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Soil Physical Property Changes during Dung Decomposition in a Tropical Pasture

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ABSTRACT

The contributions of soil macroinvertebrates to the creation and maintenance of soil structure in tropical rangeland ecosystems are poorly understood, in spite of the fact that compaction is frequently cited as a limiting factor in pasture production. Decomposition of cattle dung (fecal material) is associated with high levels of soil macroinvertebrate activity. We hypothesized that bulk density and surface penetrometer resistance would be reduced in soil beneath decomposing cattle dung patches and that soil water infiltration capacity and drainable porosity would be increased. Cattle dung was deposited in patches during the dry and wet seasons of 1991 in a seasonally dry pasture located 5 km north of Cañas, Costa Rica, on a Typic Argiustoll. At the end of the wet season, surface 3-cm bulk density was <0.93 Mg m^{-3} under dung patches, compared with 1.05 Mg m^{-3} in control plots. Drainable porosity, defined as air-filled porosity at 0.006 MPa, increased from 13% in control plots to >21% under dung. Similar, but smaller, differences were recorded at dung patch edges and at a depth of 4 to 7 cm. At the end of the wet season, equilibrium infiltration rates averaged 71 mm h^{-1} in the patch plots and 34 mm h^{-1} in the controls. Changes in penetrometer resistance were transient and no treatment effects persisted to end of the wet season. The results of this study indicate that processes associated with dung decomposition play a role in reducing surface compaction.

PASTURE DEGRADATION due to overgrazing is a major problem in Central and South America (World Resources Institute, 1992). Traditional pasture improvement strategies for reducing compaction are frequently not practicable because of financial, equipment, and topographic limitations. Recent work in temperate systems has demonstrated that macroinvertebrates, particularly earthworms, can play a significant role in maintaining and improving soil structure by contributing to aggregate and macropore formation, and that organic matter and other inputs can be managed to optimize macroinvertebrate impact (Edwards and Bater, 1992). Management of these processes in the tropics is currently limited by an inadequate understanding of them and their effects on soil structure.

Cattle dung is one of the few inputs available for management in tropical pasture systems. Dung is defined here as fecal material only. Dung decomposition has been widely associated with increased levels of soil macroinvertebrate activity (Holter, 1979; Whitford et al., 1992) and with localized improvements in soil fertility (Petersen et al., 1956; Dickinson et al., 1981; Omaliko, 1984). However, there are few reports of the effects of dung decomposition on soil physical properties, with the exception of a few studies that noted or described the creation of burrows by dung-consuming coleoptera (Alves, 1976; Brussard and Hijdra, 1986; Edwards and Aschenborn, 1987).

The objectives of this study were to: (i) evaluate the spatial effects of dung decomposition on soil bulk density, surface penetrometer resistance, soil water retention characteristics, and infiltration capacity, and (ii) compare changes within dung-affected areas for dung deposited during the dry and wet seasons.

METHODS

The study was conducted in a pasture at Hacienda La Pacifica, 5 km north of Cañas, Guanacaste, Costa Rica (10°28′36.8″N, 85°9′14.5″W; altitude: 50 m). A summary of the edaphic and climatic features of the site is presented in Table 1. The study site is typical of pastures in the seasonally dry Pacific coastal regions of Central America and is characterized by a December to April dry season. It is dominated by jaragua [*Hyparrhenia rufa* (Nees) Stapf], a low-quality (Vargas and Fonseca, 1989) pasture grass introduced from Africa (Daubenmire, 1972). This grass accounted for >99% of the aboveground biomass at the site (Herrick, 1993). Standing biomass ranged from 1.5 to 9 Mg ha^{-1} during the experiment.

Dung was produced by five 2-yr-old steers (*Bos taurus*) that were housed in stables designed to keep the dung and urine separate. The cattle were fed a low-quality diet of freshly cut African stargrass (*Cynodon nlemfuënsis* Vanderyst) in order to simulate a jaragua diet. Stargrass was substituted for jaragua because it was impossible to obtain jaragua of consistent quality in sufficient quantities. The stargrass had an in vitro dry matter digestibility of 33 to 36%, which is typical for jaragua pastures in northwestern Costa Rica (Vargas and Fonseca, 1989). All dung from the animals was collected by hand for 24 h prior to deposition on the pasture and stored in loosely closed white plastic bags in the shade. At 1400 h, the dung was thoroughly homogenized by hand, and transported to the field in 1500-g portions. The dung portions were dropped from a height of 1.5 m to assure normal dung-to-soil contact. The resulting dung patches were circular with an average diameter of 21 cm (20–22 cm), an average height of 4.3 cm (4.0–4.8 cm) and a volume of approximately 1.5 L. This volume is typical for dung patches deposited in the Guanacaste region (Herrick, 1993) and approximates that reported by Underhay and Dickinson (1978) for steers in England (1.6 L).

The experimental dung patches were deposited in 1991 at the beginning of the dry season and in different plots at the beginning of the wet season. The average dung dry matter content was 22.0% for the dry-season deposition and 17.6% for the wet-season deposition. Each patch was deposited in the center of a randomly selected 0.8 by 0.8 m plot located in a 0.5-ha grid. Controls were randomly selected from the remaining plots. Cattle were excluded from the 0.5-ha experimental area beginning in January 1990, except for a 12-h period on 18 and 19 Dec. 1990. Grass cover in the area was machine cut at 9 cm immediately prior to each dung deposition. During the rest of the study period, the pasture was maintained at a height of 20 to 53 cm by machete.

Nine dung-patch and nine control plots were randomly selected and sampled 12, 60, 140, and 270 d after the dry-season deposition, and 12, 60, and 140 d after the wet-season deposition. A different set of plots was selected for each sampling.

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Table 1. Edaphic and climatological characteristics of the study site.

Soil	
Soil classification	Typic Argiustoll
Parent material	Volcanic tuff
Slope, %	1-3
Texture (A horizon)	Loam
Sand, %	38
Silt, %	42
Clay, %	20
pH	6.0
Cation-exchange capacity, cmol$_c$ kg^{-1}	21.4
Base saturation, %	72
Olsen P, mg kg^{-1}	2.68
Climate†	
Precipitation, mm	
Annual – 70-yr avg.	1574
Annual – 70-yr regression	1206
Annual – 1991	944
Annual potential evapotranspiration (1991)	3200
Monthly avg. temperature (1991), °C	27-31
Monthly avg. relative humidity (1991), %	60-90

† Long-term precipitation data are from Hagnauer (1993). Other data from instruments located at the study site.

The dry-season deposition 270-d sampling and the wet-season deposition 140-d sampling were completed during the first week of November, following the last significant precipitation event (>5 mm) of the wet season. Bulk density and soil surface penetrometer resistance were measured at the locations and depths illustrated in Fig. 1. Bulk density was measured using the core method. Two cores 5 cm in diameter and 3 cm in height were removed from each sampling location, composited, oven dried, and weighed (Blake and Hartge, 1986). In order to reduce sampling time and to focus on the more biologically active 0- to 7-cm layer, only three of the nine replications were sampled at the 12- to 15-cm depth. Surface penetrometer resistance was measured using a modified pocket penetrometer (Bradford, 1986). The pressure required to insert the 10-mm-diam. loop of 1.9-mm-diam. steel wire 10 mm into the soil surface was determined at 15 points at each location at the original soil surface and, for locations beneath the dung, at the surface of the soil accumulated during decomposition.

Soil water retention characteristics were determined at the end of the study only, and only for soil beneath the patch centers and in the control plots. A set of intact cores was removed from all nine replications for this analysis during bulk density sampling. The cores were equilibrated at 0.001, 0.003, and 0.006 MPa on a tension table and at 0.033, 0.1, and 0.3 MPa on ceramic pressure plates. Water retention at 1.5 MPa was determined using disturbed samples from the cores (Klute, 1986). Drainable porosity and the soil water-holding capacity were calculated from the water retention data and the respective bulk densities (Danielson and Sutherland, 1986). Drainable porosity was defined as the proportion of the soil volume not occupied by solid particles or water at 0.006 MPa of suction. The soil water-holding capacity was defined as the volume of water removed from the soil between 0.006 and 1.5 MPa.

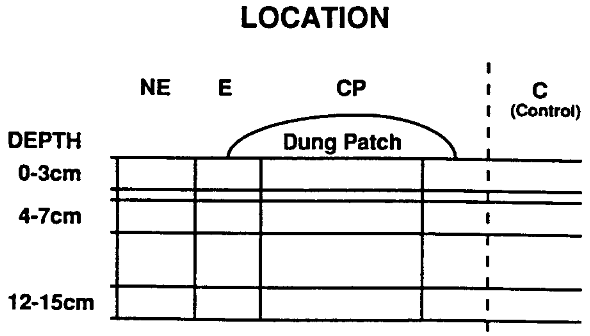

Fig. 1. Soil sampling locations and depths. The rounded object at the soil surface represents the approximate dimensions of a typical dung patch. NE, E, and CP are near edge, edge, and center of patch, respectively.

Infiltration capacity was measured in four control plots and four of the wet-season deposition plots on 20 and 21 November, 20 d after the final soil sampling and 160 d after the wet-season deposition. A double-ring infiltrometer was used (Bouwer, 1986). The inner ring had a diameter of 13.5 cm and encompassed the center and edge locations in the patch plots (CP and E in Fig. 1).

The general linear model of the analysis of variance (ANOVA) was used to identify effects of location and depth for each sampling date. Changes in bulk density and penetrometer resistance with time were also evaluated with the ANOVA for selected locations and depths. Seasonal fluctuations in bulk density and penetrometer resistance were removed by dividing by the control for the appropriate depth and date. Means separations for significant treatment effects are based on appropriate least significant differences. Kruskal–Wallis Rank tests were used when the assumptions of the ANOVA were not met due to unequal treatment variances; Dunn's equation (Neter et al., 1990) was then used for means separation. Significance was evaluated at the $P = 0.05$ level, except where otherwise noted.

A least squares analysis was used to fit the infiltration data to the integrated Philip equation (Philip, 1957):

$$I_t = St^{1/2} + At \qquad [1]$$

where t is time since initiation (h), I is cumulative infiltration at time t (mm), S is soil water sorptivity (mm$^{-1/2}$), and A is transmissivity (mm h^{-1}). Differences between the two treatments for the relationship between cumulative infiltration and time, and for the coefficients corresponding to sorptivity and transmissivity, were compared by specifying treatment as an indicator variable in the least squares analysis (Neter et al., 1990). General observations were made throughout the study of both experimental and nonexperimental plots to supplement interpretation of the results.

RESULTS AND DISCUSSION

Bulk Density

Soil bulk density was significantly reduced beneath both dry- and wet-season deposition dung patches by the end of the wet season (Fig. 2). Bulk density reductions were greatest near the surface directly beneath the dung patches and declined with increasing depth and distance from the center. Bulk density 0 to 3 cm beneath the patches declined as a proportion of the control during the early stages of decomposition for both the dry- and wet-season deposition patches (Fig. 3). No changes were recorded after 60 d for the dry-season deposition and after just 12 d for the wet-season deposition. The pattern of changes in bulk density with time illustrated in Fig. 3 was repeated at a smaller amplitude at the other depths and distances from the patch center, corresponding to the patterns recorded at the final sampling (Fig. 2).

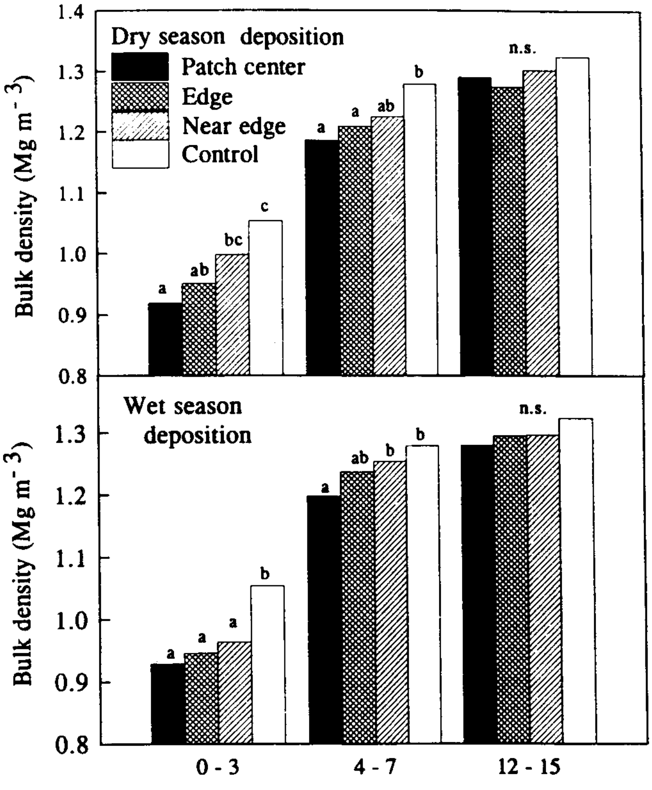

Fig. 2. Soil bulk density at the end of the wet season (November) compared for control and dry-season deposition patch locations at three depths. See Fig. 1 for sampling locations. Different letters over bars within depths indicate a significant difference ($P < 0.05$; $n = 9$ for 0–3 and 4–7 cm; $n = 3$ for 12–15 cm).

Soil Water Retention

The bulk density reduction below the center of the patches was reflected in significantly increased soil water retention in the range of 0.0 to 0.003 MPa suction for soil at 0 to 3 cm below the original patch–soil interface for both the dry- and wet-season depositions (Fig. 4). The plant available water capacity, defined as soil water availability at suctions between 0.006 and 1.5 MPa, actually declined beneath the dung (Fig. 4). This was due to the increase in macroporosity associated with the reduction in bulk density. As expected based on the bulk density data in Fig. 3, no significant differences were found at 4 to 7 cm and 12 to 15 cm beneath the original soil surface (Fig. 4).

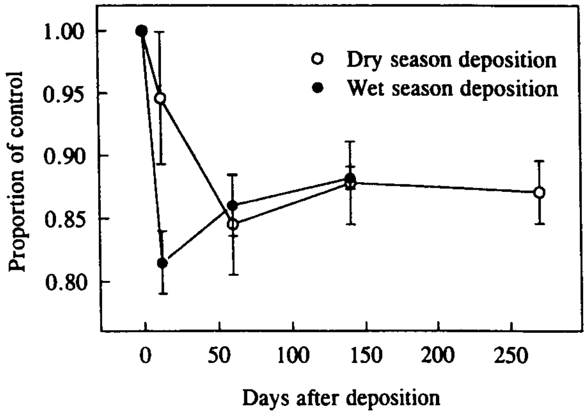

Fig. 3. Soil bulk density at 0 to 3 cm below the center of dry- and wet-season patches as a proportion of average of 0- to 3-cm depth in the control for each sampling date. Mean bars ± 1 standard error ($n = 9$).

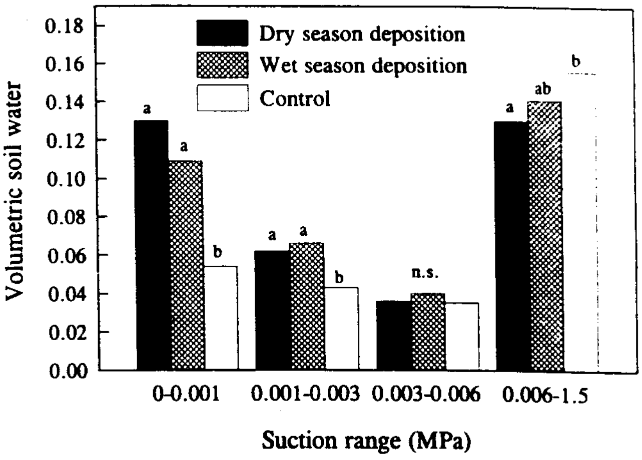

Fig. 4. Volumetric soil water-holding capacity in four ranges of soil suction between 0.0 and 1.5 MPa at the end of the study (November) compared for control and dry- and wet-season deposition patch center locations. Different letters over bars within depths indicate a significant difference ($P < 0.05$); n.s. indicates not significant ($P > 0.05$; $n = 9$).

Surface Penetrometer Resistance

Surface penetrometer resistance at the original soil surface below the patch declined for the first 60 d, then rebounded to near control levels (Fig. 5). By the end of the wet season, the effect was statistically nonsignificant for both the dry- and wet-season depositions. The penetrometer resistance of the soil that accumulated beneath the dung crust on the original soil surface was below the detection level of the penetrometer (0.21 MPa).

Infiltration Capacity

There was a significant treatment effect on the relationship between time and infiltration rate (Fig. 6, Table 2).

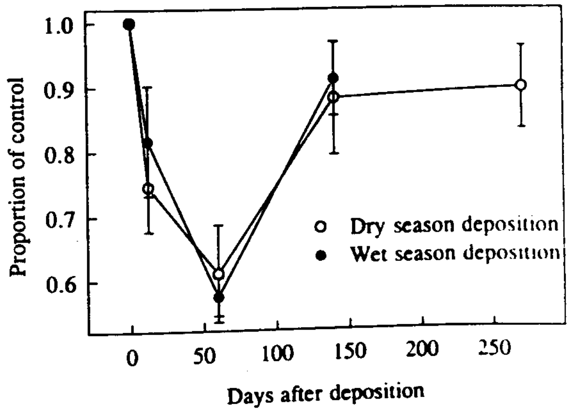

Fig. 5. Penetrometer resistance with time at original soil surface as a proportion of average of control plots for each sampling date. Mean bars ± 1 standard error ($n = 9$).

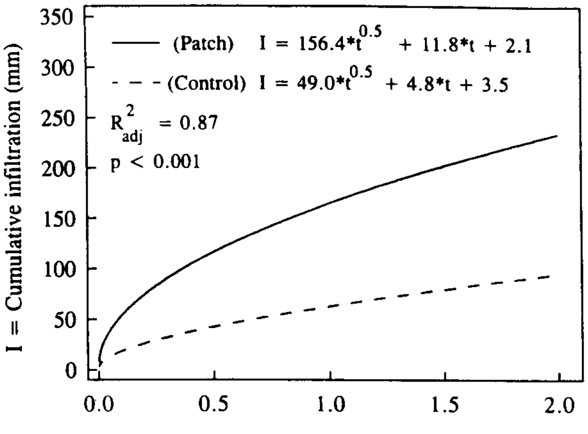

Fig. 6. Cumulative infiltration (*I*) in control and wet-season deposition patch plots at the end of the wet season (November). Curves are based on the Philip equation fit to data from four patch and four control plots. Coefficient of multiple determination is for both sets of data regressed with an indicator variable to distinguish between patch and control.

All tests indicated that the Philip equation provides an adequate fit to the data. Coefficients of multiple determination were >99.5% for all plots. The formal lack of fit test for the pooled data was highly nonsignificant ($P = 1.0$), indicating that the inclusion of additional variables would not have improved the fit of the model.

In spite of the excellent fit of the Philip equation and the highly significant difference between the models for the patch and control plots, only one of the two parameters, sorptivity (S), was significantly greater in the patch model than in the control model. Sorptivity is related to the intake capacity of the soil early in the infiltration process and therefore is closely related to the characteristics of the soil surface and the A horizon. The calculated transmissivity (A) was not significantly different between the two treatments. The transmissivity regulates the later stages of infiltration. The model is relatively insensitive to this parameter when fitted for a period as short as 2 h. The average final infiltration rate can be used in place of the transmissivity to predict the effect of the two treatments on infiltration in a saturated system. The final rate was more than twice as great in patch plots as in the controls (Table 2). The significantly greater cumulative infiltration recorded for the patch plots is a function of both the higher sorptivity and infiltration capacity. Differences in both of these parameters can be attributed to increased macroporosity below the dung patches (cf. Fig. 4).

Table 2. Parameters derived from infiltration tests ($n = 4$).†

	d*I*/d*t*	*I*(2h)	*I*(Philip)	*S*	*A*
	mm h^{-1}	mm	mm	mm $h^{-0.5}$	mm h^{-1}
Patch	71(17)a‡	237a	231a	156a	4.8a
Control	34(5)b	96b	92b	49b	11.8a

† d*I*/d*t* is the 2-h equilibrium infiltration rate and *I*(2h) is the total measured infiltration. *I*(Philip), *S*, and *A* are the total infiltration predicted by the fitted Philip equation and the coefficients of that equation based on least squares analysis of the pooled data.

‡ Means followed by the same letter are not significantly different ($P > 0.05$).

The Role of Macrofauna

The high degree of association of the soil-dwelling termites *Amitermes beaumontii* and *Hoplotermes* sp. nov. with the cattle dung patches beginning within 12 d of dung deposition and the relative paucity of other soil macroinvertebrates (Herrick, 1993) suggested that termites were responsible for most of the recorded reduction in bulk density and the increase in infiltration capacity of the soil. This conclusion is supported by the water retention data, which showed that most of the changes occurred in the 0 to 0.001 MPa suction range, corresponding to pores >0.3 mm in diameter. Termites were observed in tunnels 2 to 5 mm in diameter and in cavities 10 to 50 cm^3 in volume during soil sampling of the experimental plots. These dimensions are similar to those reportedly created by the soil-dwelling termite *Drepanotermes niger* in Australia (Whitford et al., 1992).

Although no bulk density changes were recorded below 7 cm (Fig. 2), the large increase in infiltration capacity and observations of tunnels and galleries made while excavating a soil profile indicate that at least some of the pores created near the soil surface beneath the dung penetrated at least 80 cm below the surface. The lack of changes in bulk density at 12 to 15 cm (Fig. 2) is not surprising. While the dung provides a transient focus for termite activity at the surface, tunnels connecting to more permanent cavities scattered throughout the solum would be expected to follow a direct path, which may or may not lead directly down from the dung.

Dung beetle (coleoptera) activity may explain the more rapid changes in bulk density for the wet-season deposition patch plots. While termites were found associated with dung from both depositions throughout the study, dung beetles colonized the dung only during the wet season.

Persistence of Effects

The data and literature indicate that the effects of dung decomposition on soil physical properties, while locally significant in the short term, may be short lived. Even without grazing, Elkins et al. (1986) found declines in bulk density and infiltration capacity just 4 yr following termite removal. Termite abandonment of the dung patch plots and erosion of the remaining dung crust, both of which were well underway by the end of the study, would expose the fragile soil–tunnel matrix constructed above the soil surface to erosive forces. The data show that penetration resistance at the original soil surface returned to near-control levels within 140 d of dung deposition, in spite of the fact that the resistance of the soil matrix that replaced the dung was below the detection level of the pocket penetrometer. This suggests that some filling and resettling of soil particles occurred even while the termites were present. However, the maintenance of the bulk density reductions through the end of the study indicates that some macropores were maintained. This is supported by Brussard and Hijdra (1986), who found that macroporosity remained higher in dung beetle tunnels than undisturbed soil, even after backfilling.

CONCLUSIONS

The results of this study suggest that processes associated with dung decomposition play a role in reducing surface compaction by increasing the volume of soil macropores. The air-filled porosity at 0.006 MPa increased 67% and soil bulk density was reduced by 10% in the top 0 to 3 cm of soil under dung patches deposited during both the dry and wet season, while 2-h infiltration capacity increased 240% in wet-season deposition dung patch plots. These changes appear to be tied to macroinvertebrate activity in general and soil-dwelling termite activity in particular. The factors affecting the activity of these organisms, including the quantity and distribution of cattle dung, should be considered as one potential component of strategies to improve and maintain the hydrological characteristics of pasture soils.

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REFERENCES

Alves, B.S. 1976. Incorporacao de excrementos bovinos por *Dichotomius longiceps* (Taschb., 1870). Ecossistema 1:59-60.

Blake, G.R., and K.H. Hartge. 1986. Bulk density. p. 363-375. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Bouwer, H. 1986. Intake rate: Cylinder infiltrometer. p. 825-844. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Bradford, J.M. 1986. Penetrability. p. 463-478. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Brussard, L., and R.D.W. Hijdra. 1986. Some effects of scarab beetles in sandy soils of the Netherlands. Geoderma 37:325-330.

Danielson, R.E., and P.L. Sutherland. 1986. Porosity. p. 635-662. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Daubenmire, R. 1972. Some ecologic consequences of converting forest to savanna in northwestern Costa Rica. Trop. Ecol. 13:31-51.

Dickinson, C.H., V.S. Underhay, and V. Ross. 1981. Effect of season, soil fauna and water content on the decomposition of cattle dung pats. New Phytol. 88:129-141.

Edwards, C.A., and J.E. Bater. 1992. The use of earthworms in environmental management. Soil Biol. Biochem. 24:1683-1689.

Edwards, P.B., and H.H. Aschenborn. 1987. Patterns of nesting and dung burial in *Onitis* dung beetles: Implications for pasture productivity and fly control. J. Appl. Ecol. 24:837-851.

Elkins, Z., G.V. Sabol, T.J. Ward, and W.G. Whitford. 1986. The influence of subterranean termites on the hydrological characteristics of Chihuahuan desert ecosystem. Oecologia 68:521-528.

Hagnauer, W. 1993. El Sistema agroecologico de Guanacaste: Oportunidades y desafios para la agricultura y el turismo. *In* Modernización de la agricultura y turismo con desafio ecologico: Los desafios para Cañas, Guanacaste. Cañas, Guanacaste, Costa Rica. 3 Apr. 1992. Instituto Interamericano de Cooperación para la Agricultura, San Jose, Costa Rica.

Herrick, J. 1993. Restoration of tropical pastures and the role of cattle dung patches. Ph.D. diss. Ohio State Univ., Columbus (Diss. Abstr. 94-11967).

Holter, P. 1979. Effect of dung-beetles (*Aphodius* spp.) and earthworms on the disappearance of cattle dung. Oikos 32:393-342.

Klute, A. 1986. Water retention: Laboratory methods. p. 635-662. *In* A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Neter, J., W. Wasserman, and M.H. Kutner. 1990. Applied linear statistical models. 3rd ed. Irwin, Homewood, IL.

Omaliko, C. P. E. 1984. Dung decomposition and its effects on the soil component of a tropical grassland ecosystem. Trop. Ecol. 25: 214-220.

Petersen, R.G., W.W. Woodhouse, and H.L. Lucas. 1956. The distribution of excreta by freely grazing cattle and its effect on pasture fertility: II. Effect of returned excreta on the residual concentration of some fertilizer elements. Agron. J. 48:444-449.

Philip, J.R. 1957. The theory of infiltration: 4. Sorptivity and algebraic infiltration equation. Soil Sci. 84:257-264.

Underhay, V.H.S., and C.H. Dickinson. 1978. Water, mineral and energy fluctuations in decomposing dung pats. J. Br. Grassl. Soc. 33:189-196.

Vargas, E., and H. Fonseca. 1989. Contenido mineral y proteico de forrajes para rumiantes en pastoreo en Costa Rica. Universidad de Costa Rica, San Jose.

Whitford, W.G., J.A. Ludwig, and J.C. Noble. 1992. The importance of subterranean termites in semi-arid ecosystems in south-eastern Australia. J. Arid Environ. 22:87-91.

World Resources Institute. 1992. World resources: A guide to the global environment. Oxford Univ. Press, New York.