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Indian Journal of Agricultural Sciences **86** (3): 409–13, March 2016/Article

Soil fertility, leaf nutrient concentration and yield limiting nutrients in oil palm (*Elaeis guineensis*) plantations of Surat district of Gujarat

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Received: 6 July 2015; Accepted: 28 September 2015

ABSTRACT

A survey was conducted for assessment of soil fertility status, leaf nutrient concentration and identification of yield limiting nutrients in twenty six oil palm (*Elaeis guineensis* Jacq.) plantations in Surat district of Gujarat. Soil pH, electrical conductivity (EC), organic carbon (OC), available potassium (K) (NH_4OAc-K), available phosphorus (P) (Olsen-P), exchangeable calcium (Ca) (Exch. Ca) and magnesium (Mg) (Exch. Mg), available sulphur (S) ($CaCl_2$-S) and hot water soluble boron (B) (HWB) content in surface (0-20 cm depth) and subsurface (20-40 cm depth) soil layers varied widely. Diagnosis and Recommendation Integrated System (DRIS) norms were established for different nutrient expressions and it was used to compute DRIS indices. As per DRIS indices, the order of requirement of nutrients in the area was found to be K > nitrogen (N) > B > P > Mg. Optimum leaf nutrient ranges as per DRIS norms varied from 2.63 to 2.85%, 0.16 to 0.18%, 0.56 to 0.88%, 0.34 to 0.84% and 9.10 to 32.5 mg/kg for N, P, K, Mg and B respectively. On the basis of DRIS derived optimum ranges, 65, 31, 35 and 8 per cent leaf samples had less than optimum concentration of N, P, K and B respectively. The optimum ranges developed could be used for efficient nutrient management.

Key words: DRIS, Foliar diagnosis, Leaf nutrient, Oil palm, Optimum range, Soil properties

Oil palm *(Elaeis guineensis* Jacq*)* requires balanced and adequate supply of macro and micronutrients for economic and sustainable growth and yield (Goh *et al*. 2003), which can only be achieved with judicious use of fertilizers. Commonly prevalent nutrient disorders/ deficiencies like nitrogen (N)/potassium (K) imbalance, K deficiency, magnesium (Mg) deficiency and boron (B) deficiency in different oil palm plantations are the major limitations affecting oil palm production in India (Narsimha Rao *et al*. 2014). Fertilizer recommendations in oil palm, like other crops, are based on calibrated soil and leaf tests (McLaughlin *et al*. 1999). Therefore, it is essential to continuously monitor the soil nutrient status and leaf nutrient concentration of oil palm plantations for efficient fertilizer recommendations and for sustainable yield. Information regarding soil fertility, leaf nutrient concentrations and yield limiting nutrients in oil palm plantations of different parts of India in general and western part in particular is lacking.

In plantation crops like oil palm, the selection of correct leaves, stage of sampling, age of plantations and concentration of other nutrients have made it difficult to interpret the result of foliar analysis (Walworth and Sumner 1987). The critical concentration concept addresses the issues of deficiency and sufficiency of a specific nutrient element and does not address the nutrient balance. On the other hand, Diagnosis and Recommendation Integrated System (DRIS) developed by Beaufils (1973) deals with concentration ratios, rather than individual concentration of nutrient to interpret leaf tissue analysis (Sumner 1978). In addition, it not only indicates the nutrient most likely to be limiting but also the order, in which other nutrients are likely to become limiting (Mourao Filho 2004). DRIS norms for many crops have been developed for interpreting leaf tissue analysis for routine diagnostic and advisory purpose for obtaining higher production. Scant information regarding DRIS norms in oil palm cultivated in India is available. Therefore, the present investigation was carried out to assess the soil fertility and leaf nutrient concentration and to identify yield limiting nutrients in oil palm plantations of Surat district of Gujarat, for efficient nutrient management.

MATERIALS AND METHODS

A survey was carried out in Surat district of Gujarat during 2012-13 to assess soil fertility and plant nutritional status in 26 oil palm plantations of 4 to 8 years age. The survey area located at 21°102' N, 72°502' E with average elevation of 13 m. The climate of the area is tropical with average rainfall of 1 200 mm. Most of the rainfall occurs between June to September. April and May are the hottest months, the average maximum temperature being 37 °C.

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Winter starts in December and ends in late February, with average mean temperature of around 23 °C. Soils are deep, well drained and medium black in colour with varied soil properties including clayey to loamy clay in texture.

A total of 52 soil samples were collected from 0-20 cm (surface) and 20-40 cm (subsurface) depths in the palm basins during the survey to assess soil fertility status of oil palm plantations. Each sample was formed from three random samples from an oil palm basin and pooled together to form one representative sample for analysis (Jackson 1973). The soil samples were dried in shade at room temperature, roots and debrises removed, ground and passed through 2 mm sieve and stored in polyethene bottles for analysis. The 2 mm sieved soil was further ground using pestle and mortar to pass through 0.5 mm sieve for determination of organic carbon (OC). The soil samples were analyzed for pH, electrical conductivity (EC), OC, available K, phosphorus (P), exchangeable calcium (Ca) and Mg, available sulphur (S) and hot water soluble B. Determination of soil pH and EC was done on 1:2 soil water ratio (weight (w)/volume (v)) suspension using pH meter and EC meter respectively, following half an hour equilibrium (Jackson 1973). Soil OC content was estimated by Walkley and Black (1934) method. Available K was extracted using neutral normal ammonium acetate solution (NH_4OAc-K) (Hanway and Heidel 1952) and was estimated by flame photometry. Available P (Olsen-P) was extracted using Olsen's reagent (Olsen *et al*. 1954) and estimated through spectrophotometry. Exchangeable Ca (Exch. Ca) and Mg (Exch. Mg) were extracted using neutral normal ammonium acetate solution (Jones 1998) and estimated through atomic absorption spectrometry. Available S ($CaCl_2$-S) was estimated by turbidity method (Williams and Steinbergs 1969). Hot water soluble B (HWB) was estimated through Azomethine-H reagent (Gupta 1967) using spectrophotometry. Descriptive statistics were obtained for measured soil properties.

A total of 26 leaf samples were collected by identifying 17th frond from the corresponding palm, from where soil samples were obtained, by following standard procedures (Bhargava and Raghupathi 2001, Behera and Suresh 2013). The leaf samples were decontaminated by washing in sequence with tap water to remove dirt or soil, then in 0.2% detergent solution, and then by 0.1 normal hydrochloric acid (HCl) solution to remove waxy and metallic deposits on the leaf and followed by washing in single and double distilled water. Excess water was removed by pressing between folds of blotting paper and leaf samples were air dried and then oven dried at 70 °C for 72 hr. After complete drying, the samples were powdered in stainless steel mill and were stored in polyethene bottles for analysis. The leaf samples were analyzed for N, P, K, Ca, Mg, S, B and copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe) concentrations. The samples were analyzed (except N) by taking 1 g material digesting in di-acid mixture (9:4 ratio of nitric acid and perchloric acid) using standard analytical procedures (Jackson 1973). Nitrogen was estimated by micro-Kjeldahl method, whereas P, K and S were analyzed by vanadomolybdate, flame photometer and turbidity methods, respectively. Calcium, Mg, Cu, Zn, Mn and Fe were analyzed by using atomic absorption spectrophotometer. Boron was estimated by making dry ash out of 1g leaf sample heated in a muffle furnace at 550 to 600 °C followed by its extraction in dilute HCl. The analysis was carried out by Azomethine-H method. Descriptive statistics were obtained for leaf nutrient concentrations.

DRIS norms were calculated as described by Beaufils (1973). The whole population was divided into two sub-groups, namely low yielding and high yielding type taking 20 tonnes/ha as cut-off yield. The cut-off yield was positioned

Table 1 Selected oil palm leaf nutrient expressions

Expressions	Low yielding population				High yielding population				
	Mean	Variance (Sa)	SD	CV	Mean	Variance (Sb)	SD	CV	Sa/Sb
N	2.45	0.00	0.55	0.22	2.74	0.00	0.08	0.03	0.00
P	0.16	0.00	0.01	0.10	0.17	0.00	0.00	0.03	0.00
K	0.59	0.02	0.14	0.24	0.72	0.01	0.12	0.17	2.00
Mg	0.66	0.01	0.13	0.20	0.59	0.03	0.19	0.32	0.33
B	20.7	165	12.8	0.62	20.8	77.4	8.79	0.42	2.13
N/P	15.4	13.4	3.66	0.24	15.8	0.61	0.78	0.05	21.9
N/K	4.37	1.59	1.26	0.29	3.90	0.57	0.75	0.19	2.79
N/Mg	3.84	1.55	1.24	0.32	4.92	1.58	1.25	0.25	0.98
B/N	8.54	25.4	5.04	0.59	7.63	11.8	3.43	0.45	2.15
K/P	3.65	0.58	0.76	0.21	4.14	0.51	0.72	0.17	1.13
Mg/P	4.21	1.10	1.05	0.25	3.42	1.28	1.13	0.33	0.86
B/P	127	5192	72.0	0.57	120	2586	50.8	0.42	2.00
K/Mg	0.94	0.13	0.36	0.38	1.32	0.23	0.48	0.36	0.56
B/K	36.9	516	22.7	0.62	30.6	248	15.7	0.51	2.08
B/Mg	31.0	350	18.7	0.60	38.1	574	23.9	0.63	0.61

SD, Standard deviation; CV, Coefficient of variation in such a way that high yielding sub-population reflected conditions that are deemed desirable. Nutrients deficient in oil palm plantations in India were considered for estimation of DRIS norms. Mean values of selected nutrient expressions together with their associated coefficient of variations (CV) and variances were calculated for two populations and presented in Table 1. The mean values of nutrient expressions of high yielding population were ultimately chosen as diagnostic norms. The selection of nutrient ratio expression values with relatively large variance ratio (variance of low yielding population (S_a)/variance of high yielding population (S_a)) was done. DRIS provides a means of ordering nutrient ratios into meaningful expressions in the form of indices. The DRIS indices were calculated as given below by following the formulae given by Walworth and Sumner (1987).

N index = [f (N/P) + f (N/K) + f (N/Mg) – f (B/N)] / 4

P index = [-f (N/P) - f (K/P) - f (Mg/P) – f (B/P)] / 4

K index = [-f (N/K) + f (K/P) + f (K/Mg) – f (B/K)] / 4

Mg index = [-f (N/Mg) + f (Mg/P) - f (K/Mg) – f (B/Mg)] / 4

B index = [f (B/N) + f (B/P) + f (B/K) + f (B/Mg)] / 4

where,

f (N/P) = [{(N/P)/(n/p)}-1] x (1000/CV) when N/P > n/p, f (N/P) = [1-{(n/p)/(N/P)}] x (1000/CV) when N/P < n/p.

Similarly, other functions such as f(N/K), f(N/Mg), f(B/N), f(K/P), f(Mg/P), f(B/P), f(K/Mg), f(B/N), f(B/P), f(B/K) and f(B/Mg) were calculated in the same way, using appropriate norms and CVs.

The optimum nutrients ranges in oil palm leaf tissue were determined by using DRIS technique. DRIS norms as reference values of each element obtained from mineral composition of leaf tissues of high yielding population constituted the mean of sufficiency. The optimum ranges are the values obtained from the mean ± 4/3 SD (Beaufils and Sumner 1976, Bhargava 2002).

RESULTS AND DISCUSSION

Soil fertility status of oil palm plantations

The data regarding soil fertility is presented in Table 2. The values of soil pH ranged from 6.38 to 8.28 and 6.52 to 8.22 in surface and subsurface soil layers respectively. Soil EC and OC content ranged from 0.26 to 1.16 dS/m and 6.24 to 16.8 g/kg respectively in surface soil layers and from 0.21 to 1.26 dS/m and 2.73 to 12.1 g/kg respectively in subsurface soil layers. The concentration of NH_4OAc-K and Olsen-P varied from 56.7 to 305 and 6.00 to 88.6 mg/kg respectively in surface soil layers and from 38.7 to 530 and 3.14 to 30.6 mg/kg respectively in subsurface soil layers. This indicated that the status of available K and P is low/deficient in some plantations and excess in some plantations. Similarly, wide variation in Exch. Ca and Exch. Mg concentration was recorded in both surface and subsurface soil layers. The concentration of Exch. Ca was higher than the concentration of Exch. Mg in both the soil layers. The concentration of $CaCl_2$-S and HWB varied from 9.50 to 62.5 mg/kg (mean value of 31.6 mg/kg) and 0.86 to 31.0 mg/kg (mean value of 6.51 mg/kg) respectively, in surface soil layers and from 1.50 to 91.0 mg/kg (mean value of 26.1 mg/kg) and 0.34 to 12.9 mg/kg (mean value of 4.04 mg/kg) respectively, in subsurface soil layers indicating

Table 2 Descriptive statistics of selected soil properties in surface and subsurface layers of oil palm plantations (n=26)

Soil properties	Min.	Max.	Mean	SD	CV (%)	Skew.	Kurt.
			0-20 cm depth				
pH	6.38	8.28	7.18	0.50	7.23	0.48	-0.79
EC, dS/m	0.26	1.16	0.44	0.20	45.9	1.21	1.79
OC, g/kg	6.24	16.8	10.2	3.04	29.8	0.42	-0.80
NH_4OAc-K, mg/kg	56.7	305	159	62.7	41.9	0.77	0.31
Bray's-P, mg/kg	6.00	88.6	21.8	16.6	76.0	1.78	1.01
Exch. Ca, mg/kg	467	1158	906	164	18.1	-0.96	1.10
Exch. Mg, mg/kg	121	244	178	33.2	18.6	0.53	-0.27
$CaCl_2$-S, mg/kg	9.50	62.5	31.6	15.6	49.4	0.41	-1.02
HWB, mg/kg	0.86	31.0	6.51	7.48	115	2.17	4.67
			20-40 cm depth				
pH	6.52	8.22	7.20	0.48	6.69	0.40	-0.72
EC, dS/m	0.21	1.26	0.41	0.20	49.9	1.16	1.22
OC, g/kg	2.73	12.1	7.15	2.76	38.6	0.03	-0.99
NH_4OAc-K, mg/kg	38.7	530	135	117	86.6	1.56	1.33
Olsen-P, mg/kg	3.14	30.6	13.1	8.10	61.9	0.83	-0.15
Exch. Ca, mg/kg	701	1109	912	119	13.1	-0.07	-0.84
Exch. Mg, mg/kg	119	274	178	37.1	20.8	0.13	-0.84
$CaCl_2$-S, mg/kg	1.50	91.0	26.1	17.9	68.5	1.77	1.11
HWB, mg/kg	0.34	12.9	4.04	4.14	102	1.00	-0.37

Min., Minimum; Max., Maximum; SD, Standard deviation; CV, Coefficient of variation; Skew., Skewness, Kurt., Kurtosis.

Table 3 Descriptive statistics of leaf nutrient concentrations (n=26)

Nutrient	Min.	Max.	Mean	SD	CV (%)	Skew.	Kurt.
N, %	1.46	4.20	2.49	0.51	20.6	1.03	1.21
P, %	0.12	0.18	0.16	0.01	9.54	-0.46	-0.37
K, %	0.35	0.84	0.61	0.15	24.0	-0.09	-1.12
Ca, %	0.78	2.71	1.40	0.39	27.6	1.44	1.32
Mg, %	0.41	0.96	0.65	0.14	21.4	0.18	-0.199
S, %	0.84	1.32	1.08	0.14	13.5	-0.12	-1.25
B, mg/kg	8.07	56.5	20.7	12.1	58.6	1.25	1.43
Cu, mg/kg	5.55	14.4	9.43	2.45	26.0	0.43	-0.89
Zn , mg/kg	40.0	61.0	50.3	5.31	10.6	0.33	-0.36
Mn, mg/kg	58.0	606	135	104	77.4	0.95	1.79
Fe , mg/kg	368	1924	974	469	48.2	0.59	-0.90

Min., Minimum; Max., Maximum; SD, Standard deviation; CV, Coefficient of variation; Skew., Skewness, Kurt., Kurtosis.

their higher concentration in majority of the plantations. Behera *et al*. (2015) also reported wide variation in soil properties of oil palm plantations in Karnataka. The CV values of measured soil properties in both the layers varied from 6.69 to 115 %. Soil pH in both the soil layers had low CV (<10%). Whereas, other soil properties except HWB exhibited medium CV values (10 to 100%). The highest CV values (> 100%) were recorded for HWB in both the soil layers.

Leaf nutrients concentration of oil palm plantations

The leaf nutrients concentrations in the surveyed plantations varied widely (Table 3). The mean concentration of leaf N (%), P (%), K (%), Ca (%), Mg (%), S (%), B (mg/kg), Cu (mg/kg), Zn (mg/kg), Mn (mg/kg) and Fe (mg/kg) were 2.49 ± 0.51, 0.16 ± 0.01, 0.61 ± 0.15, 1.40 ± 0.39, 0.65 ± 0.14, 1.08 ± 0.14, 20.7 ± 12.1, 9.43± 2.45, 50.3 ± 5.31, 135 ± 104 and 974 ± 469 respectively. The CV values of leaf nutrient concentration varied from 9.54 to 77.4 %. Leaf P concentration exhibited low CV (< 10%), whereas other leaf nutrients concentration had medium CV (10 to 100%). Bhargava (2002), Raghupathi and Bhargava (1999), Savita *et al*. (2013) and Behera *et al*. (2015) also reported wide variations of leaf nutrients concentration in grape, mango, sapota orchards and oil palm plantations respectively, developed on different soil types of India. This variation in leaf nutrient concentration among the plantations may be due to differences with respect to soil fertility status, quantity of fertilizers applied and adoption of other cultural practices.

DRIS norms and optimum nutrient ranges

The DRIS norms derived from N, P, K, Mg and B concentration of oil palm leaf samples were further employed to compute DRIS indices. As per DRIS indices obtained, the next kin of deficiencies for each nutrient was identified as K > N > B > P > Mg (Fig 1). This indicates the order of requirement of nutrients in the region. Potassium was found to be most limiting nutrient element in the region followed by N, B, P and Mg. Therefore, during the nutrient

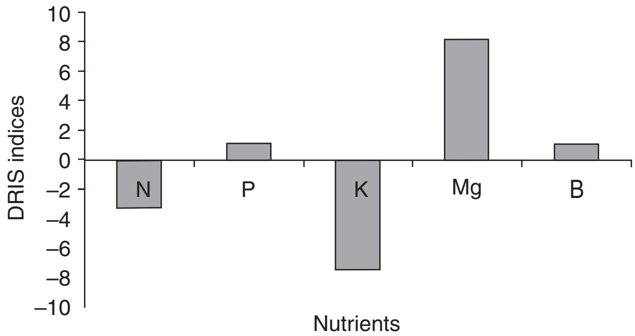

Fig 1 DRIS indices of nutrients

management of oil palm plantations in this region, priority needs to be given for management of K followed by N followed by B followed by P and followed by Mg.

The DRIS approach was employed to compute optimum ranges of nutrients. Optimum range for each nutrient was derived from the mean values of nutrient expressions of high yielding population which were ultimately chosen as diagnostic norms (Bhargava 2002). Optimum range for a nutrient indicates that the growth, yield and quality of the palm are satisfactory, and there is no need to make any changes in the schedule of manures and fertilizers. Changes in the nutrient concentration in the specified plant part do not increase or decrease growth or production. In the present study, the optimum concentration ranges of N, P, K, Mg and B in oil palm leaf ranged from 2.63 to 2.85%, 0.16 to 0.18%, 0.56 to 0.88%, 0.34 to 0.84% and 9.10 to 32.5 mg/kg respectively. Considering these optimum ranges, it was observed that 65, 31, 35 and 8 per cent leaf samples had less than optimum concentration of N, P, K and B respectively. In line with the findings of the present study, Behera *et al.* (2015) also reported optimum leaf nutrient ranges of 2.24 to 2.97 %, 0.08 to 0.14 % and 0.78 to 0.91 % for N, P and K respectively, in oil palm plantations of Karnataka. The information regarding optimum leaf nutrient ranges in oil palm for a particular area is useful for soil and leaf analysis which is the basis for taking decisions during estimation of fertilizer requirements (Fairhurst and Mutert 1999). Optimum ranges for individual nutrients varies over a considerable range, depending on several factors such as the age of palms, soil moisture regime, ratio to other nutrient concentrations, type of planting material, spacing, and inter-palm competition.

It is concluded from the investigation that the soil properties of oil palm plantations of Surat district of Gujarat varied widely. Leaf tissue analysis of oil palm plantations can be interpreted by DRIS approach to generate positive and negative indices of each nutrient. A positive index indicates adequate and above levels of the nutrient under consideration, whereas a negative index indicates below a sufficiency level; thus the nutrient requirement can be ordered relative to one another. As per DRIS indices obtained, the next kin of deficiencies for each nutrient was identified as K > N > B > P > Mg. Optimum leaf nutrient ranges as per DRIS norms varied from 2.63 to 2.85%, 0.16 to 0.18%, 0.56 to 0.88%, 0.34 to 0.84% and 9.10 to 32.5 mg/kg for N, P, K, Mg and B respectively. On the basis of DRIS derived optimum ranges, 65, 31, 35and 8 per cent leaf samples had less than optimum concentration of N, P, K and B respectively. Based on the indices obtained and the fertility status of the soil, the management levels of oil palm plantations in Surat district of Gujarat can be improved by application of right quantity and kind of fertilizers. With this approach each nutrient can be proficiently applied resulting in greater input use efficiency.

ACKNOWLEDGEMENT

Authors are thankful to the Director, ICAR-Indian Institute of Oil Palm Research, Pedavegi, West Godavari District, Andhra Pradesh, India for extending necessary advice, support and facilities to carry out the present study.

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