372E-03	1.73*
Cu/N	5.623	29.41	2.735E+00	4.912	34.01	2.791E+00	0.98
NxCu	29.423	35.81	1.110E+02	21.989	38.12	7.026E+01	1.58**
N/Zn	0.072	20.89	2.233E-04	0.045	19.14	7.418E-05	3.01**
Zn/N	18.173	25.42	2.134E+01	24.788	20.58	2.602E+01	0.82
NxZn	135.801	21.37	8.422E+02	108.883	24.23	6.960E+02	1.21
P/K	0.154	25.38	1.526E-03	0.129	21.52	7.707E-04	1.98**
K/P	9.294	22.49	4.369E+00	8.489	18.56	2.482E+00	1.76**
PxK	0.517	20.58	1.131E-02	0.401	24.52	9.668E-03	1.17
P/Ca	0.100	26.52	7.066E-04	0.129	22.22	8.216E-04	0.86
Ca/P	5.831	22.56	1.730E+00	8.198	17.72	2.110E+00	0.82
PxCa	0.328	18.41	3.654E-03	0.377	16.28	3.767E-03	0.97
P/Mg	0.342	32.31	1.220E-02	0.659	25.86	2.904E-02	0.42
Mg/P	1.569	20.39	1.024E-01	1.543	18.12	7.817E-02	1.31*
PxMg	0.057	30.51	3.047E-04	0.070	26.14	3.348E-04	0.91
P/Fe	0.001	25.23	2.511E-08	0.001	20.01	1.962E-08	1.28*
Fe/P	1391.033	19.11	7.066E+04	1428.329	16.58	5.608E+04	1.26*
PxFe	66.004	31.19	4.238E+02	64.811	29.62	3.685E+02	1.15
P/Mn	0.004	36.21	1.745E-06	0.002	30.73	3.777E-07	4.62**
Mn/P	777.107	38.78	9.082E+04	635.611	27.89	3.143E+04	2.89**
PxMn	27.051	46.76	1.600E+02	28.988	40.17	1.356E+02	1.18
P/Cu	0.025	35.86	7.719E-05	0.025	30.36	5.761E-05	1.34 *
Cu/P	50.600	38.89	3.872E+02	48.125	29.51	2.017E+02	1.92**

Table 1: Cont.....

Form ofexpression	Low yielding population (A)			High yielding population (B)			F value (V_{low}/V_{high})
	Mean	C.V. (%)	Variance (V_{low})	Mean	C.V. (%)	Variance (V_{high})	
PxCu	1.872	51.23	9.194E-01	2.171	50.01	1.179E-00	0.78
P/Zn	0.013	23.86	9.979E-06	0.005	20.11	1.011E-06	9.87**
Zn/P	209.143	24.46	2.617E+03	237.371	21.77	2.670E+03	0.98
PxZn	24.608	37.38	8.461E+01	10.982	34.72	1.454E+01	5.82**
K/Ca	0.816	15.67	1.635E-02	1.040	11.67	1.473E-02	1.11
Ca/K	0.894	16.72	2.232E-02	0.978	12.82	1.572E-02	1.42**
KxCa	2.664	22.12	3.473E-01	3.059	17.81	2.968E-01	1.17
K/Mg	3.348	24.82	6.904E-01	5.479	14.46	6.277E-01	1.10
Mg/K	0.183	24.21	1.971E-03	0.189	18.40	1.209E-03	1.63**
KxMg	0.517	23.25	1.446E-02	0.591	19.49	1.327E-02	1.09
K/Fe	0.005	17.13	8.388E-07	0.006	16.18	9.425E-07	0.89
Fe/K	196.963	19.22	1.433E+03	172.091	17.23	8.792E+02	1.63**
KxFe	457.976	26.28	1.449E+04	538.856	24.37	1.724E+04	0.84
K/Mn	0.020	37.2	5.563E-05	0.014	35.36	2.451E-05	2.27**
Mn/K	74.594	32.43	5.852E+02	76.120	23.82	3.288E+02	1.78**
KxMn	247.530	42.25	1.094E+04	241.071	33.57	6.549E+03	1.67**
K/Cu	0.125	37.19	2.146E-03	0.181	28.98	2.751E-03	0.78
Cu/K	6.764	40.49	7.500E+00	5.748	34.12	3.846E+00	1.95**
KxCu	18.340	45.15	6.856E+01	18.012	42.32	5.811E+01	1.18
K/Zn	0.041	22.83	8.622E-05	0.041	18.25	5.599E-05	1.54**
Zn/K	30.954	20.91	4.189E+01	29.013	19.13	3.080E+01	1.36*
KxZn	88.370	29.13	6.627E+02	89.991	24.09	4.700E+02	1.41**
Ca/Mg	1.998	25.14	2.523E-01	5.291	15.40	6.639E-01	0.38
Mg/Ca	0.151	28.18	1.813E-03	0.198	20.32	1.619E-03	1.12
CaxMg	0.416	32.32	1.808E-02	0.569	18.98	1.166E-02	1.55**
Ca/Fe	0.004	22.12	7.473E-07	0.006	14.86	7.950E-07	0.94
Fe/Ca	186.691	16.21	9.158E+02	177.722	15.11	7.211E+02	1.27*
CaxFe	332.258	28.29	8.835E+03	520.652	21.13	1.210E+04	0.73
Ca/Mn	0.016	36.31	3.349E-05	0.016	30.68	2.410E-05	1.39**
Mn/Ca	63.067	35.37	4.976E+02	78.891	25.92	4.181E+02	1.19
CaxMn	184.183	35.39	4.249E+03	232.425	30.97	5.181E+03	0.82
Ca/Cu	0.159	29.4	2.191E-03	0.173	27.33	2.235E-03	0.98
Cu/Ca	4.540	38.45	3.048E+00	5.943	29.23	3.018E+00	1.01
CaxCu	14.977	42.21	3.996E+01	17.901	36.62	4.297E+01	0.93
Ca/Zn	0.026	40.11	1.089E-04	0.037	18.89	4.885E-05	2.23**
Zn/Ca	23.473	29.82	4.899E+01	29.211	17.57	2.634E+01	1.86**
CaxZn	97.116	20.76	4.065E+02	86.987	19.45	2.863E+02	1.42**
Mg/Fe	0.001	16.85	2.014E-08	0.001	14.12	1.994E-08	1.01
Fe/Mg	649.206	17.99	1.364E+04	928.214	13.19	1.499E+04	0.91
MgxFe	73.671	33.97	6.263E+02	99.011	26.21	6.734E+02	0.93
Mg/Mn	0.002	38.82	8.836E-07	0.002	32.28	4.168E-07	2.12**
Mn/Mg	335.131	26.97	8.169E+03	412.165	24.83	1.047E+04	0.78
MgxMn	59.475	38.12	5.140E+02	44.011	36.89	2.636E+02	1.95**
Mg/Cu	0.028	35.12	9.557E-05	0.035	29.12	1.039E-04	0.92
Cu/Mg	28.812	32.41	8.720E+01	31.157	28.32	7.786E+01	1.12
MgxCu	3.174	45.82	2.115E+00	3.341	42.48	2.014E+00	1.05
Mg/Zn	0.006	17.97	1.061E-06	0.006	14.11	7.167E-07	1.48**
Zn/Mg	128.390	20.12	6.673E+02	155.415	17.82	7.670E+02	0.87
MgxZn	16.548	37.33	3.816E+01	16.787	30.35	2.596E+01	1.47**
Fe/Mn	2.086	38.85	6.568E-01	2.276	32.37	5.428E-01	1.21
Mn/Fe	0.409	31.01	1.610E-02	0.464	27.48	1.626E-02	0.99
FexMn	40926.076	35.08	2.061E+08	40498.832	34.93	2.001E+08	1.03
Fe/Cu	27.386	40.12	1.207E+02	29.987	29.43	7.788E+01	1.55**
Cu/Fe	0.044	44.18	3.750E-04	0.037	43.92	2.641E-04	1.42**
FexCu	2591.506	19.11	2.453E+05	3060.423	17.87	2.991E+05	0.82
Fe/Zn	6.815	19.47	1.761E+00	6.081	16.59	1.018E+00	1.73**
Zn/Fe	0.162	32.61	2.781E-03	0.171	31.81	2.959E-03	0.94
FexZn	15939.605	34.69	3.057E+07	15139.132	32.41	2.407E+07	1.27*
Mn/Cu	11.711	39.87	2.180E+01	13.399	36.53	2.396E+01	0.91
Cu/Mn	0.078	35.46	7.624E-04	0.081	32.65	6.994E-04	1.09
MnxCu	1152.849	55.36	4.073E+05	1361.944	50.24	4.682E+05	0.87
Mn/Zn	2.411	21.29	2.636E-01	2.712	19.32	2.745E-01	0.96
Zn/Mn	0.393	29.58	1.353E-02	0.379	26.71	1.025E-02	1.32*

Table 1: Cont.....

Form ofexpression	Low yielding population (A)			High yielding population (B)			F value (V_{low}/V_{high})
	Mean	C.V. (%)	Variance (V_{low})	Mean	C.V. (%)	Variance (V_{high})	
MnxZn	6704.045	44.66	8.964E+06	6728.172	42.82	8.300E+06	1.08
Cu/Zn	0.241	31.71	5.851E-03	0.209	26.01	2.955E-03	1.98**
Zn/Cu	4.441	35.49	2.484E+00	4.998	29.93	2.238E+00	1.11
CuxZn	469.659	52.43	6.064E+04	509.001	49.12	6.251E+04	0.97

* Significant at 5% level of significance; ** Significant at I % level of significance; y - Macronutrients are expressed in per cent on dry weight basis; z - Micronutrients are expressed in ppm on dry weight basis

Table 2: Comparison of DRIS norms developed in present study with norms calculated from the average of published sufficiency ranges

Nutrient expression	Norm value	C.V. (%)	F value	Sufficiency range	Norms from average of published sufficiency ranges
N/K	1.199	9.82	1.73**	1.0-1.8	1.30
N/Ca	1.301	9.98	1.38**	1.07-2.14	1.43
NxMg	0.701	24.12	2.08**	0.32-1.80	0.76
N/Fe	0.007	37.15	1.12	0.006-0.04	0.01
N/Mn	0.018	34.59	1.62**	0.01-0.06	0.02
N/Cu	0.216	30.61	1.73**	0.07-0.5	0.16
N/Zn	0.045	19.14	3.01 **	0.014-0.25	0.05
P/N	0.102	17.35	2.68**	0.065-0.143	0.09
P/K	0.129	21.52	1.98**	0.12-0.14	0.13
PxCa	0.377	16.28	0.97	0.07-1.04	0.34
P/Fe	0.001	20.01	1.28 *	0.001-0.003	0.001
P/Mn	0.002	30.73	4.62**	0.002-0.004	0.002
P/Zn	0.005	20.11	9.87**	0.002-0.02	0.005
K/Mn	0.014	35.36	2.27**	0.01-0.03	0.01
K/Zn	0.041	18.25	1.54 **	0.014-0.138	0.04
Ca/K	0.978	12.82	1.42**	0.87-0.90	0.91
CaxMg	0.569	18.98	1.55 **	0.155-1.664	0.52
Ca/Mn	0.016	30.68	1.39**	0.012-0.030	0.017
Ca/Zn	0.037	18.89	2.23**	0.013-0.123	0.038
Mg/P	1.543	18.12	1.31 *	1.6-2.1	1.50
Mg/K	0.189	18.40	1.63 **	0.22-0.25	0.19
Mg/Fe	0.001	14.12	1.01	0.001-0:005	0.001
Mg/Mn	0.002	32.28	2.12**	0.003-0.008	0.003
Mg/Zn	0.006	14.11	1.48**	0.003-0.03	0.01
Fe/K	172.091	17.23	1.63**	48.19-172.41	130.23
Fe/Ca	177.722	15.11	1.27*	54.05-192.31	141. 85
Fe/Mn	2.276	32.37	1.21	1.60-2.39	2.49
Fe/Cu	29.987	29.43	1.55**	12.19-13.33	15.68
Fe/Zn	6.081	16.59	1.73**	2.50-6.67	5.43
Cu/P	48.125	29.51	1.92 **	30-102	64.5
Cu/K	5.748	34.12	1.95**	3.6-14.1	8.3
Cu/Ca	5.943	29.23	1.01	4.05-15.76	9.04
Cu/Mg	31.157	28.32	1.12	14.28-64.06	43.03
Cu/Mn	0.081	32.65	1.09	0.12-0.20	0.16
Cu/Zn	0.209	26.01	1.98**	0.20-0.50	0.35
Zn/Mn	0.379	26.71	1.32*	0.24-0.96	0.45

* Significant at 5% level of significance; ** Significant at I % level of significance; y - Macronutrients are expressed in per cent on dry weight basis; z - Micronutrients are expressed in ppm on dry weight basis

were derived from population of 1000 trees by forming two populations (low (719 trees) and high (218 to 281 trees) yielding) taking 150 kg/tree yield as separating benchmark. Beverly *et al.* (1984) derived DRIS norms from field data consisting of 3161 observations for use in evaluating the N, P, K, Ca and Mg status of Valencia orange trees by dividing the population into high and low yielding sub-population, at 205kg/tree. Letzsch and Sumner (1984) observed that the data banks which are large, random and had substantial number of field observations were most suitable for norm derivation. Themean values of various nutrient expressions in the high yielding population were selected as the norms for calculation of DRIS indices. It was taken into consideration 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). Nutrient expressions that had relatively un-skewed distributions in the high-yielding sub-population (skewness values <1.0) were selected. DRIS is a bivariate approach, in which norms are developed from data bank of observations, representative of a particular cropping system, consisting of minimum tissue content and associated yields. The norms so developed are used as reference standards

Table 3: Published sufficiency ranges for diagnosing leaf nutrient status of apple

Nutrient	Optimum Range	Average	Reference
Nitrogen	2.33	2.33	Kenworthy (1961)
	2.50	2.50	Levy (1971)
	2.40-2.80	2.60	Bould (1966)
	2.25	2.25	Chapman (1966)
	2.33	2.33	Gautier (1975)
	1.70-2.50	2.10	Shear and Faust (1980)
	1.53-1.96	1.74	Yamazaki *et al.* (1977)
	2.30-2.60	2.45	Karkara (1987)
	2.46-2.62	2.54	Upadhayay and Awasthi (1993)
Phosphorus	0.23	0.23	Kenworthy (1961, 1979)
	0.14-0.30	0.22	Forshey (1963)
	0.22	0.22	Levy (1971)
	0.20-0.25	0.225	Bould (1966)
	0.22	0.22	Chapman (1966)
	0.16-0.18	0.17	Gautier (1975)
	0.10-0.40	0.25	Tukey and Dow (1979)
	0.15-0.30	0.205	Shear and Faust (1980)
	0.33	0.33	Karkara (1987)
	0.175-0.204	0.190	Upadhayay and Awasthi (1993)
Potassium	0.83-2.31	1.57	Batjer and Degman (1940)
	1.70-2.90	2.30	Edgerton (1948)
	1.60	1.60	Levy (1971)
	1.53	1.53	Kenworthy (1961, 1979)
	1.30-1.60	1.45	Bould (1966)
	1.13-1.75	1.44	Chapman (1966)
	1.80-2.00	1.90	Gautier (1975)
	1.20-1.90	1.55	Shear and Faust (1980)
	2.20-2.30	2.25	Karkara (1987)
	1.36-1.74	1.55	Upadhayay and Awasthi (1993)
Calcium	0.74-2.42	1.58	Walrath and Smith (1952)
	1.46-1.69	1.57	Barden and Thompson (1962)
	1.40	1.40	Kenworthy (1961, 1979)
	1.00-1.60	1.30	Bould (1966)
	1.25	1.25	Chapman (1966)
	1.49-2.00	1.74	Gautier (1975)
	1.50-2.00	1.75	Shear and Faust (1980)
	1.70-2.60	2.15	Karkara (1987)
	1.31-1.45	1.38	Upadhayay and Awasthi (1993)
Magnesium	0.41	0.41	Kenworthy (1961, 1979)
	0.30	0.30	Levy (1971)
	0.25-0.30	0.275	Bould (1966)
	0.21-0.43	0.32	Chapman (1966)
	0.289	0.289	Pant *et al.* (1976)
	0.22-0.26	0.24	Gautier (1975)
	0.30-0.35	0.325	Tukey and Dow (1979)
	0.25-0.35	0.30	Shear and Faust (1980)
	0.33-0.40	0.365	Karkara (1987)
	0.41-0.64	0.525	Upadhayay and Awasthi (1993)
Iron	66-420	243	Walrath and Smith (1952)
	75-144	109.5	Walker and Mason (1960)
	135	135	Simons (1960)
	225	225	Oberly and Kenworthy (1961)
	220	220	Chapman (1966)
	220	220	Kenworthy (1979)
	100-400	250	Tukey and Dow (1979)
	40-500	270	Shear and Faust (1980)
	120-152	136	Karkara (1987)
	353-484	418.5	Upadhayay and Awasthi (1993)
Manganese	60-124	92	Epstein and Lilleland (1942)
	28-144	86	Boynton *et al.* (1952)
	38-200	119	Kenworthy (1950)
	105-209	157	Dilley *et al.* (1958)
	98	98	Kenworthy (1961)
	52	52	Awad and Kenworthy (1963)
	30-100	65	Bould (1966)

Table 3: Cont.....

Nutrient	Optimum Range	Average	Reference
	40-87	63.5	Chapman (1966)
	25-100	62.5	Tukey and Dow (1979)
	25-150	87.5	Shear and Faust (1980)
	82-138	110	Karkara (1987)
	72-94	83	Upadhayay and Awasthi (1993)
Copper	3-12	7.50	Dunne (1938)
	3-40	21.5	Kenworthy (1950)
	9.5-40.6	12	Smith and Taylor (1952)
	10-41	25.5	Oberly and Kenworthy (1961)
	5-12	8.5	Bould (1966)
	5-10	7.5	Chapman (1966)
	6-40	23	Tukey and Dow (1979)
	5-12	8.5	Shear and Faust (1980)
	15	7.5	Karkara (1987)
	17.25	21	Upadhayay and Awasthi (1993)
Zinc	16-80	48	Chandler *et al.* (1934)
	9.6-10.8	10.2	Bouldet *al.* (1949)
	6.0-40.0	23.0	Woodbridge (1951)
	24.0-45.5	34.7	Dev and Kapoor (1973
	15.0-25.0	20.0	Bould (1966)
	9.0-53.0	31.0	Chapman (1966)
	15.0-200.0	107.5	Shear and Faust (1980)
	39.0-102.0	70.5	Karkara (1987)
	28.0-44.0	36.0	Upadhayay and Awasthi (1993)

Macronutrients are expressed in per cent on dry weight basis; Micronutrients are expressed in ppm on dry weight basis

against which diagnosis is done. These norms are calculated, as the means of various forms expressing the nutrients for a high yielding population of plants (Beaufils, 1973; Sumner, 1986). It is considered that plants present nutritional balance for a given nutrient when the values of the indices, defined in the DRIS method, are close to zero (Walworth and Sumner, 1987). When nutrients are in a state of imbalance, the negative DRIS index values mean that the nutrients are undersupplied while positive DRIS index values mean oversupply. In all, 108 expressions (ratios, their reciprocals and products) from 36 nutrient pairs were evaluated for their influence in achieving higher yields in apple. Variance ratios (variance in low yielding population divided by variance in high yielding population) were used as criteria for identifying important nutrient expressions that distinguish the yield gap. The study (Table 1) reveals that ratios N/K, N/Ca, N/Mn, N/Cu, N/Zn, P/K, P/Fe, P/Mn, P/Cu, P/Zn, K/Mn, K/Zn, Ca/Mn, Ca/Zn, Mg/Mn, Mg/Zn, Fe/Cu, Fe/Zn, Cu/Zn and reciprocal expressions *viz.* P/N, Ca/N, Mn/N, K/P, Mg/P, Fe/P, Mn/P, Cu/P, Ca/K, Mg/K, Mn/K, Zn/K, Fe/Ca, Zn/Ca, Cu/Fe, Zn/Mn were associated with higher yields. Apart from them, products NxP, NxMg, NxMn, NxFe, NxCu, PxK, PxZn, KxMn, KxZn, MgxMn, MgxZn, FexZn were also found to have significant relationship with higher yield. The nutrient expression that recorded highest variance ratio amongst the three (ratios, reciprocals and products) was selected as DRIS norm (Table 2). Among nutrient pairs involving macronutrients, the expressions N/K, N/Ca, NxMg, P/N, PxCa, Ca/K, CaxMg, Mg/P and Mg/K were selected as DRIS norms having corresponding mean values 1.199, 1.301, 0.701, 0.102, 0.129, 0.377, 0.978, 0.569, 1.543 and 0.189 with CV (%) of 9.82, 9.98, 24.12, 17.35, 21.52, 16.28, 12.82, 18.98, 18.12 and 18.40, respectively. Amongst the expressions involving macro and micronutrients N/Fe, N/Mn, N/Cu, N/Zn, P/Fe, P/Mn, P/Zn, K/Mn, K/Zn, Ca/Mn, Ca/Zn, Mg/Fe, Mg/Mn, Mg/Zn, Fe/K, Fe/Ca, Fe/Mn, Cu/P, Cu/K, Cu/Ca and Cu/Mg were identified as DRIS norms with mean values 0.007, 0.018, 0.216, 0.045, 0.001, 0.002, 0.005, 0.014, 0.041, 0.016, 0.037, 0.001, 0.002, 0.006, 172.091, 177.722, 2.276, 48.125, 5.748, 5.943 and 31.157, respectively. Among expressions involving micronutrients only Fe/Mn, Fe/Cu, Fe/Zn, Cu/Mn, Cu/Zn and Zn/Mn qualified for DRIS norms with mean values 2.276, 29.987, 6.081, 0.081, 0.209 and 0.379, respectively. Seven expressions *viz.* N/Fe, PxCa, Mg/Fe, Fe/Mn, Cu/Ca, Cu/Mg, and Cu/Mn out of the 36 DRIS norms were although found non-significant in the present study but selected as norms because they have neutral effect on index calculation (Parent and Granger, 1989). On the basis of nutrient survey of apple orchards in Himachal Pradesh (Singh, 1996), expressions viz. N/K, NxCa, NxMg, NxFe, NxMn, N/Zn, P/N, P/K, PxCa, PxMg, PxFe, PxMn, P/Zn, KxCa, KxMg, KxFe, KxMn, K/Zn, Ca/Mn, CaxCu, CaxZn, Mg/Ca, MgxFe, Mg/Mn, MgxCu, MgxZn, Fe/Ca, FexMn, FexZn, Cu/N, Cu/P, Cu/K, CuxFe, Cu/Zn, MnxCu and MnxZn with their respective values 1.3, 3.6, 0.69, 580.1, 265.9, 0.07, 0.086, 0.11, 0.30, 0.06, 45.8, 21.7, 0.005, 2.8, 0.53, 462.3, 205.7, 0.05, 0.02, 12.1, 75.1, 0.19, 88.5, 0.004, 2.3, 14.3, 167.0, 34720.0, 12108.5, 3.4, 41.6, 4.5, 2012.7, 0.22, 873.6 and 6164.2 were selected as DRIS norms. Das (1999) developed DRIS norms for apple in Kullu (Himachal Pradesh) and selected N/P, N/K, N/Ca, N/Mg, N/Fe, N/Mn, N/Cu, N/Zn, P/K, P/Mn, P/Cu, P/Zn, K/Mn, K/Cu, K/Zn, Ca/P, Ca/K, CaxMg, Ca/Mn, Ca/Cu, Ca/Zn, Mg/P, Mg/K, Mg/Fe, Mg/Mn, Mg/Cu, Mg/Zn, Fe/P, Fe/Ca, Fe/Mn, Fe/Cu, Fe/Zn, Mn/Cu, Cu/Zn and Zn/Mn expressions as norms with values 9.74, 1.20, 1.23, 6.84, 0.01, 0.02, 0.21, 0.04, 0.13, 0.002, 0.02, 0.004, 0.01, 0.18, 0.04, 7.95, 0.98, 0.53, 0.01, 0.17, 0.03, 1.44, 0.18, 0.001, 0.002, 0.03, 0.01, 1476.01, 182.97, 187.38, 2.55, 31.63, 6.39, 13.23, 0.22 and 0.40, respectively. Singh *et al.* (2000) on the basis of data bank consisting of

1800 observations from six main apple growing areas in Himachal selected 36 nutrient expressions as DRIS norms. They advocated that DRIS approach revealed nutrient deficiencies in the range normally considered to be sufficient and increased precision was found in the evaluation of nutrient balance, which was ignored in critical value approach.

Comparison of DRIS norms with norms developed from average of published sufficiency ranges:

DRIS norms derived in the present study were compared (Table 2) with the norms computed from the average of published sufficiency ranges (Table 3). A close agreement was observed with expressions N/K, N/Ca, NxMg, N/Fe, N/Mn, N/Cu, N/Zn, P/N, P/K, PxCa, P/Fe, P/Mn, P/Zn, K/Mn, K/Zn, Ca/K, CaxMg, Ca/Mn, Ca/Zn, Mg/P, Mg/K, Mg/Fe, Mg/Mn, Mg/Zn, Fe/Mn, Fe/Zn, Cu/K and Zn/Mn with norms derived from means of sufficiency ranges. In the present study norm expressions Fe/K, Fe/Ca, Fe/Cu, Cu/P, Cu/Ca, Cu/Mg, Cu/Mn, Cu/Zn differed slightly fromthe norms calculated from average of sufficiency ranges. The variation in some of the norms from the mean of sufficiency ranges is due to variations in cultural management, agro-climatic conditions and physiological processes within the plant system (Kenworthy, 1961).

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