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ESTIMATION OF THE TOTAL SURFACE AREA IN INDIAN ELEPHANTS (*ELEPHAS MAXIMUS INDICUS*)

K.P. Sreekumar and **G. Nirmalan**
College of Veterinary and animal Sciences,
Kerala Agricultural University, Mannuthy, Trichur, Kerala, India 680651

ABSTRACT

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Twenty-four adult Indian elephants *(Elephas maximus indicus)* of both sexes and different ages and weights, belonging to the Temple Devaswome, the Forest Department of the Government of Kerala and Gemini Circus formed the experimental subjects from which formulae were derived to predict the total surface area from either body measurements or areas of individual regions. Several models, using the parameters studied either singly or in combination, were tried independently for males and females and also for adults irrespective of sex. The best prediction of total surface area (s) in m^2 was obtained for adults irrespective of sex by using the two parameters, the height at the shoulders (H) in m and forefoot pad circumference (FFC) in m in the formula S=-8.245 + 6.807H +7.073FFC. No Significant imporvement in the accuracy of prediction resulted from the use of the independent best fit formulae for males and females. The conventional method of using the exponential of body weight (kg) for predicting suface area was not found to yield and equivalent accuracy in these animals.

Keywords: biometry, elephant, surface area

INTRODUCTION

Metabolic rate can be expressed as a function of the total surface area during life. Even though expression in terms of body weight is preferred, the customary practice of expressing heat production in relation to surface area (Dale, 1984) is still widely prevalent.

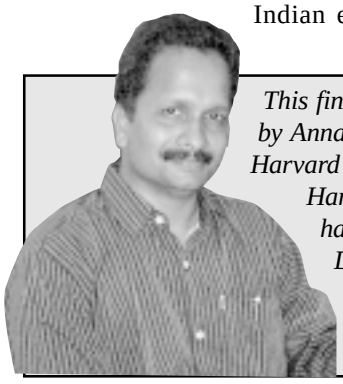
The surface area can be measured directly or it can be estimated by conventional formulae. An attempt was made in the present work to estimate the total surface area of adult Indian elephants with reasonable accuracy and to derive a simple and reliable prediction equation for estimating total surface area indirectly.

MATERIALS AND METHODS

The study was conducted on 12 female and 12 male adult Indian elephants *(Elephas maximus indicus),* varying in age from 18 to 60 years and in weight from 1880 to 5290 kg, maintained by the Temple Devaswoms, the Forest Department of the Government of Kerala and the Gemini Circus. All the animals were clinically healthy and were maintained under an optimal nutritional regime.

The body weight, the height at the shoulders and the body length from the base of the forehead to the base of the tail were recorded as described earlier (Sreekumar and Nirmalan, 1989). All measurements were taken in duplicate with a strong tape measure which withstood the rough handling without stretching, shrinking, curling or breaking, and the average value was used.

For determination of the total surface area, the elephant was divided geometrically into differnent surface anatomical regions (Figures 1, 2, 3 and 4) and the area (m^2) was calculated for each individually. The sum total of the areas of the individual regions then gave the total surface area.



This finding was awarded the Ig Nobel prize. Also known as the Ignatius Nobel prize, is sponsered by Annals of Improbable Research, Harvard University, USA; The Harvard Computer Society, The Harvard - Radcliff Science fiction association and the Harvard-Radcliff Society of Physics Students, Harvard University, USA. Every year 10 prizes are given to people whose achievements should have a curious property and also entice more people to become interested in science.

Dr. K.P. Sreekumar and his late Professor Dr. G. Nirmalan were honoured for their achievement in Estimating the Total Body Surface Area of Indian Elephants and for deriving a simple equation for predicting the total body surface area using height and foot circumference of elephants.

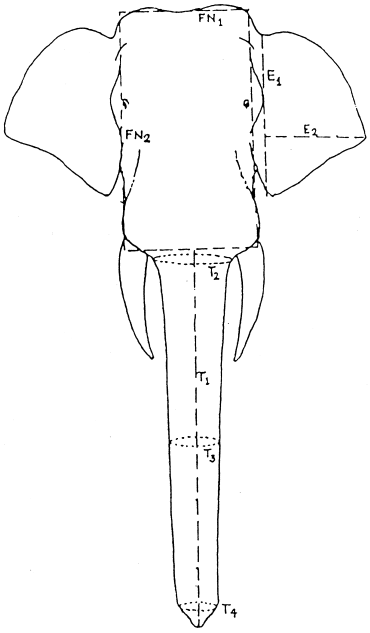


Figure 1. Sites at which body measurements have been taken (m):
T_1 - Trunk length
T_2, T_3, T_4 - Trunk circumference
FN_1 - Fronto-nasal length
FN_2 - Fronto-nasal breadth
E_1 - Ear base length
E_2 - Ear altitude

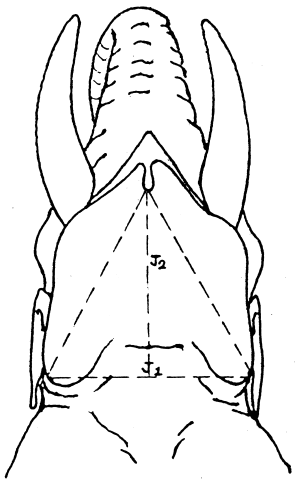


Figure 2. Sites at which body measurements have been taken (m):
J_1 - Jowl base length
J_2 Jowl altitude

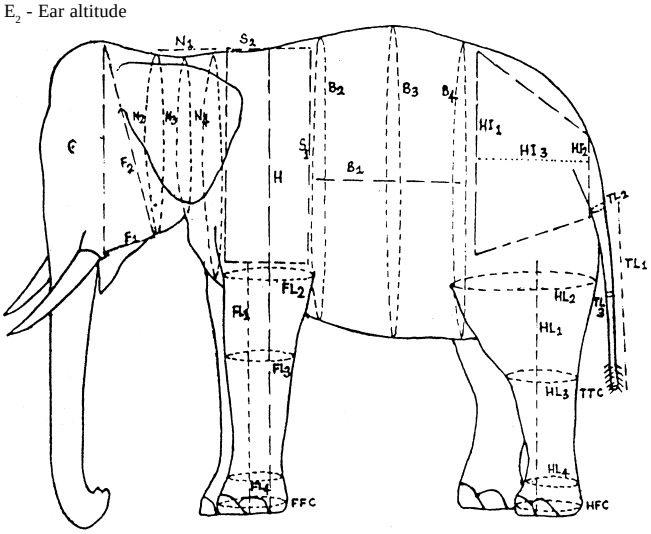


Figure 3. Sites at which body measurements have been taken (m):
F_1 - Face base length
F_2 - Face altitude
N_1 - Neck length
N_2,N_3,N_4 - Neck circumference
S_1-Shoulder length
S_2-shoulder breadth
H-Height at the shoulders
B_1-Body length
B_2-B_3,B_4-Body circumference
HI_1, HI_2 - Length of the two parallel sides of the hip
HI_3-Breadth between the two parallel Sides of the hip
FL_1 - Forelimb length
FL_2, FL_3, FL_4 - Forelimb circumference
FFC-Fore-footpad circumference
HL_1-Hindlimb Length
HL_2,HL_3,HL_4-Hindlimb circumference
HFC-Hind Footpad circumference
TL_1 - Tail length
TL_2, TL_3-Tail circumference
TTC-Tail tip circumference

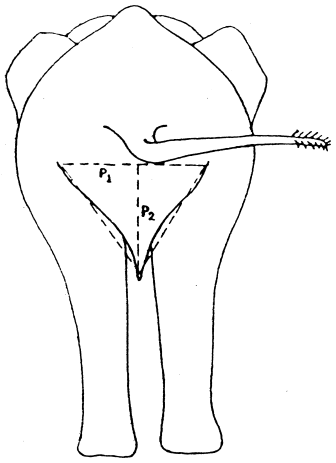


Figure 4. Sites at which body measurements have been taken(m)
P_1-Perineal region base length, P_2-Perineal region altitude

The trunk of the elephant was considered as a cylinder with both ends open. The length from the central point of the transverse line connecting the base of the two tusks (Base of the trunk) to the tip of the trunk was taken as the length of the trunk (T_1). The circumference was taken at three places,namely the base (T_2), middle (T_3) and tip of the trunk (T_4), and the mean of these three values was taken as the circumference of the trunk (Figure $_1$)

The fronto-nasal region (front of the head) was regarded as a rectangle; the straight line connecting the two fronto-lateral angles of the forehead was taken as one side and the line connecting the base of the tusks as the other side, the average of these two being FN_1. The straight lines drawn downwards connecting the above lines at their lateral ends formed the other two sides, the average of these being FN_2 (Figure 1)

The face region (side of the head) was treated as a triangle with the straight line length from the fronto-lateral angles of the forehead to the angle of the mandible as the altitude of the triangle (F_2) and the length from the angle of the mandible to the level of the caudal border of the mandibular symphysis as its base (F_1). The straight line connecting the caudal border of the mandibular symphysis and the fronto-lateral angle of the forehead then formed the third side of the triangle (Figure 3)

The ear of the elphant resembled a triangle, the length from the rostral angle of the attached border to the caudal angle of the ear forming the base (E_1). The rostral border (attached border) and the caudal border joined at the free end making the distal angle (apex). The height of the triangle was taken as the straight line length between the base and the apex of the ear (E_2) (Figure 1)

The jowl region was also considered as a triangle with the straight line distance between the angle of the mandibles as the base of the triangle (J_1) (Figure 2). The two horizontal rami of the mandibles which join in front at the mandibular symphysis formed the other two sides of the triangle. The

straight line distance from the apex of the lower lip to the base of the triangle formed the altitude of the triangle (J_2).

The neck was regarded as a cylinder with both ends open and was divided into three regions, namely, rostral, middle and caudal. The circumference of the rostral part (N_2) was taken at the level around the neck just at the angle of the mandible. The circumference of the middle region (N_3) was taken at about the level of the fourth cervical vertebra. Measurement of the caudal region (N_4) was taken at the base of the neck in front of the shoulder. The mean of these three measurements was taken as the circumference of the neck. The length of the neck (N_1) was taken as the length between the rostral transverse line, just behind the mandible, and the caudal transverse line, just in front of the shoulder (Figure 3).

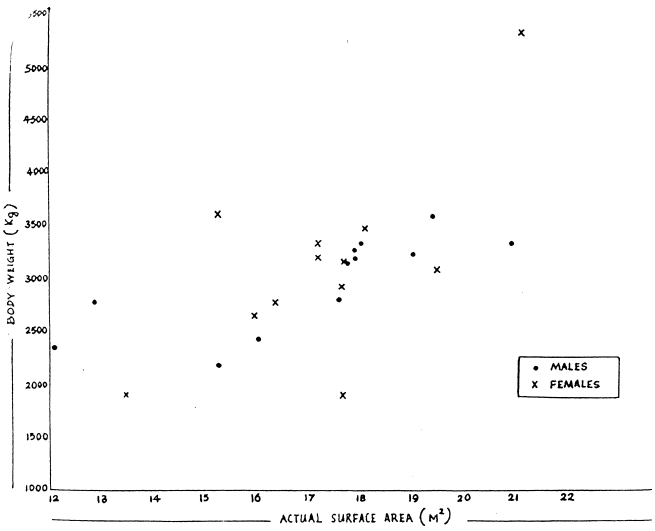
The body was regared as a cylinder with both ends open and the measurements were noted during the period of expiration at three levels - anterior, middle and posterior regions. The anterior body girth (B_2) was taken at the anterior part of the chest behind the transverse line connecting the external angle of the scapula to the olecranon process (anterior transverse line). The middle girth (B_3) was taken at the level of the eleventh rib and the posterior body girth (B_4) at the region in front of the posterior transverse line connecting the rostral end of the external angle of the ilium to the flap of skin ventrally (connecting the stifle to the belly). Again the mean of these three measurements was taken as the circumference of the body. The body length was taken as the distance between the anterior and posterior transverse lines (B_1) (Figure 3).

The shoulder region was regarded as a rectangle. The perpendicular line drawn from the spine of the seventh cervical vertebra down to the level of the lower end of the middle third of the arm formed one side and the perpendicular line drawn from the level of the fifth thoracic vertebra down to the level of the lower end of the middle third of the arm formed the other side, the average of these two measurements being S_1. The straight lines joining the ends of both these sides formed the other two sides formed by the straight line connecting the dorsal angle of the ilium to the lower end of the middle third of the thigh region (HI_1) and the other by the straight line from the level of the first coccygeal vertebra to the ischial tuberosity (HI_2). These two sides formed the parallel sides of the trapezium, the distance between them being HI_3 (Figure 3).

The fore-and hindlimbs were both considered as cylinders with one end closed. The height of the forelimb (FL_1) was the distance from the lower end of the middle third of the arm to the level of the footpad. The circumference was taken at three places, namely, the lower end of the middle third of the arm (FL_2), just below the elbow joint (FL_3) and just below the carpal joint (FL_4). The average of these three values was taken as the mean circumference. The height of the hindlimb was the distance from the lower end of the middle third of the thigh to the level of the footpad (HL_1). The circumference of the hindlimb was measured at the lower end of the middle third of the thigh (HL_2), just below the stifle joint (HL_3) and just below the hock joint (HL_4). The average of these three measurements was taken as the mean circumference of the hindlimb. Both the fore- and hind-footpads were assumed to be circular and their circumference was taken at the base of the foot around the nails the calculated areas of the footpads (FFC and HFC) were than added to the already calculated areas for vertical surfaces of the respective limbs to get the surface areas of the fore and hindlimbs (Figure 3).

The tail gave the appearance of a cylinder with one end closed (the tip of the tail). The circumference of the tail was taken at two places, these being the base (midline intersection of tuber ischii) (TL_2) and the middle (TL_3). The average of these two was taken as the mean circumference. The straight line distance from the base of the tail to the tip of the tail consituted the length (TL_1). The tail tip was assumed to be a circular figure; its circumference was measured and the calculated area (TTC) was added to the area of the tail (Figure 3).

The perineal region was taken to be a triangle extending from the lower end of the anal opening down the loose flap of skin lying between the thighs. The transverse line connecting the tuber ischii formed the base of the triangle (P_1). Two lines drawn from the tuber ischii connected at the apex, so as to include the loose flap of skin in the perineal region. The vertical length from the apex of the loose flap of skin to the base then formed the height of the triangle (P_2) (Figure 4).



Relationship between body weight (kg.) and total surface area (m^2)

Thus the total surface area of each elephant dould be derived as follows:

Area No.	Region	Calcuation (lengths in m from Figures 1-4)
1	Trunk	$T_1 \frac{T_2 + T_3 + T_4}{3}$
2	Fronto-nasal	$FN_1 x\ FN_2$
3	Face	$F_1 \times F_2$
4	Ears	$2 (E_1 \times E_2)$
5	Jowl	$(J_1 \times J_2) /2$
6	Neck	$N_1 \frac{(N_2 + N_3 + N_4)}{3}$
7	Shoulders	$2 (S_1 \times S_2)$
8	Forelimbs	$\frac{FFC^2}{2} + \frac{2FL^1 (FL^2 + FL^3 + FL^4)}{3}$
9	Body	$B_1 \frac{(B_2 + B_3 + B_4)}{3}$
10	Hips	$HI_3 (HI_1 + HI_2)$
11	Hindlimbs	$\frac{HFC^2}{2\pi} + \frac{2HL^1 (HL^2 + HL^3 + HL^4)}{3}$
12	Tail	$\frac{TTC^2}{4\pi} + \frac{TL^1 (TL^2 + TL^3)}{2}$
13	Perineum	$(P_1 \times P_2) /2$
	Total	$\sum_{13}^{1}$

The areas of the face, shoulder, hip and fore-and hindlimbs so calculated were doubled to incorporate both sides, while for the ear the area was quadrupled, since each ear has two surfaces.

The least square method of analysis (Snedecor and Cochran, 1967) was used to assess the relationship and derive prediction equations. The standard errors of the predicted values (SEEM) were taken as indicators of the relative accuracy of prediction of the various formula.

RESULTS

The measured total surface area of the adult female elephants (nos. 1 to 12 in Table III) ranged from 13.56 to 21.18m^2 and that of the adult male elephants (nos. 13 to 24 in table III) ranged from 12.16 to 20.97m^2. To derive simple prediction formulae, the areas of the individual regions and the measurements for the individual regions were correlated singly or in combination with the total surface area. In the case of individual regions, only those areas which gave correlation coefficients of above 0.70 were considered. In the case of individual measurements, only those giving a correlation coefficient of 0.80 and above were considered. The optimal equations thus worked out for predicting the total surface area of males and females or of adults irrespective of sex from the various parameters, singly or in combination, are shown in Table I. The most accurate prediction of total surface area appeared to be achieved by using two parameters, namely the height at the shoulders (H) and the forefootpad circumference (FFC) (SEEM = 0.80 $m^{2)}$

The accuracy of the prediction obtained using the formula s=-8.245 + 6.807H+ 7.073FFC is shown in Figure 5. However, application of this formula was by no means entirely accurate. One male elephant having a measured surface area of 12.16 m^2 was overestimated by 1.44m^2 (11.84% error) while another male having a measured surface area of 16.09 m2 was underestimated by 0.89m^2 (5.50% error).The highest overestimation in a female was 8.22% and the worst underestimation was 8.35%.

DISCUSSION

The total surface area of an animal can be used as an indicator of its total daily heat production (basal energy metabolism) and provides a valuable aid for determining the necessary supply of daily dietary energy. Since actual measurement of the surface area, adopting the techniques described in this paper, is strenuous and laborious under practical field conditions, a formula incorporating the exponential of the body weight, on the lines of conventional Meeh's formula (Dukes, 1955) for predicting the total surface area was tried. It was found that the coefficients of determination were low (r^2 = 0.5589 in males, 0.3972 in females and 0.3849 in adults irrespective of sex) and the SEEM values were also high. Hence the relationship between the body weight and actual surface area (Figure 6) was widely scattered and the use of the exponential of body weight cannot be recommended for predicting the total surface area in adult Indian elephants. Exponential equations were also fitted incorporating height along with body weight on the lines of Dubois' formula (Cena and Clark, 1981) but again the SEEM values were relatively high.

When the areas of individual regions were used to derive similar equations, relatively high correlations were obtained between the forelimb area (FLA, r= 0.7689) and total surface area, and between the ear area (EA, r = 0.7459) and total surface area. Hence, these two areas were used individually and in combination, in both simple linear and multiple linear regressions. However, again the SEEM values were high in all cases.

Individual measurements were then tried to obtain a better prediction equation. It was observed that measurements such as the height at the shoulders (H, r=0.9234), the forefootpad circumference (FFC, r= 0.8797) and the forelimb circumference (FLC, r = 0.8062) gave correlation ratios greater than 0.8 with total surface area and hence these were also used to derive simple linear and multiple linear

regressions (Table I). Of these simple equations involving only one parameter, the height at the shoulders (H), had the lowest SEEM value in the case of adult males, adult females and audlts irrespective of sex (Table II). Among the multiple linear regressions fitted, the SEEM value was lowest in adults irrespective of sex for the involving the height at the shoulders and the fore-footpad circumference. Although in the case of male elephants the lowest SEEM value was that for the equation S=-10.85 + 11.86 FFC+12.13FLC involving the height at the shoulders (H) and the forelimb circumference (FLC), the total surface areas obtained by adopting these equations in males and females respectively were not statistically different from the results obtained by applying the former equation. Hence, for simplicity's sake, the equation involving the height at the shoulders and the fore-footpad circumference is recommended for us with adult Indian elephants, irrespective of sex.

Benedict (1936) established the surface area of a single Indian elephant as 23.8m^2 using the conventional formula. The lower mean value for surface area recorded in the present study (Table III) can be attributed to the larger size of the sample as well as to the use of a better predictor.

Table III

The measured and estimated surface area (mean ± SE) using the recommended formula in 24 adult Indian elephants irrespective of sex.

Elephant	Meaured	Estimated surface area (m^2)
no.	surface area	S=-8.245 + 6.807H + 7.073FFC
1	17.17	16.73
2	17.22	17.55
3	17.21	16.46
4	17.74	16.58
5	18.17	18.31
6	15.33	16.59
7	13.56	13.69
8	17.72	16.24
9	21.18	21.42
10	16.06	16.21
11	19.51	18.63
12	16.44	16.58
13	12.90	13.83
14	12.16	13.60
15	17.60	16.79
16	18.03	18.65
17	20.97	20.70
18	17.91	18.31
19	16.09	15.20
20	19.40	19.33
21	17.90	18.65
22	15.30	14.65
23	19.05	19.68
24	17.75	17.97
Mean ± SE	17.18±0.46	17.18±0.43

S=Total surface area (m^2)

H=Height at the shoulders (m)

FFC = Fore-footpad circumference (m)

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