SOIL HYDROLOGIC RESPONSE TO INTENSIVE ROTATION GRAZING:

A STATE OF KNOWLEDGE

Steven D. Warren

Pages 488-501. In: Y.S. Fok (editor), Proceedings of the International Conference on Infiltration Development and Application. January 6-9, 1987. Water Resources Research Center, University of Hawaii at Manoa, Honolulu, Hawaii, USA

SOIL HYDROLOGIC RESPONSE TO INTENSIVE ROTATION GRAZING: A STATE OF KNOWLEDGE

Steven D. Warren[1]

An extensive review of the available scientific literature provides no support for a hypothesis suggesting that infiltration rates improve with the implementation of intensive systems of rotational grazing. Intensive rotational grazing systems are generally characterized by significantly lower infiltration rates than are ungrazed exclosures, indicating a negative hydrologic impact. The detrimental impact of intensive rotation grazing is very similar to that incurred under comparably stocked continuous grazing regimes. The decline in infiltration rates is most apparent in recently grazed pastures versus rested pastures, and is related to reductions in protective organic cover and modifications of surface soil properties which accompany intense periodic livestock activity. Stocking rate may be the most important variable governing the hydrologic impact of intensive rotation grazing systems. As stocking rates increase beyond recommended moderate levels, infiltration rates decline dramatically.

INTRODUCTION

Rotational grazing, in its simplest form, originated with the early pastoral or transhumant cultures over 5,000 years ago. Under this system, which is still widely used today in Asia and Africa, domestic livestock are moved from one area to another on the basis of forage availability. Human survival is dependent upon locating areas with sufficient forage to sustain the livestock. Fences are virtually unknown and families may travel very long distances in search of adequate pastorage. Although practiced for survival purposes, transhumant grazing has ecological merit. As herds are moved from one area to another, grazed areas are successively rested. Periods of rest, if sufficiently long, allow the forage resource to recover and the soil hydrologic status to stabilize. However, even under a transhumant system, excessive or too frequent grazing leads to range deterioration.

In developed countries where land is subdivided and fenced under private-ownership land tenure systems, transhumant grazing is seldom practiced. Nevertheless, the ecological principles of rotational grazing may be utilized on a smaller scale. As early as the 1700's, an intensive rotational grazing system was suggested whereby an area of land would be divided into numerous subdivisions, and a single livestock herd would be rotated through the smaller paddocks on the basis of forage availability (Voisin 1959). Under current range management terminology this form of

---

[1]Environmental Research Scientist, U.S. Army Construction Engineering Research Laboratory, Environmental Division, P.O. Box 4005, Champaign, IL 61820, USA.

multi-pasture rotational grazing is often referred to as short-duration grazing or intensive rotation grazing. Such a system is defined as having a stocking density index > 2 (i.e., the total land area within the grazing system is greater than twice the area available to the livestock at any given point in time; Range Term Glossary Committee 1974). Such systems are in contrast to less intense deferred-rotation systems (stocking density index > 1 and ≤ 2) and continuous yearlong or season-long grazing (stocking density index = 1).

Although a relatively old concept, intensive rotation grazing has recently received considerable renewed interest. Some modern supporters of this method have proposed that forage and animal productivity will increase dramatically under intensive rotational systems even when stocked at levels which double or triple conventionally accepted moderate stocking rates (Acocks 1966, Savory 1978). Moderate stocking rates are traditionally designed to permit utilization of approximately half of the current year's forage production while leaving the remainder to facilitate replenishment of plant carbohydrate reserves and to protect the soil surface. A rather novel hypothesis currently espoused by some rotation grazing enthusiasts is that of improved soil hydrologic condition through intense livestock trampling activity or "hoof action" associated with very high, short-term stocking densities (Savory 1983, Walter 1984). A high stocking density, which reflects a large number of grazing animals per unit area of land at a given point in time, may be created by increasing the number of animals (i.e., increasing the stocking rate) or by increasing the number of pastures in a rotational grazing system, thus reducing the area available to the herd while on any particular pasture.

Extensive literature reviews have shown that, as a general rule, continuous yearlong or season-long grazing at any commonly accepted stocking rate causes a statistically significant decline in infiltration rate when compared to no grazing (Blackburn 1984, Gifford and Hawkins 1978). The biological significance of impaired infiltration, in terms of unacceptable levels of associated soil loss and reduced forage productivity, is most apparent when livestock numbers exceed moderate stocking rates. According to the rotation hypothesis, periodic intense trampling may be the solution to the hydrologic deterioration and desertification which currently plagues many rangelands and pastures under heavily stocked continuous grazing regimes. The hypothesis is based upon the assumption that almost all soils develop a very thin surface crust which may limit infiltration to some degree. Periodic intense trampling purportedly breaks the soil crust and forms miniature catchment basins in each hoofprint, thus increasing rainfall infiltration (Goodloe 1969, Howell 1974).

It is the purpose of this endeavor to evaluate the foregoing hypothesis in light of evidence from the available scientific literature which relates hydrologic responses to intensive rotational grazing systems. This will be accomplished by evaluating four corollaries which must be true in order for the principal hypothesis to be true:

1. Infiltration rate should be greater from pastures under intensive rotation grazing than from ungrazed exclosures or from comparably stocked

continuously grazed pastures or deferred-rotation pastures.

2. Within a given intensive rotational system, the infiltration rate from recently grazed pastures should be greater than from rested pastures.

3. The infiltration rate from intensively grazed rotational pastures should increase as the number of pastures increases (i.e., stocking density increases).

4. The infiltration rate from intensively grazed rotational pastures should increase as stocking rate increases.

STATE OF KNOWLEDGE

Comparisons of Grazing Systems

The earliest available information which is interpretable in terms of comparing infiltration response to intensive rotation grazing and continuous grazing comes from the Texas Agricultural Experiment Station near Spur, Texas (Fisher and Marion 1951). Soil under the rotation system ([3-1;30:60 da], notation follows Kothmann 1974; i.e., [3 pastures - 1 herd; 30 days grazed:60 days rest per rotation cycle]) and an adjacent continuously grazed pasture ranged from heavy clay to clay loam. Both systems were grazed at a moderate stocking rate. Following an intense summer storm which produced 85 mm rainfall, the average depth of the soil wetting front under the rotationally grazed pastures was 362 mm while the average depth of moisture penetration on the continuously grazed pasture was 534 mm.

The effect of heavy stocking under a system of rotation grazing [4-1;7:21 da] was measured on sandy loam soil of the Delmarva Peninsula, Maryland (Pearson et al. 1975). Soil moisture content while animals were on the pastures was generally high due to frequent irrigation with effluent from a food processing factory. Infiltration rates were always lower on pastures in the rotational system than on ungrazed areas. No level of significance was determined.

The first study to provide quantitative statistical comparisons of infiltration rates between intensive rotation grazing and continuous grazing was conducted at the Texas Experimental Ranch near Throckmorton, Texas. This study compared the hydrologic impacts of a moderately stocked intensive rotation system [8-1;17:119 da], moderate and heavy continuous grazing, a moderately stocked deferred-rotation system [4-3;12:4 mo], and two ungrazed exclosures (Wood and Blackburn 1981). At the time of the study, the intensive rotation system had been in operation for four years while all other treatments had been operating for twenty years. In bunchgrass communities, the highest infiltration rate was recorded from the ungrazed exclosures, although this was not statistically different from the deferred-rotation system (Table 1). Infiltration rate from a recently grazed intensive rotation pasture was significantly lower than from the deferred-rotation system and the ungrazed exclosure, but not signficantly different from a fully rested intensive rotation pasture or the moderate continuous pasture. The hydrologic response of the recently grazed intensive rotation pasture was most similar to the heavily stocked, continuously grazed pasture. There were no statistically significant differences in infiltration rate between grazing treatments on shortgrass communities or beneath shrub canopies.

Studies conducted at the Sonora Agricultural Experiment Station on the Edwards Plateau of Texas evaluated systems similar to those at the Texas Experimental Ranch. Treatments including extreme heavy continuous grazing, moderate continuous grazing, and a moderately stocked intensive rotation system [8-1;17:119 da] were implemented in 1978 (Blackburn et al. 1980, Knight 1980). Data were collected approximately every 60 days over a period of two years. During that period the rotationally grazed pasture and the moderate continuous pasture remained hydrologically similar while the condition of the extreme heavy continuous pasture rapidly declined and consistently exhibited significantly lower infiltration rates (Table 1).

In response to increasing interest by the livestock industry in more intense forms of rotation grazing, the rotational system at the Sonora Experiment Station was modified [14-1;4:50 da] and the stocking increased to a heavy rate in 1980 (McCalla et at. 1984, Thurow 1985). Sampling procedures and schedule remained the same as in the previous study. Over the next four years the intensified rotation system became increasingly dissimilar to the moderate continuous pasture in terms of hydrologic characteristics. At the end of the study, infiltration rates recorded for the rotational system were significantly less than from the moderate continuous pasture but still somewhat greater than from the heavy continuous pasture (Table 1). The greatest influence appeared to be an inability of the rotational system and heavy continuous pasture to recover following depressed hydrologic conditions which accompanied drought.

At the Fort Stanton Experimental Ranch in south-central New Mexico, a heavily stocked intensive rotational system [4-1;4:12 mo] was compared with a heavy continuous pasture and an ungrazed exclosure (Gamougoun et al. 1984). All treatments had been in operation for at least ten years. It was determined that the ungrazed exclosure was characterized by significantly higher infiltration rates than either of the grazed treatments, and infiltration rates on the continuously grazed pasture were significantly greater than infiltration rates on the rotationally grazed pastures (Table 1).

During subsequent research at the Fort Stanton Experimental Ranch, a heavily stocked intensive rotation system [7-1;2-7:12-42 da] was compared with moderate and heavy continuous pastures and a pasture from which grazing had been excluded for 29 years (Weltz and Wood 1986). The continuously grazed pastures had been under their respective treatments for 17 years while the rotational system was only one year old. The ungrazed exclosure retained a statistically higher hydrologic condition than the other treatments (Table 1). Infiltration rates recorded for fully rested intensive rotation pastures were significantly higher than for the heavy continuous pasture but significantly less than for the moderate continuous pasture. Recently grazed rotation pastures were hydrologically similar to the heavy continuous pasture.

Table 1. Comparison of infiltration rates from comparably stocked grazing treatments and ungrazed exclosures. Infiltration rates represented by the same letter are not significantly different as determined by the respective authors. When differences exist, the letter A indicates the highest infiltration rate followed by B, C, etc.

Location	Soil	Stocking Rate	System[1]	INFILTRATION RATE: Intensive Rotation	Continuous Grazing	Deferred Rotation	Ungrazed Exclosure	Source
Texas[2]	clay	mod.	[8-1;17:119 da]	BC/C[3]	BC	AB/AB[3]	AB	Wood and Blackburn 1981
Texas	silty clay	mod.	[8-1;17:119 da]	A	A	-	-	Knight 1980
Texas	silty clay	heavy	[14-1;4:50 da]	B	C	-	A	Thurow 1985
New Mexico	loam	heavy	[4-1;4:12 mo]	C/D[3]	B	-	A	Gamougoun et al. 1984
New Mexico	loam	heavy	[7-1;2-7:12-42 da]	B/C[3]	C	-	A	Weltz and Wood 1986
New Mexico	clay loam	heavy	[7-1;4:24 da]	B	-	A	-	Wood 1983
Kenya	sandy loam	mod.	[3-1;3:6 mo]	AB/AB[3]	B	-	A	Mbakaya 1985
Kenya	sandy loam	mod.	[16-1;14:210 da]	A/B[3]	B	-	A	Mbakaya 1985

[1]Notation follows Kothmann (1974) (eg., [8 pastures - 1 herd; 17 days grazing:119 days rest per rotation cycle]).

[2]Bunchgrass community only. There were no differences between treatments for shrub understory or shortgrass communities.

[3]Fully rested/recently grazed.

The effect of grazing systems on the hydrology of a sloping grassland community was also evaluated at the Ft. Stanton Experimental Ranch (Wood 1983). A heavily stocked intensive rotation system [7-1;4:24 da] was compared with an equally stocked but less intensive deferred-rotation system. Infiltration rate was significantly lower on the intensive rotation system than on the rest-rotation system (Table 1).

At the Buchuma Range Research Station in Kenya a 3-pasture rotational system [3-1;3:6 mo] and a more intensive 16-pasture system [16-1;14:210 da] were compared with a continuously grazed pasture and an ungrazed exclosure twelve years after the treatments were implemented (Mbakaya 1985). All grazing treatments were stocked at a moderate rate. Hydrologic condition of the 3-pasture system, was similar to the continuously grazed pasture and the ungrazed exclosure (Table 1). When fully rested, the 16-pasture system was also comparable to the ungrazed exclosure. However, in a recently grazed state, infiltration rates were significantly lower and were similar to the continuously grazed pasture.

Stage of Rotation

In addition to comparing the hydrologic impact of various grazing strategies, several of the previously discussed studies also provided information regarding the hydrologic condition of intensive rotation pastures at different stages in the rotation cycle (Table 2). For two studies in New Mexico (Gamougoun et al. 1984, Weltz and Wood 1986), infiltration rate was significantly greater on fully rested pastures than on recently grazed pastures. Similar results were obtained in Kenya from a 16-pasture rotational system, but no differences in infiltration rate were detected for stages of a less intensive 3-pasture system (Mbakaya 1985). At the Texas Experimental Ranch, there were no significant differences between fully rested or recently grazed pastures (Wood and Blackburn 1981).

A subsequent two-year study at the Texas Experimental Ranch, made similar comparisons on a newly implemented intensive rotational system [14-1;2-5:26-65 da] (Pluhar 1984). One of the 14 pastures from the original system was divided into three equal parts so that, as the livestock were rotated through the system, the three smaller pastures simulated a more intense 42-pasture system [42-1;0.5-1.5:32-64 da]. There were no significant differences between stages of the rotation cycle for either system in terms of infiltration rate (Table 2).

Research at the Sonora Experiment Station in Texas also compared stages of an intensive rotational grazing system [7-1;8-12:48-72 da] (Warren et al. 1986a). During the growing season, there were no significant hydrological differences associated with stages of the rotation cycle (Table 2). During periods of winter or drought-induced dormancy, however, rested pastures were characterized by significantly higher infiltration rates. The response of the watershed to rotation grazing was apparently related to the hydrologic condition of the watershed at the time of impact. During the growing season when soil moisture status, soil aggregate stability, soil organic matter content,

Table 2. Comparison of infiltration rates from intensive rotation pastures when fully rested and recently grazed. Infiltration rates represented by the same letter are not significantly different as determined by the respective authors. Where differences exist, the letter A represents the higher infiltration rate.

				INFILTRATION RATE		
Location	Soil	Stocking Rate	System[1]	Fully Rested	Recently Grazed	Source
New Mexico	loam	heavy	[4-1;4:12 mo]	A	B	Gamougoun et al. 1984
New Mexico	loam	heavy	[7-1;2-7:12-42 da]	A	B	Weltz and Wood 1986
New Mexico	sandy loam	heavy	[7-1;2-7:12-42 da]	A	B	Weltz and Wood 1986
Kenya	sandy loam	moderate	[3-1;3:6 mo]	A	A	Mbakaya 1985
Kenya	sandy loam	moderate	[16-1;14:210 da]	A	B	Mbakaya 1985
Texas	clay	moderate	[8-1;17:119 da]	A	A	Wood and Blackburn 1981
Texas	clay loam	heavy	[14-1;2-5:26-65 da]	A	A	Pluhar 1984
Texas	clay loam	heavy	[42-1;0.5-1.5:32-64 da]	A	A	Pluhar 1984
Texas	silty clay	heavy	[7-1;8-12:48-72 da][2]	A	A	Warren et al. 1986a
Texas	silty clay	heavy	[7-1;8-12:48-72 da][3]	A	B	Warren et al. 1986a
Texas	silty clay	moderate	[8-1;4:28 da]	A	B	Warren et al. 1985d
Texas	silty clay	heavy[4]	[8-1;4:28 da]	A	B	Warren et al. 1986d

[1]Notation follows Kothmann (1974) (eg., [4 pastures - 1 herd; 4 mo. grazing: 12 mo. rest per rotation cycle]).

[2]Growing season.

[3]Winter and drought-induced dormant seasons.

[4]Similar results when moderate rates were doubled or tripled.

soil bulk density, microbial and arthropod activity, and above- and belowground plant growth were near optimum levels, the potential to withstand livestock impact was high, as was the potential to recover following the removal of livestock. During periods of dormancy, however, resistance to damage from grazing and subsequent recovery after grazing were minimized.

A related study at the Sonora Experiment Station compared the hydrologic status of bare soil both before and after trampling in a simulated rotational grazing system [8-1;4:28 da] (Warren et al. 1986d). Across three stocking rates and two levels of soil moisture, infiltration rate was consistently lower following trampling than before (Table 2).

Two additional studies have evaluated the impact of simulated livestock trampling on infiltration rates (Dadkhah and Gifford 1980, Packer 1953). When as little as 10-20 percent of the soil surface was disturbed following a single application of the trampling treatment, infiltration rates were significantly reduced.

It has been suggested that the impact of livestock hooves is far more damaging to the condition of a watershed than the removal of vegetation through grazing (Shankarnarayan 1977), and is a likely cause rather than a cure for deterioration and desertification of rangelands (Dregne 1983). Research has shown increased soil bulk density (Carter and Sivalingam 1977, Edmond 1974, Kelly 1985, Witschi and Michalk 1979), increased bearing capacity of the soil surface (Edmond 1974, Kelly 1985, Lagocki 1978), and reduced size and stability of soil aggregates (Edmond 1958, Mullen et al. 1974, Warren et al. 1986c, Wood and Blackburn 1984) following periodic intense trampling treatments. These factors, as well as the removal of protective vegetative cover, are largely responsible for the decline in infiltration rates which often accompany periodic livestock activity in intensive rotation grazing systems.

Number of Pastures

As pastures within a given rotational grazing system are subdivided to increase the total number of pastures, the land area available to the livestock at any given point in time is reduced (i.e., stocking density is increased). To date, only two studies have addressed the possibility of variable hydrologic response due to number of pastures. At the Texas Experimental Ranch where a 14-pasture rotational system was compared to a 42-pasture system, there were no consistent differences in infiltration rate related to stocking density (Pluhar 1984). At the Sonora Experiment Station, three pastures representing 7-, 9-, and 14-pasture rotation systems ([7-1;8-12:48-72 da], [9-1;6-9:50-75 da], and [14-1;4-6:52-78 da], respectively) were evaluated over two summers (Warren et al. 1986b). Stocking density increased proportionally to the number of pastures. No differences, logically attributable to stocking density, were apparent between pastures in terms of infiltration.

The apparent absence of hydrologic variability relative to stocking density in the foregoing studies may be due to the relatively large number of pastures in relation to the length of the rotation cycles (Warren et. at. 1986b). While it is true that subdividing pastures of an existing rotational grazing system results in a higher stocking density during the period of time that livestock are on any given pasture, the length of the period of grazing must also be considered. As the number of pastures increases and the pasture size decreases, the length of stay on each pasture must be reduced proportionately in order to avoid overgrazing. The total impact in terms of animal unit days per unit area per rotation cycle remains the same regardless of the number of subdivisions. The principal difference is the number of days over which the impact occurs and the length of the subsequent rest period. Since the data indicate that intense short-term grazing is detrimental to infiltration rate, maximization of the rest period appears to be essential to allow sufficient hydrologic recovery. The potential to significantly alter the length of the rest period is greatest when the number of pastures is small. Beyond approximately 8 pastures the potential is minimized.

Stocking Rate

The hydrologic impact of periodic livestock trampling on bare soil at three stocking rates was evaluated on a simulated rotation system [8-1;4:28 da] at the Sonora Experiment Station (Warren et al. 1986d). Measurements were taken from both dry and moist soils. Under both soil moisture conditions, trampling at a moderate stocking rate caused a significant decline in infiltration capacity when compared to untrampled areas. Trampling at stocking rates which doubled and tripled the moderate rate caused an additional significant decline, but the difference in infiltration between these two higher stocking rates was not significant.

Soil physical properties measured during the course of the former study lend some explanation to the hydrologic results (Warren et al. 1986c). As stocking rate increased, trampling on dry soil caused an increased disruption of soil aggregates and compaction of the soil surface. Heavier stocking rates on moist soil caused a progressive deformation of existing aggregates and led to the creation of a flat, comparatively impermeable surface layer composed of dense, unstable clods. Other studies have also shown an increase in soil compaction (Bryant et al. 1972; Edmond 1963, 1964, 1974; Hunt 1979) and a decline in the size and stability of soil aggregates (Edmond 1958, Mullen et al. 1974) as stocking rates increase under rotational or periodic trampling.

Two previously mentioned studies involving simulated trampling (Dadkhah and Gifford 1980, Packer 1953) can also be interpreted in terms of hydrologic response to increased stocking rate. In each case, as the percent disturbance of the soil surface increased, the infiltration rate decreased. The decline was attributed to soil compaction and a reduction in organic soil cover for the two studies, respectively.

SUMMARY AND CONCLUSIONS

From the foregoing overview of the available scientific literature, it appears that all four of the corollary hypotheses must be rejected. In those studies which have compared intensive rotational grazing systems with ungrazed exclosures, infiltration rates have never been improved by the rotational system. To the contrary, the rotational systems have generally been characterized by significantly lower infiltration rates. It appears, therefore, that intensive rotation grazing has a negative hydrologic impact. The impact appears to be no less than that which occurs under comparably stocked continuous grazing regimes. Only one study has indicated superiority of intensive rotational grazing over continuous grazing. All other studies have shown equivalent or inferior condition in terms of infiltration rate.

In comparing the hydrologic condition of intensive rotation pastures at different stages of the rotation cycle, none of the studies to date have furnished any evidence to indicate that intensive livestock activity provides hydrologic benefit. Indeed, the majority of the available literature has documented a significant decline in infiltration rate from rotation pastures in a recently grazed condition as compared to a rested condition.

The number of pastures within an intensive rotational grazing system does not appear to have a significant influence on the hydrologic response of the watershed, at least when the number of pastures is large. Where the number of pastures is less than approximately eight, subdivision of the pastures has the potential to significantly alter the ratio of grazed and rested days per pasture per rotation cycle, and thus perhaps effect hydrologic characteristics. That potential is minimized when the number of pastures exceeds eight.

Contrary to the corollary hypothesis suggesting hydrologic improvement via increases in stocking rate under intensive rotation grazing, research indicates that increasing the number of animals will most likely be accompanied by a decline in infiltration capacity of the soil. Stocking rate may be more important in determining hydrologic response to grazing than is the particular form of grazing system. Similar conclusions have been drawn after examining the effects of stocking rate and grazing system on vegetation and livestock responses (McMeekan and Walshe 1963, O'Rourke 1978).

Based on the rejection of all four corollary hypotheses, one must also reject the primary hypothesis suggesting hydrologic benefit from intensive rotation grazing, and accept an alternative hypothesis of negative or neutral hydrologic impact. In terms of overall impact to the watershed, the former alternative hypothesis is the logical candidate. When comparing intensive rotational grazing with other grazing management stategies, the latter alternative hypothesis may be more appropriate.

Intensive rotational grazing may provide some benefits to the livestock industry. However, in light of the available scientific literature, it is doubtful that the benefits will be derived in terms of improved infiltration rates resulting from intense livestock trampling. Acknowledging the detrimental impact of trampling on soil hydrologic condition, researchers should concentrate on the development of grazing systems which provide adequate periods of rest to allow recovery and stabilization of the vegetation and soil resources prior to subsequent livestock impact.

LITERATURE CITED

Acocks, J. P. H. 1966. Non-selective grazing as a means of veld reclamation. Proc. Grassl. Soc. S. Afr. 1:33-39.

Blackburn, W. H. 1984. Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses, p. 927-983. In: Developing strategies for rangeland management. National Research Council/National Academy of Sciences. Westview Press, Boulder, CO.

Blackburn, W. H., R. W. Knight, M. K. Wood, and L. B. Merrill. 1980. Watershed parameters as influenced by grazing, p. 552-572. In: Proc. Symp. Watershed Manage., Amer. Soc. Civil Eng., Boise, ID.

Bryant, H. T., R. E. Blaser, and J. R. Peterson. 1972. Effect of trampling by cattle on bluegrass yield and soil compaction of a Meadowville loam. Agron. J. 64:331-334.

Carter, E. D., and T. Sivalingam. 1977. Some effects of treading by sheep on pastures of the Mediterranean climatic zone of South Australia, p. 641-644. In: Proc. 13th Int. Grassl. Cong.

Dadkhah, M., and G. F. Gifford. 1980. Influence of vegetation, rock cover, and trampling on infiltration rates and sediment production. Water Resour. Res. 16:979-986.

Dregne, H. E. 1983. Desertification of arid lands. Harwood Academic Publ., Chur, Switzerland.

Edmond, D. B. 1958. The influence of treading on pasture: A preliminary study. N.Z. J. Agr. Res. 1:319-328.

Edmond, D. B. 1963. Effects of treading perennial ryegrass (Lolium perenne L.) and white clover (Trifolium repens L.) pastures in winter and summer at two soil moisture levels. N.Z. J. Agr. Res. 6:265-276.

Edmond, D. B. 1964. Some effects of sheep treading on the growth of 10 pasture species. N.Z. J. Agr. Res. 7:1-16.

Edmond, D. B., 1974. Effects of sheep treading on measured pasture yield and physical condition of four soils. N.Z. J. Exp. Agr. 2:39-43.

Fisher, C. E., and P. T. Marion. 1951. Continuous and rotation grazing on buffalo and tobosa grassland. J. Range Manage. 4:48-51.

Gamougoun, N. D., R. P. Smith, M. K. Wood, and R. D. Pieper. 1984. Soil, vegetation, and hydrologic responses to grazing management at Fort Stanton, New Mexico. J. Range Manage. 37:538-541.

Gifford, G. F., and R. H. Hawkins. 1978. Hydrologic impact of grazing on infiltration: A critical review. Water Resour. Res. 14:305-313.

Goodloe, S. 1969. Short duration grazing in Rhodesia. J. Range Manage. 22:369-373.

Howell, D. 1976. Observations on the role of grazing animals in revegetating problem patches of veld. Proc. Grassl. Soc. S. Afr. 11:59-63.

Hunt, W. F. 1979. Effects of treading and defoliation height on the growth of Paspalum dilatatum Poir. N.Z. J. Agr. Res. 22:69-75.

Kelly, K. B. 1985. Effects of soil modification and treading on pasture growth and physical properties of an irrigated red-brown earth. Aust. J. Agr. Res. 36:799-807.

Knight, R. K. 1980. Hydrologic response of selected grazing systems on the Edwards Plateau. Ph.D. Dissertation, Texas A&M Univ., College Station, TX.

Kothmann, M. M. 1974. Grazing management terminology. J. Range Manage. 27:326-327.

Lagocki, H. F. R. 1978. Surface soil stability as defined and controlled by a drainage criterion, p. 233-237. In: W. W. Emerson, R. D. Bond, and A. R. Dexter (eds), Modification of soil structure. John Wiley & Sons, Chichester.

Mbakaya, D. S. 1985. Grazing systems effects on infiltration rate and sediment production of a bushed grassland, Buchuma, Kenya. M. S. Thesis, Texas A&M University, College Station, TX.

McCalla, G. R., W. H. Blackburn, and L. B. Merrill. 1984. Effects of livestock grazing on infiltration rates, Edwards Plateau of Texas. J. Range Manage. 37:267-269.

McMeekan, C. P., and M. J. Walshe. 1963. The interrelationships of grazing method and stocking rate in the efficiency of pasture utilization by dairy cattle. J. Agr. Sci. 61:147-163.

Mullen, G. J., R. M. Jelley, and D. M. McAleese. 1974. Effects of animal treading on soil properties and pasture production. Irish J. Agr. Res. 13:171-180.

O'Rourke, J. T. 1978. Grazing rate and system trial over 5 years in a medium-height grassland of northern Tanzania, p. 563-566. In: Proc. 1st Int. Rangel. Congr.

Packer, P. E. 1953. Effects of trampling disturbance on watershed condition, runoff, and erosion. J. Forest. 51:28-31.

Pearson, G. A., G. A. Jung, R. E. Fowler, and D. M. Mitchell. 1975. Effects of grazing on infiltration rates in waste water spray fields. Proc. Soil Sci. Soc. Am. 39:954-957.

Pluhar, J. J. 1984. Hydrologic impacts of selected grazing systems on the Texas Rolling Plains. M. S. Thesis, Texas A&M University, College Station, TX.

Range Term Glossary Committee. 1974. A glossary of terms used in range management. Soc. Range Manage., Denver, CO.

Savory, A. 1978. A holistic approach to range management using short duration grazing, p. 555-557. In: Proc. 1st Int. Rangel. Congr.

Savory, A. 1983. The Savory grazing method or holistic resource management. Rangelands 5:155-159.

Shankarnarayan, K. A. 1977. Impact of overgrazing on the grasslands. Ann. Arid Zone 16:349-359.

Thurow, T. L. 1985. Hydrologic interrelationships with vegetation and soil as affected by selected livestock grazing systems and climate on the Edwards Plateau. Ph.D. Dissertation, Texas A&M University, College Station, TX.

Voisin, A. 1959. Grass productivity. Philosophical Library, Inc., New York, NY.

Walter, J. 1984. Rangeland revolutionary: An interview with Allan Savory. J. Soil Water Conserv. 39:235-240.

Warren, S. D., W. H. Blackburn, and C. A. Taylor, Jr. 1986a. Effects of season and stage of rotation cycle on hydrologic condition of rangeland under intensive rotation grazing. J. Range Manage. 39:486-491.

Warren, S. D., W. H. Blackburn, and C. A. Taylor, Jr. 1986b. Soil hydrologic response to number of pastures and stocking density under intensive rotation grazing. J. Range Manage. 39:500-504.

Warren, S. D., M. B. Nevill, W. H. Blackburn, and N. E. Garza. 1986c. Soil response to trampling under intensive rotation grazing. Soil Sci. Soc. Am. J. 50:1336-1341

Warren, S. D., T. L. Thurow, W. H. Blackburn, and N. E. Garza. 1986d. The influence of livestock trampling under short-duration grazing on soil hydrologic characteristics. J. Range Manage. 39:491-495.

Weltz, M., and M. K. Wood. 1986. Short duration grazing in central New Mexico: Effects on infiltration rates. J. Range Manage. 39:365-368.

Witschi, P. A., and D. L. Michalk. 1979. The effect of sheep treading and grazing on pasture and soil characteristics of irrigated annual pastures. Aust. J. Agr. Res. 30:741-750.

Wood, J. C. 1983. Best management practices for improving infiltration and runoff water quality on New Mexico rangelands. M. S. Thesis. New Mexico State Univ., Las Cruces, NM.

Wood, M. K., and W. H. Blackburn. 1981. Grazing systems: Their influence on infiltration rates in the Rolling Plains of Texas. J. Range Manage. 34:331-335.

Wood, M. K., and W. H. Blackburn. 1984. Vegetation and soil responses to cattle grazing systems in the Texas Rolling Plains. J. Range Manage. 37:303-308.