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THREE-DIMENSIONAL SAMPLING METHOD FOR CHARACTERIZING ANT MOUNDS

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ABSTRACT

A field-portable 3D laser scanner was employed as a means of digitizing the surface of fire ant (*Solenopsis invicta* Buren) mounds for analysis of shape and orientation in Mississippi and Oklahoma. Estimates of above-ground mound volume obtained through manual measurements of mound length, width, and height were higher and more variable than estimates obtained by summing the area underneath interpolated mound surfaces. Mounds were typically elliptical in shape and oriented in a north-south direction. The mound apex was offset to the northeast of the mean mound center by an average of 46 ± 5 mm. Additional mound characteristics extracted from 3D data included slope (degrees), surface area, and slope within mound aspect (northeast, southeast, etc.). Advantages of the methodology employed in this study and possible explanations for fire ant mound shape are discussed.

RESUMEN

Se utilizó un escáner portátil de tercera dimensión para digitalizar la forma y orientación de los montículos de las hormigas de fuego (*Solenopsis invicta* Buren) en Mississippi y Oklahoma. Los estimados del volumen de los montículos midiendo a mano el largo, ancho y altura de la porción que se encuentra encima del terreno, fueron mayores y tuvieron más margen de error que los datos obtenidos sumando el área por debajo de la superficie interpolada del montículo. Los montículos de forma elíptica en su mayoría, tuvieron el vértice del montículo desviado al noreste en un promedio de 46 ± 5 mm. Otras características adicionales extraídas de los datos de tercera dimensión incluyeron los grados de inclinación, área y orientación de la inclinación (noreste, sureste, etc.). Se discuten las ventajas de la metodología utilizada en este estudio y las posibles explicaciones sobre la forma de los montículos de las hormigas de fuego.

Translation provided by the author.

The nests of true mound-building ants, comprising some 10 genera within 3 subfamilies of the Formicidae (Hölldobler & Wilson 1990), are generally thought to facilitate microclimatic regulation. Ant mounds have been the subject of numerous studies related to thermal regulation, especially mounds of wood ants of the genus *Formica* Linné (Frouz 2000; Galle 1973; Horstmann & Schmid 1986). Mounds of some ant species are predictably asymmetrical, a characteristic so reliable that native peoples of the Alps use them as a sort of crude compass (Hölldobler & Wilson 1990).

Fire ant (*Solenopsis invicta* Buren) mounds have long been known to be asymmetrical. Hubbard & Cunningham (1977) noted that fire ant mounds tended to be oriented with the major axis extending in a north-south direction. Their findings were confirmed by Vogt et al. (2004). Additionally, there is evidence that fire ant mound shape is at least partially dependent upon season, presumably due to seasonal changes in temperature and sun angle (Vogt et al. 2004). The typical shape and orientation of fire ant mounds are thought to contribute to their function as solar collectors.

Previous attempts to estimate three dimensional (3D) characteristics of fire ant mounds, such as above-ground volume, have relied on assumptions that mounds are consistent, and conform to a specific, definable shape such as a semi-ellipsoid or an elliptic paraboloid (Porter et al. 1992; Vogt et al. 2004). Fire ant mounds are quite variable, however, and accurate determination of volume, slope, aspect, and other mound characteristics requires sampling methodology capable of assessing mound-to-mound variability. A rapid means of characterizing mounds in 3 dimensions would be very useful.

An experiment was conducted to test the performance of a portable laser scanner in digitizing fire ant mounds. Data extracted from 3D point clouds generated by the scanner were compared with volume estimates obtained based on previous methodology (Vogt et al. 2004). General mound orientation and shape characteristics were described, as well as relationships between surface aspect, surface area, and slope.

MATERIALS AND METHODS

A portable 3D laser scanner (Polhemus FastSCAN™ Cobra™, Polhemus, Colchester, Vermont, USA) was used to obtain 3D point clouds of

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fire ant mounds in the field. The scanner casts a fan of laser light over the object being scanned, and records the cross sectional profile of the object with a camera mounted on the wand with the laser light source. The orientation and position of the wand is recorded by a FASTRAK® device embedded in the wand and a receiver placed next to the object being scanned. A complete description of the scanner can be viewed at http://www.polhemus.com/fastscan.htm (last accessed October 16, 2006). Scanner resolution varies slightly with the distance of the wand to the object and is typically 1 mm at 200 mm distance.

Fire ant mounds were scanned and measured in Jackson, Mississippi (32°12'19" N, 90°14'32" W; Feb 2005; $n = 9$) and Durant, Oklahoma (34°0'59"N, 96°16'17" W; May 2006; $n = 10$). Both sites were vacant lots where *S. invicta* mounds were in good repair and showed evidence of recent mound construction. Fire ant populations at both sites were assumed to be monogyne based upon previous colony collections.

Mounds were prepared for sampling by clipping excess grass from the mound periphery and surface. A small (about 5 cm long) wooden arrow mounted on a dowel was placed next to each mound prior to sampling and oriented toward magnetic north. Scan progress was monitored in real time on a laptop computer. A light dusting of talcum powder on the mound surface and a surveyor's umbrella (Jackson site) or small hunting blind (Oklahoma site) were employed to increase reflectance of the laser on the mound surface and decrease the effects of ambient light. Scanning was stopped when the operator concluded that the point cloud sufficiently covered the mound surface and area immediately surrounding it. Raw data files consisted of about 100,000 to 160,000 points. Each mound also was measured with a meter stick (length, width, height) to the nearest cm.

Scanner data were exported in AutoCAD format (Autodesk, Inc., San Rafael, California, USA) as 3D point clouds on a 1 mm Cartesian coordinate system. Data were imported into ArcGIS 9.1 (ESRI, Redlands, California, USA) for extraction of shape characteristics. First, a 3D raster representing the mound surface was interpolated from the point cloud based on an Inverse Distance Weighted (IDW) procedure with a power of 0.5 and a variable search radius with 12 points (Fig. 1A). A power of 2 is typically used for IDW; reducing the power reduces the emphasis on the points nearest the point being estimated, resulting in a smoother surface. A new shapefile representing the outline of the mound was drawn manually to correspond with the apparent edge of the mound in the interpolated raster. The raster file was then clipped to the dimensions of the mound shapefile. The influence of grass stubble in the mound surface was reduced by calculating the average elevation of a circular neighborhood in the raster with a radius of 3 cells with the focal statistics tool in ArcGIS (Fig. 1B). The resulting raster was used to extract mound dimensions and shape. Major and minor axes were drawn through the mean center of the mound, the apex of the mound was located, and a line drawn from the mean mound center to the apex (Fig. 1C).

Mound volume (L) was calculated from manual measurements with the formula for the volume of half an ellipsoid:

$$\text{Volume} = 2/3 \cdot \pi \cdot a \cdot b \cdot c$$

where a is the semi-major axis, b is the semi-minor axis, and c is height from ground level (Porter et al. 1992) (manual method). Volume also was calculated with the surface volume tool in ArcGIS, which uses area, projected surface, and elevation data to calculate volume above a reference plane (in this case, the lowest elevation in the raster) (raster method). As a check on accuracy, we scanned a plastic cake pan cover and compared volumetric and raster-derived measurements, which were equivalent at 4.5 L. Volume data were analyzed with analysis of variance by Proc Mixed in SAS (Littell et al. 1996) to compare methodologies within the 2 sites.

Additional mound characteristics were extracted from the 3D rasters with 3D Analyst and Spatial Statistics tools in ArcGIS. Aspect and slope rasters were calculated (Fig. 1D, E, respectively). Aspect rasters were simplified into 4 classes for analysis; northeast (0°-90°), southeast (91°-180°), southwest (181°-270°), and northwest (271°-360°). Mean slope was calculated for each of the 4 aspect classes, and combined north- and south-facing aspects. Slopes were compared betweens sites with analysis of variance for a completely randomized design with mounds within sites as replicates by Proc Mixed in SAS (Littell et al. 1996). The distance between the mean mound center and the apex was determined as well as deviation from magnetic north for the line connecting the mound center with the apex. Mound shape in the plane of the ground was expressed as eccentricity (minor axis/major axis). Deviation of the major axis from magnetic north was noted as a measure of mound orientation. Average size and slope of the various aspects were compared with analysis of variance by site with Proc Mixed in SAS (Littell et al. 1996) for a randomized complete block design with mounds being the blocking factor. Means were expressed as mean ± SE and were considered different at the 0.05 significance level. Simple t-tests were used to test significance of other mound shape variables, combined between sites.

RESULTS

The formula for volume of half an ellipsoid overestimated mound volume compared with summing the area under a raster of the mound

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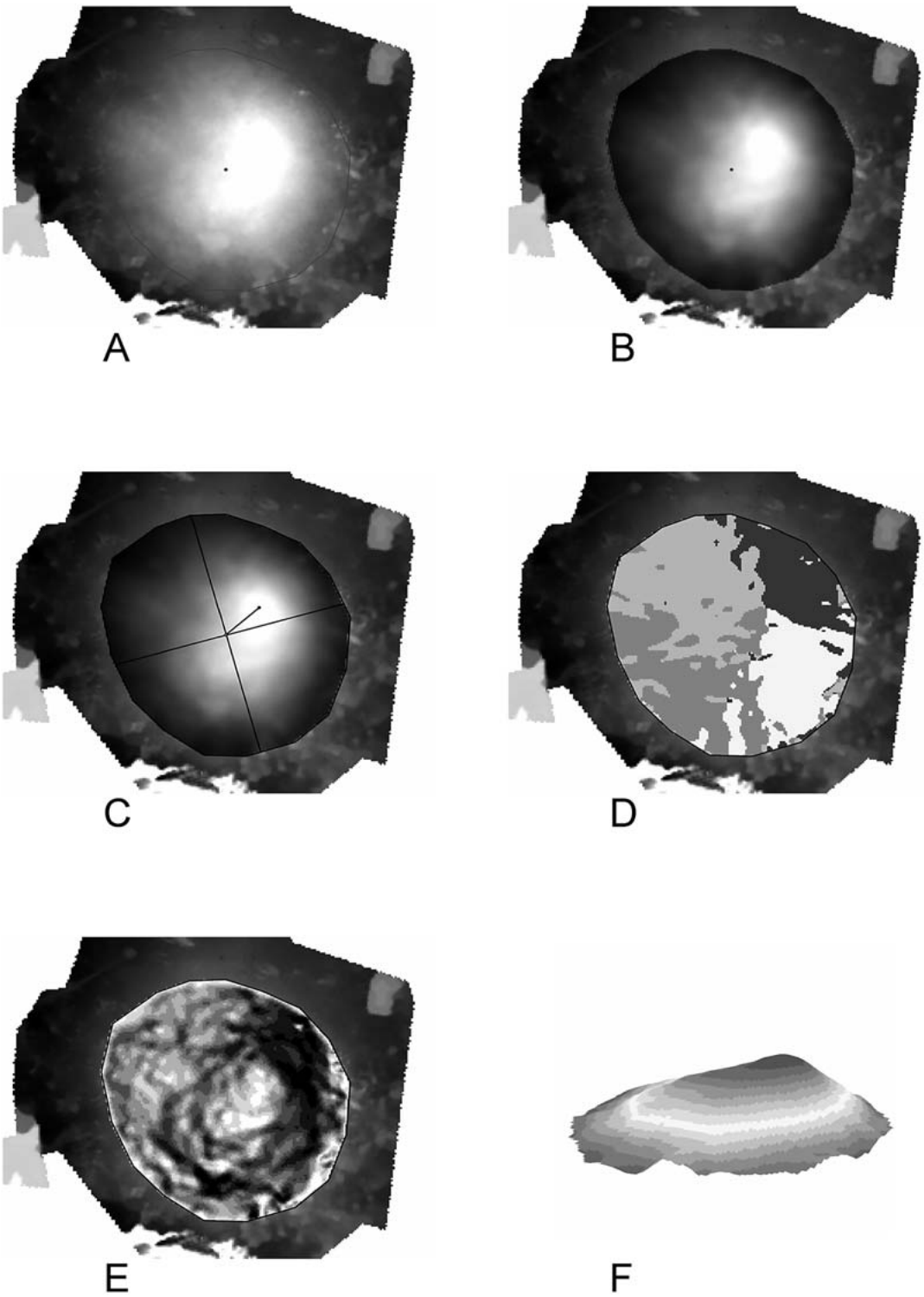


Fig. 1. Three dimensional representation of a fire ant mound. Interpolated surface with average center and mound outline (A); mound surface smoothed by focal statistics (B); major and minor axes, and line connecting average center to apex (C); aspect raster with 4 classes (NE, SE, SW, NW) (D); slope raster (steep slopes are darker) (E); classified 3D rendering of mound (F).

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surface (Paired *t*-test, $P = 0.0046$ and $P = 0.0120$ for Jackson and Oklahoma, respectively). Means obtained through the raster method were less variable than means obtained through the manual method. Data are presented graphically in Fig. 2. Overestimation of mound volume by the manual method increased with increasing mound size. Mound shape generally diverged from a standard ellipsoid, more closely resembling an oblique cone or hyperboloid (Fig. 1F). A more accurate estimate of mound volume derived from manual measurements of length, width, and height was given by calculating the volume of an oblique cone with an eccentric base:

$$y = \{1/3 * \pi * (0.5 * \text{length}) * (0.5 * \text{width}) * \text{height}\},$$

regressing y over the volume as determined by the raster method to yield slope m (0.7764) and intercept b (-0.2621), and adding a correction factor: $y * (1 - m) + (0 - b)$ (Fig. 2).

Site had a significant effect on overall average mound slope ($F = 18.3$, $df = 1, 17$, $P = 0.0005$). Mean mound slope at the Jackson site was about 30% higher than at the Oklahoma site (slope = 32.6 ± 1.0 and 23.4 ± 0.8%, respectively). Average slope of the mound surface varied by aspect for both the Jackson and Oklahoma sites ($F = 8.5$, $df = 3, 24$, $P = 0.0005$ and $F = 3.1$, $df = 3, 27$, $P = 0.0428$, respectively). In Jackson, northeast-facing slopes were steepest, while in Oklahoma west-facing slopes were steepest. Aspect had a significant effect on surface area (cm^2) at the Jackson site ($F = 6.83$, $df = 3, 24$, $P = 0.0017$) but not at the Oklahoma site ($P = 0.3071$). Generally, northwest-facing aspects were largest. Combined south-facing slopes were similar to combined north-facing slopes at both sites ($P > 0.05$). Results are summarized in Table 1.

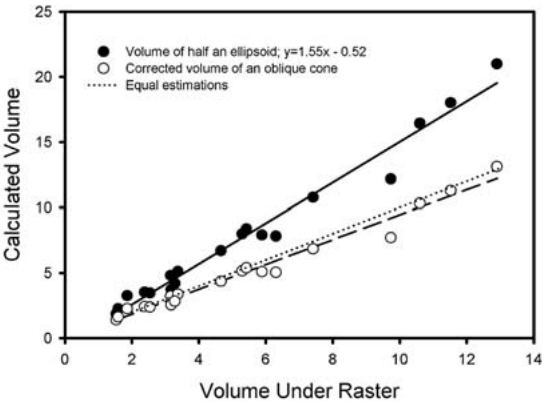


Fig. 2. Fire ant mound volume determined with the formula for volume of half an ellipsoid (solid line) and modified formula for volume of an oblique cone (dashed line) (y axis, "calculated volume") plotted as a function of summed volume under a raster surface (x axis, "volume under raster"). The dotted line represents equal estimations (slope = 1).

The position of the mound apex was significantly different from the position of the mean mound center (average distance = 45.8 ± 5.1 mm, $n = 19$, $t = 8.9$, $P < 0.0001$). On average, the line connecting the center to the apex was offset from magnetic north by 52.1 ± 18.2 degrees. The major axis of the mound was offset from magnetic north by -5.2 ± 8.8 degrees, which was statistically indistinguishable from zero ($n = 19$, $t = -0.596$, $P = 0.5585$). Average mound eccentricity was significantly different from 1 (1 = perfect circle) ($n = 19$, $t = -11.8$, $P < 0.0001$) and averaged 0.81 ± 0.02. A hypothetical fire ant mound based on these data and viewed from above is illustrated in Fig. 3.

Discussion

Accurate characterization of nest volume is important for relating nest size to colony biomass. The estimation method presented above, based on manual measurements, geometric formulae, and a correction factor based on equal estimations, represent a significant improvement over previous methods of estimating mound volume. This method should prove useful to researchers who do not have access to a 3D laser scanner, or require rapid measurement of several mounds in the field.

Laser scanning methodology will be useful for formulating hypotheses regarding mound shape and function. If mounds serve as solar collectors, mound shape may be related to sun angle, which is dependent upon geographic location and date. Specifically, mound slope may be inversely related to maximum sun angle, since insolation increases as a surface approaches perpendicular to the sun. In this study, mounds at the Jackson site (maximum sun angle = 46°) had steeper average slopes than mounds at the Oklahoma site (maximum sun angle = 73°). Interestingly, the ratio of sun angles between sites (0.63) closely approximated the ratio of mound slopes (0.71). If south-facing slopes maximize insolation, then the sum of the average mound slope and the maximum sun angle should approach 90°. This sum was 77.4° and 96.2° at the Jackson and Oklahoma sites, respectively. Work is underway to compare slope-aspect relations under varying geographic and temporal conditions to test this hypothesis.

The mound apex was predictably offset to the north of the mean mound center. This trend, as well as the trend toward a greater proportion of the mound surface facing south at the Jackson site, increases southern exposure of the mound. Mounds were also elongated in a north-south direction, confirming earlier findings by Hubbard & Cunningham (1977) and Vogt et al. (2004). This predictable shape may be useful as remote sensing methods for detecting and quantifying imported fire ant mounds are developed (Vogt 2004).

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TABLE 1. FIRE ANT MOUND SHAPE CHARACTERISTICS AT 2 STUDY SITES.

Site	Aspect	Surface area[1] (cm^2)	Mean slope (degrees)
Jackson	Northeast	202 ± 45 b	36.1 ± 1.9 a
	Southeast	266 ± 45 a	33.8 ± 1.9 ab
	Southwest	269 ± 45 a	29.0 ± 1.9 c
	Northwest	301 ± 45 a	31.5 ± 1.9 bc
Oklahoma	Northeast	333 ± 68 a	21.5 ± 1.6 b
	Southeast	328 ± 68 a	23.1 ± 1.6 ab
	Southwest	350 ± 68 a	24.4 ± 1.6 a
	Northwest	375 ± 68 a	24.7 ± 1.6 a

[1]Estimated least squares means; means within a site followed by the same letter are not significantly different (Pairwise Differences of Least Squares Means). Data extracted from 3D laser scans.

Potential drawbacks to this technology include the initial investment in equipment (>$15,000) and training in 3D and spatial analyses. Portability of the scanning device in the field is limited by the need for a power supply (in this case, a 12 V deep cell marine battery), which requires a cart or field vehicle for transport. The portable 3D laser scanner employed in this study does, however, offer several advantages over previous methods used to characterize mound shape. Most importantly, digitized data easily can be imported into 3D and spatial analysis software programs for extraction of data relating to slope and aspect, enabling more rigorous testing of hypotheses relating to mound function. Minor difficulties with low reflectance of the mound surface and interference from ambient light can be overcome by dusting the surface with talcum powder and shading the mound. Additional work is targeted toward examination of mound shape in different soils, under varying geographic and temporal conditions.

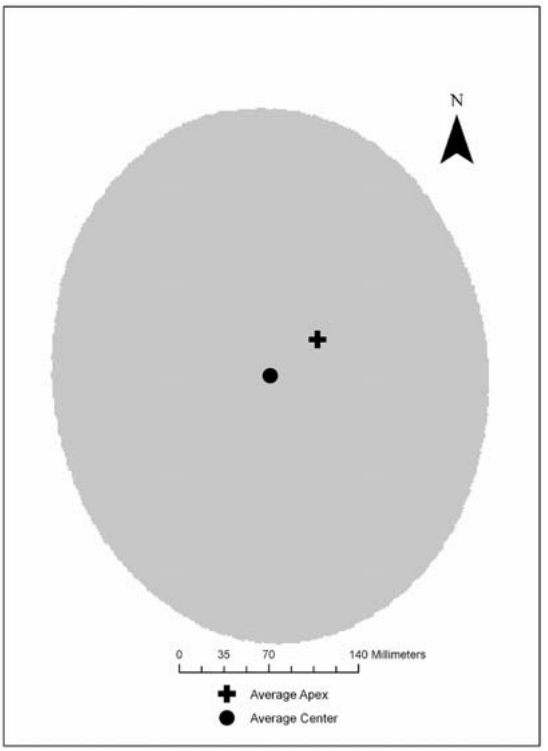


Fig. 3. Aerial view of hypothetical fire ant mound.

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