requires less power consumption. Based on the calculation result obtained from the fitting equation shown in Figure 9, the optimum length of thin cutter l is 13.07 mm.

The banana crown-cutting tool using combined cutters is a core component of the banana harvest machine. It requires less energy consumption and provides high grade of cut surface quality. Experimental results show that the number of cutter sets, width of the thick cutter and length of the thin cutter have significant impact on cutting quality. Cutting speed, thickness of thick cutter and length of thin cutter have an impact on cutting force and power consumption. The optimum parameters of the cutter sets are as follows: number of cutter sets n is five groups, cutting speed v is 60 mm/s, cutting edge angle θ of thick cutter is 16°, thickness δ and width d of the thick cutter are 2 and 12 mm respectively, and length of the thin cutter l is 13.07 mm.

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Estimation of soil properties and leaf nutrients status of oil palm plantations in an intensively cultivated region of India

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Oil palm (*Elaeis guineensis* Jacq.) is cultivated in several countries of the world. The information pertaining to soil properties and status of leaf nutrients in oil palm plantations (OPP) is essential for proper nutrient management to obtain higher yield of the crop. The study, therefore, was undertaken by conducting a survey of OPP in west Godavari district, India and collecting 306 soil samples and 153 leaf samples. Collected samples (soil and leaf) were analysed for different parameters after their processing. The studied soil parameters (soil pH, electrical conductivity, organic carbon, available phosphorous, available potassium, exchangeable calcium, exchangeable magnesium, available sulphur and available boron) in surface (0 to 20 cm) and sub-surface (20 to 40 cm) soil varied widely. The soil parameters had CV values

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from 7.13% to 80.7%. The concentrations of nitrogen (N), phosphorus (P) and potassium (K) in leaf samples were 0.62–3.97%, 0.04–0.26%, and 0.34–1.38% respectively. Whereas, the concentrations of calcium (Ca), magnesium (Mg), sulphur (S) and boron (B) were 0.66–2.66%, 0.10–1.03%, 0.02–0.35% and 9.55–119 mg kg^{-1} respectively. The norms and indices of Diagnosis and Recommendation Integrated System (DRIS) were obtained using various nutrient expressions. The leaf nutrient requirement order was B > Mg > K > N > P. The optimum concentrations of leaf nutrients were 1.57–2.63% for N, 0.08–0.16% for P, 0.48–0.88% for K, 0.25–0.71% for Mg and 22.6–60.2 mg kg^{-1} for B. Information about soil nutrient status and nutrient requirement order and optimum leaf nutrient ranges can be used for effective management of nutrients in the OPP of the study region.

Keywords: DRIS, leaf nutrient, oil palm, soil property.

THE potential oil yielding capacity of oil palm (*Elaeis guineensis* Jacq.) is ≈19.0 t oil/ha/year, which is the highest among the oil seed crops. Oil palm is cultivated in different countries of the world[1]. Of these, countries like Indonesia and Malaysia lead in palm oil production and export. Understanding the importance of the crop, efforts are being made in India to increase the acreage under oil palm crops to mitigate the vegetable oil demand of the country. Presently, it is being cultivated in 0.331 million ha area covering fourteen states, whereas the country has potential area of 1.93 million ha for oil palm cultivation spreading in nineteen states[2]. Andhra Pradesh state has 170,000 ha area under oil palm plantation (OPP) of which 70,000 ha area lies in West Godavari district alone.

Oil palm requires relatively higher amount of nutrients for optimum growth and production of fresh fruit bunch (FFB), which is the economic part of the palm. According to Mengel and Kirkby[3], oil palm needs 162 kg nitrogen (N), 30 kg phosphorus (P), 217 kg potassium (K), 36 kg calcium (Ca) and 38 kg magnesium (Mg), for production of 10 t FFB/ha/year. The FFB yield levels of OPP of India vary widely due to various soil-crop management practices adopted by the farmers[4]. But the mean yield to the tune of 15–20 t FFB/ha/year is obtained in well-managed plantations. Among the biotic factors, nutrient deficiencies (K, Mg and boron (B)) and N/K imbalance in oil palm leaves play important roles in adversely affecting FFB yield in India[5,6]. Best fertilizer management in oil palm through soil and leaf analysis is needed for correcting nutrient disorders and obtaining higher FFB production, as leaf nutrient concentration is directly correlated with FFB yield[7]. Hence, there is need for periodic evaluation of soil properties and leaf nutrient concentration in OPP for effective fertilizer management. The information pertaining to soil fertility status and leaf nutrient concentrations in OPP of the country in general and OPP of Andhra Pradesh state in particular is limited.

For the proper elucidation of leaf nutrient analysis values, Diagnosis and Recommendation Integrated System (DRIS) technique is used as it deals with ratios of nutrient concentration and not the individual nutrient concentration[8,9]. Researchers have used DRIS technique to elucidate leaf nutrient analysis values in many crops like mango (*Mangifera indica*), apple (*Malus pumila*), sapota (*Manilkara zapota*) and guava (*Psidium guajava*)[10–13] including oil palm[14–16]. It indicates the order of limiting nutrients so that appropriate corrective measures can be taken up. The information regarding DRIS norms of OPP in different parts of India is scarce. The current study was therefore carried out (i) to estimate soil properties and leaf nutrient status, and (ii) to derive DRIS norms and optimum leaf nutrient ranges in OPP of West Godavari, Andhra Pradesh, India.

The soil and leaf samples were obtained by conducting a survey in OPP of West Godavari, Andhra Pradesh, India situated on 16°07′N lat. and 81°01′E long. Hot and humid tropical climate prevails in the area. The area receives mean annual rainfall of 950 mm, out of which most rainfall occurs during June to September months. The months of May and December experience the mean highest (39°C) and the mean lowest (23°C) temperature respectively. Relative humidity of the area is the highest (90%) in July–August months and the lowest (60%) in February month. The soils of the area developed from metamorphic, sedimentary, and igneous geological formations, fall under Entisols, Alfisols and Vertisols soil order[17]. Soil texture varied from sandy clay loam to loamy sand. Oil palm is planted in equilateral triangular design with a spacing of 9 m × 9 m × 9 m and managed as an irrigated crop in the area.

Altogether 306 soil samples (153 each from 0 to 20 cm (surface) and 20 to 40 cm (sub-surface) soil depths) were collected from OPP of West Godavari district. One hundred and fifty three leaf samples were also collected. Soil samples were collected from a point having 1 m distance from the palm trunk inside 3 m radius palm basins. The leaf samples were gathered from the 17th frond of the palm, from where soil samples from the palm basin were collected using the recommended protocol[18]. Air-drying of collected soil samples was carried out in a dust-free environment at ambient temperature. The roots and debris present in dried soil samples were discarded and the samples were ground using pestle and mortar to pass through a sieve of 2 mm size. After processing, the soil samples were analysed for soil parameters, viz. pH[19], electrical conductivity (EC)[19], organic carbon (OC)[20], available P[21], available K[22], exchangeable Ca[23], exchangeable Mg[23], available S[24] and available B[25]. The collected leaf samples were washed first with tap water followed by 0.2% detergent solution, 0.1 N HCl solution and double-distilled water. The excess water is removed using blotting papers. The washed leaf samples were dried at 70°C in an oven for 3 days after air-drying for a while. The dried leaf samples were powdered in a stainless steel mill. For estimation of concentration of P, K, Ca, Mg and S in processed leaf samples using recommended protocols[19], the powdered leaf samples were digested using nitric acid-perchloric acid mixture (9 : 4 ratio). Nitrogen concentration in leaf samples was determined by micro-Kjeldahl method. Azomethine-H method was used for estimation of B concentration[26].

The descriptive statistical parameters of soil properties and leaf nutrient concentration were obtained. DRIS norms and indices for different nutrients (according to the formulae given below) were obtained (as suggested by Beaufils[8] and Walworth and Sumner[27]) by dividing the whole population into low-yielding and high-yielding groups by considering cut-off FFB yield level of 20 t/ha. For estimation of DRIS norms, the nutrients found deficient in OPP of India were taken into account. The high-yielding population reflected the desired condition. The mean nutrient expressions of high-yielding population were considered as diagnostic norms and they formed mean values of sufficiency. The optimum ranges of leaf nutrients were obtained from the mean ± 4/3 SD according to Bhargava[28].

$$\text{Index N} = \frac{[f(\text{N/P}) + f(\text{N/K}) + f(\text{N/Mg}) - f(\text{B/N})]}{4},$$

$$\text{Index P} = \frac{[-f(\text{N/P}) - f(\text{K/P}) - f(\text{Mg/P}) - f(\text{B/P})]}{4},$$

$$\text{Index K} = \frac{[-f(\text{N/K}) + f(\text{K/P}) + f(\text{K/Mg}) - f(\text{B/K})]}{4},$$

$$\text{Index Mg} = \frac{[-f(\text{N/Mg}) + f(\text{Mg/P}) - f(\text{K/Mg}) - f(\text{B/Mg})]}{4},$$

$$\text{Index B} = \frac{[f(\text{B/N}) + f(\text{B/P}) + f(\text{B/K}) + f(\text{B/Mg})]}{4}.$$

Then,

$$f(\text{N/P}) = [\{\text{N/P})/(\text{n/p})\} - 1] \times (1000/\text{CV}),$$

where N/P > n/p

$$f(\text{N/P}) = [1 - \{(\text{n/p})/(\text{N/P})\}] \times (1000/\text{CV}),$$

where N/P < n/p. N, P, K, Mg and B indicate nitrogen, phosphorus, potassium, magnesium and boron respectively. Using respective norms and CVs, other functions like f(K/P), f(N/K), f(B/N), f(N/Mg), f(K/Mg), f(Mg/P), f(B/N), f(B/P), f(B/Mg), f(B/P) and f(B/K) were also estimated.

Soil pH, EC and OC content ranged from 5.44 to 8.26 (mean 7.35), 0.05 to 0.58 dS m^{-1} (mean 0.22 dS m^{-1}) and 1.17 to 31.2 g kg^{-1} (mean 9.66 g kg^{-1}) respectively, in 0 to 20 cm soil depth, and from 5.15 to 8.24 (mean 7.38), 0.05 to 0.78 dS m^{-1} (mean 0.20 dS m^{-1}) and 0.39 to 26.9 g kg^{-1} (mean 5.33 g kg^{-1}) in 20 to 40 cm soil depth respectively (Table 1). The values of available P and K ranged from 29.0 to 1045 and 17.4 to 442 kg ha^{-1} respectively in 0 to 20 cm depth soil and from 27.6 to 998 and 13.3 to 297 kg ha^{-1} in 20 to 40 cm depth soil respectively. The values of exchangeable Ca, exchangeable Mg, available S, and available B spanned from 2.19 to 8.04 meq 100 g $soil^{-1}$, 0.20 to 5.70 meq 100 g $soil^{-1}$, 9.54 to 205 mg kg^{-1} and 0.10 to 22.2 mg kg^{-1} respectively, in 0 to 20 cm depth soil and from 2.10 to 7.85 meq 100 g $soil^{-1}$, 0.10 to 5.60 meq 100 g $soil^{-1}$, 3.46 to 181 mg kg^{-1} and 0.05 to 17.6 mg kg^{-1} respectively, in 20 to 40 cm depth. Soil properties had the CV values from 7.13% to 80.7% in both the soil layers. The variations in soil properties are predominately attributed to the varied fertilizer application practices along with other cultural practices adopted by plantation managers. This parallels the observation of Behera *et al.*[29] who recorded similar values of soil properties in soil layers of OPP in coastal region of western India.

The leaf nutrient concentration varied widely (Table 2). The mean value of leaf nutrient concentration followed the order N > Ca > K > Mg > S > P > B. This corroborates the observation of Lee *et al.*[30] who recorded 2.49–2.81% N, 0.16–0.18% P, 0.96–1.20% K, 0.68–1.02% Ca, 0.17–0.26% Mg, 0.14–0.16% S and 13.7–17.3 mg kg^{-1} B in the leaf samples of FELDA clone and FELDA D × P planting material grown in Pahang, Malaysia. Behera *et al.*[31] recorded mean values of leaf nutrient concentration of 2.21–2.49% N, 0.10–0.53% P and 0.56–0.78% K, in OPP of different areas of India. The variation in leaf nutrient concentration in the study area is ascribed to differences in soil properties and crop management ways. The CV values for leaf nutrient concentration varied from 23.3% to 45.8%.

The leaf nutrient (N, P, K, Mg and B) concentration values were used to derive DRIS norms for the two populations (Table 3). The selected nutrient ratio expressions had higher variance ratio. The DRIS indices for different nutrients were estimated using DRIS norms (Table 4). DRIS indices were found to be 1.21 for N, 2.84 for P, 1.04 for K, –0.21 for Mg and –4.88 for B. It followed the order B > Mg > K > N > P which reveals the importance of nutrient requirement in the study area. While devising nutrient management ways in OPP of the area, steps must be undertaken to manage B first. Subsequently, Mg, K, N and P nutrients need to be managed for obtaining better yield. Behera *et al.*[14,15] also recorded nutrient orders of B > K > Mg > P > N for Mizoram state and P > Mg > K > N > B for west coastal area of India. This variation in nutrient requirement of oil palm plantations

Table 1. Descriptive statistics of soil properties of oil palm plantations of West Godavari, Andhra Pradesh, India (n = 153)

Properties	Minimum	Maximum	Mean	SD	CV (%)	Skewness	Kurtosis
0–20 cm depth							
pH	5.44	8.26	7.35	0.13	7.36	–0.66	0.28
EC (dS m^{-1})	0.05	0.58	0.22	0.10	48.0	1.12	1.37
OC (g kg^{-1})	1.17	31.2	9.66	5.46	56.6	1.19	1.84
Available-P (kg ha^{-1})	29.0	1045	359	279	77.6	0.93	–0.28
Available-K (kg ha^{-1})	17.4	442	127	80.0	62.8	1.09	1.43
Exchangeable Ca (meq 100 g $soil^{-1}$)	2.19	8.04	4.53	1.31	28.8	0.37	–0.43
Exchangeable Mg (meq 100 g $soil^{-1}$)	0.20	5.70	2.15	1.07	49.9	0.54	–0.12
Available-S (mg kg^{-1})	9.54	205	44.3	28.2	63.7	2.30	7.90
Available-B (mg kg^{-1})	0.10	22.2	4.71	5.32	113	1.30	0.95
20–40 cm depth							
pH	5.15	8.24	7.38	0.53	7.13	–1.09	2.14
EC (dS m^{-1})	0.05	0.78	0.20	0.10	53.7	1.84	5.72
OC (g kg^{-1})	0.39	26.9	5.33	3.48	65.3	2.26	10.1
Available-P (kg ha^{-1})	27.6	998	330	266	80.7	1.13	0.14
Available-K (kg ha^{-1})	13.3	297	87	57.7	66.3	1.24	1.36
Exchangeable Ca (meq 100 g $soil^{-1}$)	2.10	7.85	4.36	1.42	32.6	0.52	–0.66
Exchangeable Mg (meq 100 g $soil^{-1}$)	0.10	5.60	2.07	1.12	54.4	0.56	–0.00
Available-S (mg kg^{-1})	3.46	181	37.7	24.8	65.7	2.38	8.94
Available-B (mg kg^{-1})	0.05	17.6	3.90	4.41	113	1.15	0.21

SD, Standard deviation; CV, Coefficient of variation.

Table 2. Descriptive statistics of leaf nutrient concentrations for entire population of oil palm plantations of West Godavari, Andhra Pradesh, India (n = 153)

Nutrients	Minimum	Maximum	Mean	SD	CV (%)	Skewness	Kurtosis
N (%)	0.62	3.97	2.34	0.57	24.3	0.18	0.39
P (%)	0.04	0.26	0.13	0.04	27.2	–0.08	0.65
K (%)	0.34	1.38	0.68	0.16	23.7	1.00	1.71
Ca (%)	0.66	2.66	1.41	0.33	23.3	0.37	0.53
Mg (%)	0.10	1.03	0.51	0.18	35.7	0.29	–0.22
S (%)	0.02	0.35	0.17	0.05	29.0	0.37	1.52
B (mg kg^{-1})	9.55	119	48.7	22.3	45.8	0.72	–0.04

SD, Standard deviation; CV, Coefficient of variation.

Table 3. Leaf nutrient norms of oil palm plantations of West Godavari, Andhra Pradesh, India

	Low yielding population				High yielding population				
Nutrient expressions	Mean	Variance (Sa)	SD	CV	Mean	Variance (Sb)	SD	CV	Sa/Sb
N	2.08	0.13	0.36	17.6	2.10	0.16	0.40	19.1	0.81
P	0.13	0.00	0.03	25.6	0.12	0.00	0.03	27.0	0.96
K	0.67	0.02	0.13	19.2	0.68	0.02	0.15	21.5	0.76
Mg	0.47	0.04	0.19	40.3	0.48	0.03	0.17	36.4	1.33
B	33.2	177	13.3	40.1	41.4	199	14.1	34.1	0.89
N/P	17.4	33.9	5.82	33.5	18.9	80.9	8.99	47.5	0.42
N/K	3.22	0.65	0.80	25.0	3.19	0.69	0.83	25.9	0.94
N/Mg	5.32	8.09	2.84	53.4	5.10	6.68	2.58	50.7	1.21
B/N	16.9	70.2	8.37	49.6	20.6	68.9	8.30	40.3	1.02
K/P	5.57	3.70	1.92	34.5	6.10	7.40	2.72	44.6	0.50
Mg/P	3.96	4.72	2.17	54.8	4.30	5.35	2.31	53.8	0.88
B/P	286	23394	153	53.5	368	32736	181	49.2	0.71
K/Mg	1.77	1.15	1.07	60.5	1.66	0.76	0.87	52.3	1.51
B/K	52.0	660	25.7	49.4	63.6	650	25.5	40.3	1.02
B/Mg	86.1	2821	53.1	61.7	99.3	2829	53.2	53.6	1.00

SD, Standard deviation; CV, Coefficient of variation.

Table 4. DRIS indices for nutrients of oil palm plantations of West Godavari, Andhra Pradesh, India

Nutrients	Indices
N	1.21
P	2.84
K	1.04
Mg	–0.21
B	–4.88

Table 5. Optimum leaf nutrient ranges of oil palm plantations of West Godavari, Andhra Pradesh, India

Nutrients	Optimum concentration
N (%)	1.57 to 2.63
P (%)	0.08 to 0.16
K (%)	0.48 to 0.88
Mg (%)	0.25 to 0.71
B (mg kg^{-1})	22.6 to 60.2

in different parts of the country is because of differences in climatic conditions, soils and crop management ways. Optimum leaf nutrient ranges for the study area were estimated by considering mean leaf nutrient concentration values of high-yielding group. It was 1.57–2.63% for N, 0.08–0.16% for P, 0.48–0.88% for K, 0.25-0.71% for Mg and 22.6–60.2 mg kg^{-1} for B (Table 5). Optimum leaf nutrient range indicates that palms having optimum leaf nutrient concentration produce satisfactory yield and there is no need to make changes in fertilizer schedule.

Estimation of soil properties and leaf nutrient concentration of OPP and derivation of DRIS norms and indices could help in understanding the nutritional status of the plantations, which varies from area to area depending upon soils, climatic conditions and crop management ways. It was found that the order of requirement of nutrients in OPP of west Godavari district is B > Mg > K > N > P. The optimum concentrations of leaf nutrients were 1.57–2.63% for N, 0.08–0.16% for P, 0.48–0.88% for K, 0.25–0.71% for Mg and 22.6–60.2 mg kg^{-1} for B. Based on this information, better ways of nutrient management can be formulated for obtaining improved yield in OPP.

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Crustal depth estimation over the Indian lithospheric plate using satellite geoid and a gravimetric–isostatic model

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Moho depth or simply, Moho, in general, describes the boundary between the earth's crust and the mantle and is a very important geophysical parameter. It is also related to the earth's crustal thickness at any point. Geoid and gravity anomalies derived from satellite altimetry are gradually gaining importance in marine geo-scientific investigations. However, satellite gravity technique is not working over land/continent. So, we need to develop technique like the VMM model which is equally working over land. In addition of generating crustal thickness, it also saves energy to generate Bouguer anomaly over land and ocean.

Keywords: Crustal depth, geoid, gravity anomaly, lithospheric plate, satellite altimetry

THE Mohorovičić discontinuity or Moho is one of the most important geophysical parameters for defining the subsurface crustal thickness. It also defines the boundary between the earth's crust and mantle. Gravity field models (mostly via satellites) are being used for a variety of geophysical and oceanographic explorations. Surface gravity data also generate the gravity field, but acquiring data uniformly over the earth is difficult and time-consuming. Since the sea surface largely conforms to the geoid, satellite altimetry provides precise measurements of the marine gravity field, provided that proper corrections are made to altimeter data and other relevant errors[1].

Now-a-days, it is possible to generate large-scale altimeter-derived residual/prospecting geoid and gravity anomaly maps over the oceans. They are used to infer subsurface geological structures analogous to gravity anomaly maps generated through ship-borne surveys. Geoid is generated by the equipotential surface over the oceans[2–4], which contains information regarding mass distribution inside the entire earth. Geoid is then converted to gravity using a simple technique[4,5]. Gravity anomaly maps provide information on the subsurface density distribution, major tectonic and structural lineaments, geodynamic aspects of a plate margin and structure of the crust and lithosphere[6]. However, satellite gravity technique cannot be used over land/continent. So, we need to develop a technique like the Vening Meinesz–Moritz (VMM) model which works equally well over land for generating crustal thickness[7]. It also helps generate Bouguer anomaly over land and ocean.

An improved spherical harmonic model of the earth's gravitational potential up to degree and order 360 has been generated by NASA, NIMA and OSU (USA)[8]. The Earth Gravitational Model 1996 (EGM96) incorporates improved surface gravity data. A very high-resolution geoid (spatial resolution as high as ~4 km) and gravity anomalies have been generated from ERS-1, Seasat, GeosatGeodetic Mission (GGM) and TOPEX/POSEIDON data[4,8]. The Bouguer gravity map brings out the following striking features[9–11]: (i) Dominance of negative Bouguer anomalies over a major part of the Indian subcontinent, reaching a maximum value of 380 mGal over the Himalayas. (ii) Belts of positive Bouguer anomalies are seen along the west coast. Positive anomaly trends characterize part of the east coast and the Shillong plateau. (iii) The trends of anomalies are parallel to the major structural trend: NNW–SSE Dharwar trend in South India, NE–SW Aravalli trend and the Himalayan trend[9–11]. (iv) Several gravity highs and lows can also be identified. Figure 1 shows the residual geoid anomaly map generated using high-resolution altimeter data over oceans surrounding Indian peninsula. The bathymetric and tectonic features as observed in the residual geoid image are given elsewhere[3,4]. They provide important information on the structure of the compensated lithosphere.

The Bouguer anomaly map of India has also been digitized and the values interpolated at 10 km interval to

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