



A survey of soil properties on five ranches practicing intensive time-controlled grazing in south central Montana

by John Melville Heyneman, Jr

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

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Abstract:

Five ranches in south central Montana were studied to identify trends in soil parameters resulting from intensive time-controlled grazing. All five ranches practice varying degrees of intensive grazing with cattle or cattle and sheep. Cell centers with a single water source were located on each ranch and transects were established in randomly selected pastures. Transects radiated away from the water source approximately 340 meters. Soil and vegetation parameters were measured at predesignated distances along the transect. Early, mid and late growing season measurements were taken for two years. Few strong relationships were found between rates of infiltration, levels of nitrogen, bulk density and the distance from the water source. The combination of planned recovery time and natural freeze thaw processes seem to be ameliorating negative aspects of intensive grazing.

A SURVEY OF SOIL PROPERTIES ON FIVE RANCHES PRACTICING INTENSIVE
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A thesis submitted in partial fulfillment
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APPROVAL

of a thesis submitted by

John Melville Heyneman Jr.

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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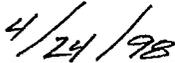
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ABSTRACT

Five ranches in south central Montana were studied to identify trends in soil parameters resulting from intensive time-controlled grazing. All five ranches practice varying degrees of intensive grazing with cattle or cattle and sheep. Cell centers with a single water source were located on each ranch and transects were established in randomly selected pastures. Transects radiated away from the water source approximately 340 meters. Soil and vegetation parameters were measured at predesignated distances along the transect. Early, mid and late growing season measurements were taken for two years. Few strong relationships were found between rates of infiltration, levels of nitrogen, bulk density and the distance from the water source. The combination of planned recovery time and natural freeze thaw processes seem to be ameliorating negative aspects of intensive grazing.

INTRODUCTION

Defining soil health/quality has been the focus of increasing research efforts (Doran 1993, Larson and Pierce 1991, Karlen and Stott 1994). Connections between efficient natural systems and a well functioning soil base highlight the importance of soil quality. Tillage methods continue to evolve reflecting the concern for preserving healthy soil by decreasing erosion and soil compaction, but the health of range soils remains relatively unexamined. Herrick and Whitford (1995) attribute the difficulty of gathering accurate range soils information to the diversity of uses and spatial irregularities. Most soil health research has been in cropping situations. Very little soil health work has included range environments.

Grazing management is of interest to anyone with a concern for public and private rangelands. Ranchers try to harvest available forage while balancing rations for their livestock while people concerned with resource conservation are outraged by plentiful examples of range degradation (Jacobs 1991). Range management is a complex issue, and has been a focus of research since the early part of the century. Many different grazing systems have been developed and promoted as the best grazing management. Countless papers have been written, and symposiums held to explain and discuss the differences and merits of grazing systems (Kothman 1984). Researchers conduct carefully controlled tests at research stations to quantify results, but results and interpretations vary widely. Very little has been agreed upon.

Spatial and temporal variability is a principal factor in range science research.

Range carrying capacity and range quality assessments are ambiguous because of environmental uncertainties (Herrick and Whitford 1995, Roe 1997). The scientific literature emphasizes the dynamic nature of range conditions, and concludes that many short term fluctuations in soil parameters result from weather variability rather than livestock management. Researchers have documented increases in soil bulk density from soil drying during summer and fall months (Laycock and Conrad 1967). Early research correlated bulk density to infiltration rates (Wood and Blackburn 1981, Rauzi and Hanson 1966). Riggel (1989) found bulk density increases from time-controlled grazing are ameliorated each winter by freezing and thawing processes. Mooers (1989) found surface roughness of pastures to increase dramatically over the winter and attributed the increase to freezing and thawing.

The impact of livestock around water sources is familiar to resource managers and researchers alike. Animal impact with little or no time for recovery results in a landscape devoid of vegetation with poorly functioning water and mineral cycles. Sacrifice zones around water sources, especially developed water, are common in arid regions. Andrew and Lang (1986) found animal impact focused around water sources, and measured greatest stocking pressure near the water source. Piosphere (Pios, meaning to drink in Greek) conditions are thought to be a good indicator of arid ecosystems (Lange 1968, Andrew 1988). However, Mooers (1989) found no clear relationship between soil surface roughness resulting from livestock trampling and distance from water in intensive time-controlled grazing research.

What is Intensive Time-Controlled Grazing?

Intensive time-controlled grazing is an attempt to utilize the impact of grazing animals to increase forage and animal production and quality. Many different terms are used to describe intensive grazing management: rotational grazing, intensive grazing, intensive rotational grazing, time controlled grazing, and short duration grazing all describe a management designed to maximize forage production and minimize environmental damage.

Practitioners of time-controlled grazing attempt to manage their livestock in a way that replicates the grazing patterns and impacts of wild ungulates. Before domesticated livestock became prevalent, large herds of ungulates roamed throughout the interior of North America. Animal dung and urine contribute to the mineral cycle, an important aspect of soil fertility. Predators kept the animals tightly bunched and agitated. Hoof action disturbed the soil surface, incorporating organic matter (seeds, plant matter, manure), increasing water retention and decreasing runoff. While large numbers of animals probably did a great deal of trampling and short term damage, they may not have returned to the same region for extended periods of time.

Time-controlled management acts on the same principles of large numbers of animals in a tight bunch. Fences limit the movements of the herd rather than predators, and operators move the animals from pasture to pasture depending on growing conditions. Management employs fences and timing in combination to control the time plants are exposed to livestock. Livestock is moved to new pastures before plants are overgrazed. Ideally, all plants are bitten once, and then rested. Plant utilization is balanced with

recovery time, and both livestock and vegetation flourish.

Central to the strategy of time-controlled grazing is a grazing plan with sufficient stock density to mimic the action of the roaming herds of the past, but guarantees that plants, once grazed, are given sufficient recovery time (Savory, 1988). Growing conditions and thus, recovery times vary throughout the growing and grazing season. Thirty days may be an adequate recovery period in spring/early summer when growing conditions are optimal. Thirty days may not be an adequate recovery period for plants later in the summer when dry conditions do not favor rapid regrowth. An efficient time-controlled grazing plan must contain enough flexibility to speed or slow animal rotations to compensate for plant recovery time. The importance of varying recovery times throughout the growing season has often been overlooked by researchers. Ranches operating under a system of time-controlled grazing for numerous years have experience in adapting grazing schedules to their specific environment. Ranch managers have more experience and more vested interest than researchers. It seems logical that ranchers would be more proficient. For these reasons, this study is conducted on working ranches experienced with time-controlled grazing.

Animal Impact

Animal impact is an important and controversial aspect of time-controlled grazing. Intensive grazing proponents claim that animal impact will increase soil fertility by incorporating organic matter, breaking up soil crusts and increasing water infiltration. Opponents claim animal impact will increase soil bulk density, decrease water infiltration,

and increase water and sediment runoff. The scientific literature is varied. Researchers have shown animal impact to degrade soil quality (Darmaar et. al. 1989), decrease water infiltration rates and increase erosion rates (Warren et. al. 1986), as well as decrease forage production (Ralphs et. al. 1990). Other researchers found no detrimental effects of time-controlled grazing (Abdel-Magid et al. 1987), and operators increasingly experiment with time-controlled grazing. Many who have adopted the method are pleased with the improvements in their land and livestock (Orchard 1996). Numerous descriptive case studies document advantages of time-controlled grazing (Dagget 1995, HRM Quarterly 1995). Additional data showing improved forage conditions on reclaimed mine sites as well as range are increasingly available (Erickson and Carlson 1995, Carlson and Erickson 1995). Such varying results have left the scientific community unconvinced of time-controlled grazing benefits.

OBJECTIVES

The purpose of this study was to identify trends in soil physical and chemical characteristics resulting from intensive time-controlled grazing. The hypothesis was that animal impact associated with intensive time-controlled grazing negatively affects soil characteristics. Animal impact was assumed to be more intense at points nearer the only available water source. A variety of soil measurements were taken to test the hypothesis. Measurements of soil compaction, bare ground, and nitrogen were expected to be consistently greater near the water source. Microbial respiration, soil water and infiltration rates were expected to be consistently less near the water source.

METHODS

Site Selections

Practitioners of intensive time-controlled grazing in south-central Montana were identified and asked to participate in this study. Sites were selected in Three Forks, Bozeman, Fishtail, Roundup and Ballantine, Montana. All five ranches have practiced time controlled grazing for at least eight years and try to employ animal impact to improve their soil and forage resources.

All the ranches manage some of their pastures with cell centers. A cell center design allows a single water source to provide water to a number of pastures. Typical cell centers resemble a wagon wheel with the water source in the center of the circle, and pastures or cells, stretching away from the water like spokes. All ranches had multiple cell centers. Older, more intensively used cell centers with a single water source were chosen for this study. Only cell centers with a single water source were included.

When an appropriate cell center was located, thirty percent of the pastures radiating from it were randomly selected. The number of pastures within a cell center varied on each ranch. All cell centers studied had three to nine pastures. Three pastures were selected from a cell center consisting of nine pastures, two pastures selected from a cell center of six pastures, one pasture selected from a cell center of three pastures. A minimum of three pastures were selected at each ranch. Three cell centers were sampled on the Morton ranch (Bozeman), two on the Heynemann ranch (Fishtail), two on the Milton ranch in (Roundup), two on the Lane ranch in (Three Forks), one on the Shaule ranch (Ballantine).

Total size of grazing pastures limits the acreage available to animals, and thus impacts animal density. Pasture shape also affects distribution of livestock. Designs with narrow cells force animal density higher at least in the vicinity of the water source. Ranchers have found that forcing animal density to increase near water discourages animals from lounging near water for extended periods.

All the ranches in this study operate with cell centers, but cell centers were rarely uniform. Centers and pastures within centers were often not the same shape or size. Pastures within a cell center were usually grazed with the same number of livestock, but were often grazed for different amounts of time. The stocking rates and grazing durations differed during the two years of study on all ranches. 1996 and 1997 averages were used for each ranch to calculate grazing totals.

Only ranches that actively practice time-controlled grazing, and only pastures that were grazed intensively were included. No control pastures were designated. This study cannot make direct comparisons between soil characteristics of the study sites and sites not operated with intensive time-controlled grazing. While the presence of control pastures may benefit the interpretations of the results, the design of this research targeted ranches that had been working for a number of years with intensive time-controlled grazing.

A typical cell center is diagramed in figure 1. An example of the sampling transect within pastures is diagramed in figure 2.

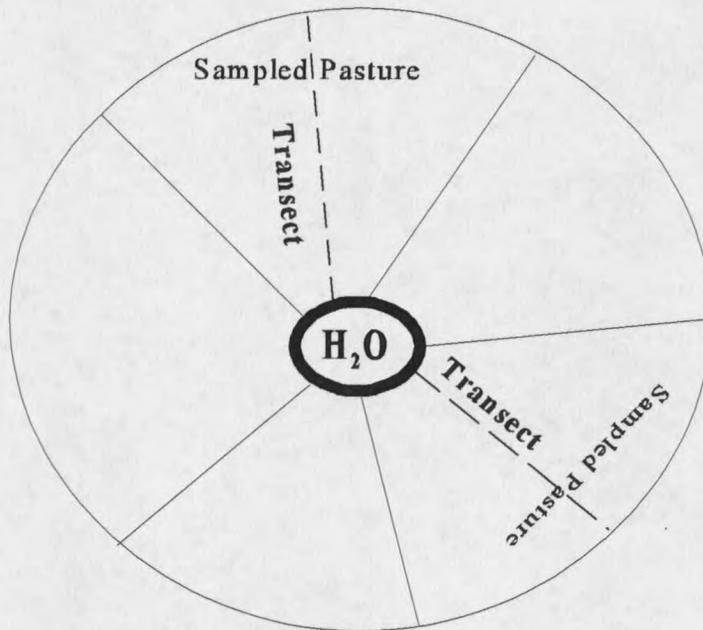


Figure 1. Typical cell center with a wagon wheel design.

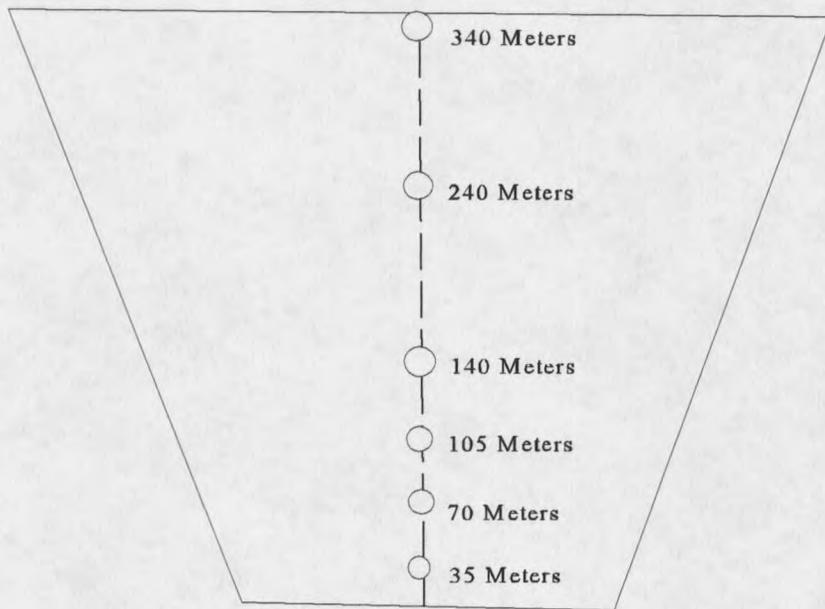


Figure 2. Transect with sample sites at predesignated distances from water source.

Site Descriptions

The Milton ranch is located on sedimentary silty soils in Musselshell County T10N, R27E, S32. Average annual precipitation is 21.4-25.3 cm (10-12 inches) (Caprio et.al., 1994). Pastures averaged 288 acres. The average grazing period consisted of 230 animal units of cows and sheep for 14 days. Stocking density was maintained at 1.8 animals/acre, or 7-10 animal days/acre (ADAs).

The Shaule ranch is located on sedimentary silty clay soils in Bighorn County, T1S, R30E, S8. Annual precipitation averages 25.4-30.5 cm (12-14 inches) (Caprio et.al., 1994). Pastures in this study averaged 320 acres. The average grazing period consisted of 500 animal units of cows with calves for 10.5 days. Stocking density was maintained at an average of 1.6 animals/acre, or 18 animal days/acre (ADAs).

The Heyneman ranch is located on loams and clay loams in Stillwater County, T5S, R17E, S13. Annual precipitation averages 35.5-51.0 cm (16-20 inches) (Caprio et.al., 1994). Pastures in this study averaged 100 acres. The average grazing period consisted of 316 animal units of cattle and sheep for 4 days. Stocking density was maintained at 3.2 animals/acre, or 15 animal days/acre (ADAs).

The Lane ranch is located on sandy clay soils in Madison County, T1N, R2E, S26. Annual precipitation averages 30.5-35.5 cm (14-16 inches) (Caprio et.al., 1994). Pastures averaged 160 acres. The average grazing period consisted of 250 animal units of cows with calves for 5 days. Stocking density was maintained at 1.5 animals/acre, or 10 animal days/acre (ADAs).

The Morton ranch is located on alluvial silty clay loams in the foothills of the

Bridger mountains in Gallatin County, T1S, R7E, S3. Annual precipitation averages 63.5-88.3 cm (30-40 inches) (Caprio et.al., 1994). Pastures averaged 40 acres. The average grazing period consisted of 77 animal units of cows with calves and yearling heifers for 12 days. Stocking density was maintained at 1.9 animals per/acre, or 28 animal days/acre (ADAs).

Locations of the five study ranches are displayed in figure 3.

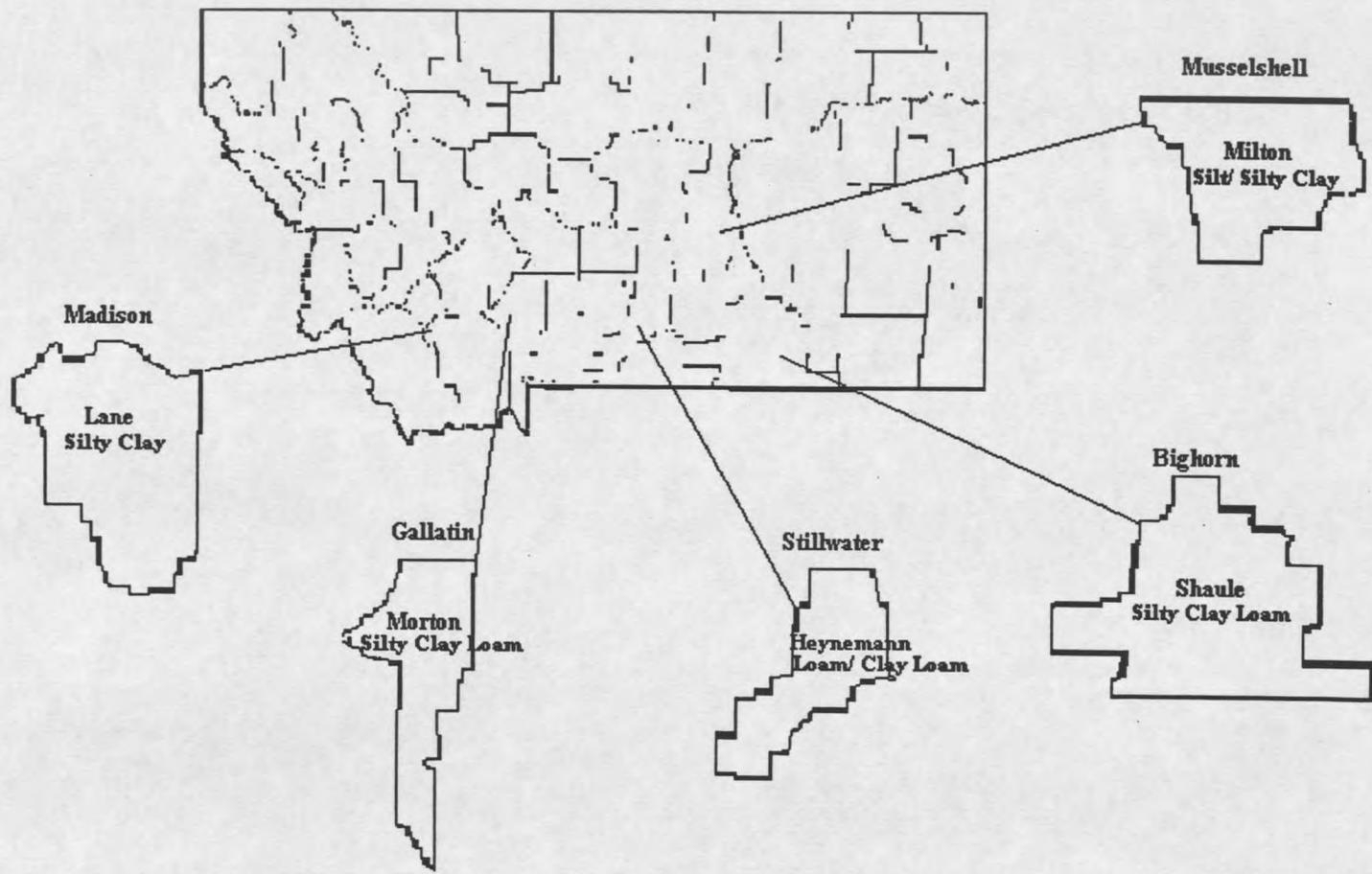


Figure 3. General map of study sites.

Sampling Procedures

A transect approximately 340 meters long was constructed in each selected pasture. Transects stretched directly away from the water source through the middle of the pasture. Markers were placed at predetermined distances of thirty-five, seventy, one hundred five, one hundred forty, two hundred forty, and three hundred forty meters from the water source. Refer to figure 2 for a diagram of the sampling transect.

Examinations were performed at each of the six sites on the transect. Vegetative cover estimations and infiltration tests were performed in the field. Soil samples were gathered and transported to the laboratory for bulk density, soil water, and nitrogen analyses. Gulleys, steep hillsides or other geographic features inconsistent with the area were considered non representative. Samples from non representative sites were ignored.

Data collection was not timed to correspond with a particular phase in the grazing rotations. The study design included data collection early or pre-growing season (May), mid-growing season (June), and late or post-growing season (September). Data were collected in 1996 in mid-growing season on all five ranches, and post-growing season on three ranches. Early snowfall prohibited data collection on the remaining two ranches. In 1997, data was collected pre, mid, and post-growing season on all five ranches.

Soil Tests

The following tests were carried out at each of the six sites along each transect in each pasture included in the study. The tests were performed several times during the growing season but they were not duplicated in the same testing period.

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Water Infiltration: A sixteen cm diameter PVC ring was pounded into the ground, and the time for one liter of water to completely infiltrate into the soil surface was measured. If infiltration time exceeded fifty-nine minutes, the time was noted as sixty minutes.

Bulk density was measured by digging a hole approximately six inches deep, lining the hole with a thin plastic bag, and filling the hole with sand. The sand required to fill the hole was saved in the bag and taken to the laboratory. The volume of sand was then recorded and used to calculate the soil's bulk density.

g Water/ g Soil was determined by dividing the difference of the weight of the soil sample taken in the bulk density procedure before oven drying and the weight of the soil after oven drying.

Nitrate was measured in parts per million with a spectrophotometer according to a process developed at Montana State University, Bozeman (1996).

Microbial respiration was measured by screwing a one gallon tin can into the ground. Inside the tin, a petri dish with 50 ml of 1M KOH solution was held above the soil surface with a wire frame. The KOH was exposed for approximately 24 hours to measure evolved CO₂. The exposed solution was sealed in airtight containers, transported to the laboratory and titrated with 0.1M HCl (Lundegardh, 1927; Anderson, 1973; Gupta and Singh, 1976). The net evolved CO₂/m²/day was calculated according to Anderson, (1982).

1m² quadrant. Only the right half of the quadrant was clipped at each point. Plant matter was bagged and oven dried before weighing.

Estimated % vegetative cover was measured by visually estimating the percent of bare ground in the immediate area of the sample point.

RESULTS

When ranches were grouped together, linear regressions of soil parameters and distance from water source resulted in no statistical significant relationships. Table 1 shows linear regression coefficients of soil parameters and distance for all ranches combined.

Table 1. Regression coefficients for soil parameters vs. distance from water source on all ranches over two growing seasons.

Soil Parameter	r^2	p
BD (g/cm ³)	.005	.65
Respiration (CO ₂ /m ² /day)	.002	.99
Infiltration (l/minute)	.008	.58
Soil Water (g H ₂ O/g soil)	.0007	.63
NO ₃ (ppm)	.005	.4

No statistical significance was found in the relationship between soil parameters and distance from water source when ranches were grouped together or when values for individual ranches were examined. Relationships are stronger for individual ranches than as aggregates. Table 2 displays linear regression coefficients for soil parameters and distance from water source at each ranch.

Table 2. The relationships (r^2) of distance from water source to six soil parameters during two grazing seasons at each ranch. Values for each ranch at all sampling times combined.

	BD (g/cm ³)	Respiration (CO ₂ /m ² /day)	Infiltration (l/minute)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)	Est. % Veg. Cover
Milton	.002	.003	.042	.008	.0001	.001
Shaule	.069	.001	.008	.004	.053	.229
Heynemann	.01	.0002	.009	.01	.029	.0008
Lane	.011	.008	.0002	.003	.039	.004
Morton	.003	.003	.039	.018	.005	.001

The lack of strong correlation as shown above is consistent regardless of soil type, animal density and time of sampling at each ranch. Only when the data are separated and analyzed by sampling time are significant correlations identified. Table 3 displays soil parameters and linear regression coefficients at each time of data collection.

Table 3. Relationships (r^2) for soil parameters at all test sites during each sampling time over two growing seasons. Data are missing from the fall 1996 as a result of early snowfall. Relationships significant at a 95% confidence interval are marked with an asterisk.

		6/96	9/96	5/97	6/97	9/97
Milton	BD (g/cm ³)	.05	.046	.0001	.18	.012
	Respiration (CO ₂ /m ² /day)	.001	.006	.004	.003	.035
	Infiltration (l/minute)	.188	-	.097	.001	.168
	Soil Water (g H ₂ O/g soil)	.008	0.054	.036	.122	.001
	NO ₃ (ppm)	.012	.048	.085	.040	.068
Shaule	BD (g/cm ³)	.232	.119	.203	.222	.429*
	Respiration (CO ₂ /m ² /day)	.16	.004	.0002	.136	.421*
	Infiltration (l/minute)	.011	-	.052	.01	.034
	Soil Water (g H ₂ O/g soil)	.037	.006	.117	.022	.028
	NO ₃ (ppm)	.489*	.006	.048	.291	.16
Heynemann	BD (g/cm ³)	.071	-	.182	.041	.00008
	Respiration (CO ₂ /m ² /day)	.021	-	.042	.004	0.00
	Infiltration (l/minute)	.153	-	.0003	.153	.085
	Soil Water (g H ₂ O/g soil)	.004	-	.066	.101	.034
	NO ₃ (ppm)	.042	-	.081	.113	.047
Lane	BD (g/cm ³)	.214	-	.001	.005	.005
	Respiration (CO ₂ /m ² /day)	.013	-	.072	.023	.075
	Infiltration (l/minute)	.215	-	.066	.018	.001
	Soil Water (g H ₂ O/g soil)	.008	-	.003	.001	.008
	NO ₃ (ppm)	.0008	-	.232	.160	.316
Morton	BD (g/cm ³)	.05	.0001	.008	.00027	.014
	Respiration (CO ₂ /m ² /day)	.001	.083	.01	.001	.01
	Infiltration (l/minute)	.188	-	.103	.034	.049
	Soil Water (g H ₂ O/g soil)	.008	.023	.097	.00	.052
	NO ₃ (ppm)	.012	.043	.177	.1	.0001

Despite gathering data several times throughout the growing season for two years, few relationships were found to be statistically significant. Each ranch's strongest relationships are listed in Table 4.

Table 4. Statistical data from the strongest relationships at each ranch show weak relationships between soil parameters and distance from water source. The values from the Shaule ranch highlight the strongest relationships.

	SD	r ²	p	Slope	Y int
Milton					
Infiltration Rate (l/minute), 9/97	7.96	0.168	0.06	-0.033	35.8
Soil Water (g H ₂ O/g soil), 7/97	0.017	0.122	0.607	0.00005	0.027
Shaule					
Est.% Veg. Cover, 6/96	12.8	0.55	0.023	0.128	-4.38
NO ₃ (ppm), 6/96	5.22	0.489	0.009	0.045	81.22
Respiration (CO ₂ /m ² /day), 9/97	0.007	0.421	0.045	0.000059	0.4387
BD (g/cm ³), 9/97	0.077	0.429	0.04	0.0006	0.4701
Heynemann					
Infiltration (l/minute), 7/97	14.282	0.153	0.172	-0.055	46.65
NO ₃ (ppm), 7/97	26.526	0.113	0.75	-0.086	76.16
Lane					
NO ₃ (ppm), 5/97	8.813	0.232	0.221	0.046	84.48
NO ₃ (ppm), 9/97	15.783	0.316	0.248	0.103	25.22
Morton					
NO ₃ (ppm), 5/97	10.343	0.177	0.67	0.0433	82.254
Infiltration (l/minute), 5/97	16.997	0.103	0.755	-0.052	25.826

Throughout two growing seasons, four relationships were found to be statistically significant to a 95% confidence interval. All were found on the Shaule ranch, and all were found immediately after cattle had grazed the pastures. June 1996 correlations between

nitrogen and vegetative cover were significant to a 95% confidence level. September 1997 correlations between soil bulk density and microbial respiration were significant to a 95% confidence level.

Figure 4 illustrates NO_3 on the Shaule ranch increasing as distance from the water source increases. Figure 5 shows the trend was contrary to the general trend of the other ranches at the same sampling time.

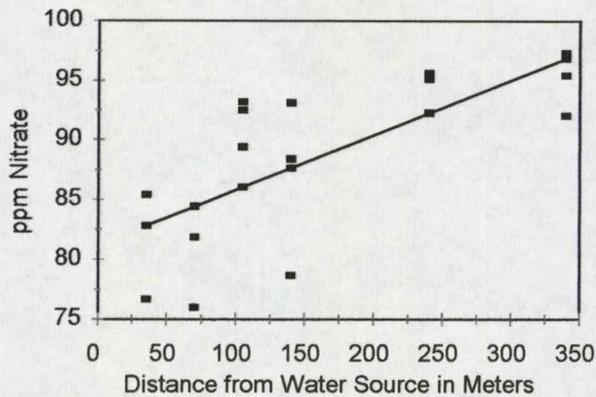


Figure 4. Linear regression of NO_3 and distance from water source. Sample taken from Shaule ranch June 1996. $r^2=.489$, $p=.009$.

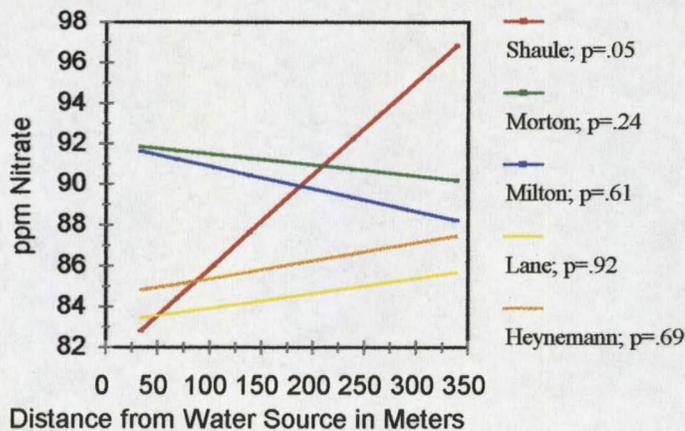


Figure 5. Relationship of NO_3 and distance from water on all ranches in June, 1996.

Figure 6 shows respiration rates increasing with distance from water source on the Shaule ranch. Figure 7 suggests little difference between the results of the Shaule ranch and the other study ranches.

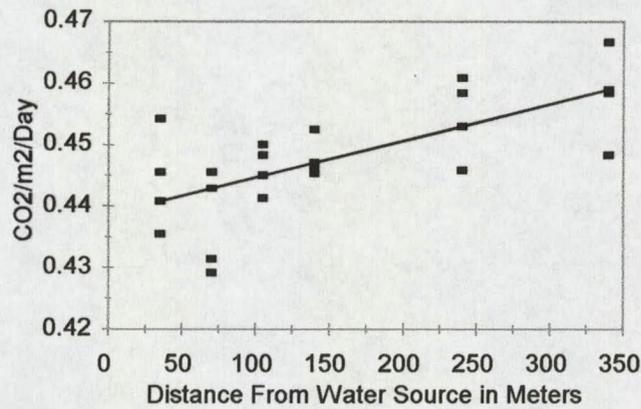


Figure 6. Linear regression of microbial respiration and distance from water source. Samples taken from Shaule ranch in September, 1997. $r^2=.42$, $p=.045$.

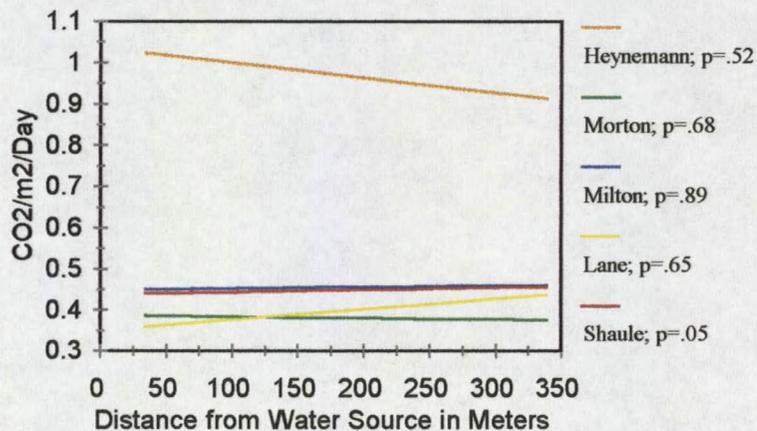


Figure 7. Relationship of evolved CO₂ and distance from water for all ranches during September, 1997.

Figures 8 and 9 show vegetative cover results from 1996. Shaule results differ considerably from the norm of the other ranches.

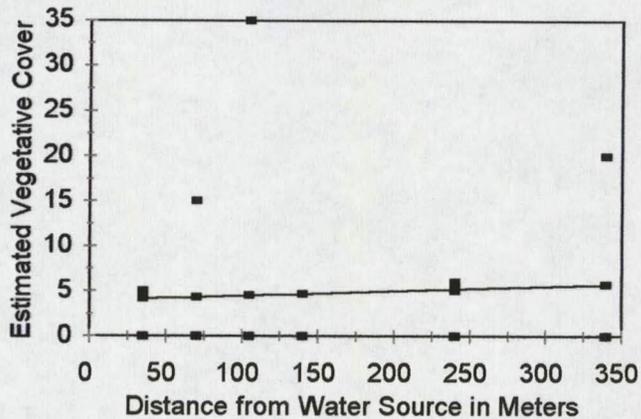


Figure 8. Linear regression of vegetative cover. Very little cover remained after livestock had grazed pasture. Sample taken in June 1996

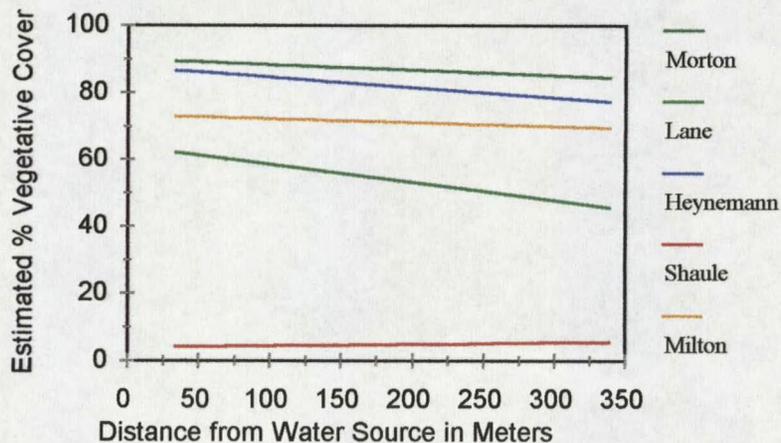


Figure 9. Relationship of vegetative cover and distance from water source on all ranches in 1996.

Figure 10 displays combined 1996 and 1997 bulk density results for all ranches. The Shaule ranch does not follow the trend of the other ranches.

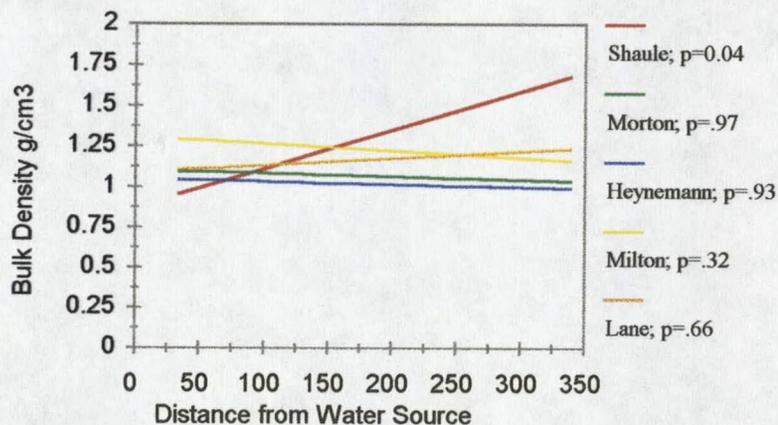


Figure 10. Relationship of bulk density and distance from water source on all ranches in 1996 and 1997.

Refer to the appendix for additional data. The full range of values for each soil parameter is listed. Information for each ranch is organized by sampling time.

DISCUSSION

The design of this study made no attempt to minimize variability. Working ranches were chosen because they operate within whole natural systems without the privilege of reduced variability possible in more controlled experiments. The study sought to learn how the ranches were managing their resources. Including sites with different soils, moisture regimes, pasture sizes, grazing intensities and durations made conclusions difficult, if not impossible. But it also more accurately depicts the inherent variability and difficulties of range management.

Soil physical and chemical properties were measured to identify patterns in soil characteristics on five ranches practicing time-controlled grazing in south central Montana. Animal impact was expected to relate strongly to distance from water source. Because all livestock had to drink from the same water source, sample sites closer to the water source were expected to be more impacted than sites further from water. Actual results differed from anticipated results. Few significant relationships were found within 340 meters from the water source. All significant relationships were found on the Shaule ranch, and only when sampled immediately after grazing.

Strong relationships were expected on the Shaule ranch. Observations from the field noted more extensive animal impact than on the other ranches. High animal numbers combined with narrow pastures near the water source resulted in extreme animal concentration. The area of visible animal impact quadrupled that of the other ranches. All vegetation was consumed and the soil surface was pulverized for over 100 meters extending away from the water source. High impact areas on the other four ranches

extended only 10-30 meters.

Animal impact is not solely a function of animal numbers. Significant relationships were found only on the Shaule ranch, but two other ranches had comparable stocking rates. The Morton ranch had greater animal density (animals/acre) and grazing intensity (animal days/acre), and the Heynemann ranch had only slightly lower stocking rates. Animal impact was visible, but to a lesser extent. Significant relationships between soil characteristics and distance were not found at any sampling time.

Soil and climatic differences may explain the lack of strong relationships on the Morton and Heynemann ranches. The Morton and Heynemann ranches consist of loam soils, and receive greater precipitation than Shaule's clayey soils. Potential for soil compaction is greater in moist soils (Warren et.al., 1986c), but plentiful moisture also facilitates recovery from grazing. A short growing season in the mountain foothills limits the time available for plant regrowth, but more severe freeze thaw processes may increase natural amelioration of soil compaction. The importance of freeze thaw processes has been documented (Mooers 1989, Riggle 1989). These differences may allow soils on the Morton and Heynemann ranches to more fully recover from animal impact than the soils of the Shaule ranch and help explain the absence of significant relationships.

Among ranches with similar soils receiving roughly equal amounts of precipitation, significant relationships were found only on the most intensively grazed ranch. The Lane, Milton and Shaule ranches possess similar soils and climatic regimes, but Shaule's grazing intensity (18 ADA) was nearly twice that of Lane (10 ADA) and Milton (7-10 ADA). No relationship significant to a 95% confidence interval was found on the

Milton or Lane ranch. One relationship significant to a 90% confidence interval was found on the Milton ranch. A dramatically higher grazing intensity may explain why significant relationships were found only on the Shaule ranch.

Strong relationships found on the Shaule ranch may be the result of sampling timing. Significant relationships were only found when sampling corresponded with the end of grazing rotations. In both June 1996 and September 1997, livestock were removed from the pastures shortly before sampling revealed significant relationships. No strong relationships were found when sampling and grazing did not coincide.

Timing did not appear to be a factor on the ranches grazed less intensively. In July 1997 livestock were removed shortly before sampling on the Heynemann ranch, the Lane ranch, and the Morton ranch. In July 1997 and in September 1997 sampling corresponded with sampling on the Milton ranch. No strong relationships were found during these sampling times.

The importance of these findings is not clear. Significant relationships were few and scattered. No patterns among trends were identified regardless of climate, soil type, stocking density or grazing intensity. Thus, the results do not support the hypothesis that intensive animal impact is degrading rangeland. The few significant trends found in soil characteristics do not consistently show degrading results from intensive grazing. The four significant relationships found could be erroneous findings. Sufficient possibilities exist that with 5% error, all significant relationships could be the result of coincidence.

The results of this study can not indicate that time-controlled grazing is improving or degrading range. No base-line data were gathered to that end. The lack of significant

trends points to one of two interpretations:

- 1) The five ranches are successfully mitigating the impact of increased livestock densities on their range. Because soil parameters were not found to be effected by livestock around the water source, it appears that management is successfully harvesting forage without incurring negative trends on the soil resource. Pastures are grazed intensively, but sufficient recover time is allowed for natural processes to ameliorate trends in soil properties. The importance of seasonal change to soil parameters has been well documented (Thomsen, 1968, Warren et.al. , 1986a).
- 2) All the pastures in the study, and all areas along the transect were equally impacted by time-controlled grazing. The study does not include a control, thus the possibility that all the pastures are equally affected by the grazing treatments exists.

One of the primary arguments for time-controlled grazing management is that it replicates the natural grazing patterns of herbivores more closely than traditional seasonal grazing management. The ranches included in this study seem to be successfully employing livestock grazing, animal impact and rest/recovery to emulate natural, well functioning rangeland. This argument is supported by the lack of linear trends in physical and chemical soil data. Only four pastures had trends significant to a 95% confidence interval during two growing seasons. The five ranches contain different soils, moisture regimes, growing season lengths, and apply varying degrees of intensive grazing. It seems highly unlikely that such uniform results would come from such varying situations.

Results may be inconclusive because the study ranches are not operating at a high enough level of intensity. Shaule ranch results deviated from the results of the other

ranches. This could suggest that more conclusive evidence of the advantages or disadvantages of intensive grazing will be seen at higher stocking levels than currently found in the study. Some ranches are experimenting with stocking rates as high as 100-200/acre (Kroos, 1998). Further examination of the impact of extremely high stocking rates may help us understand how animal impact resulting from intensive time-controlled grazing affects ecological systems.

CONCLUSIONS

Animal impact in intensive rotational systems is more evenly distributed than previously thought. No consistent pattern of strong relationships between animal impact and distance from a water source was detected along a 340 meter transect at any of the study sites. Relationships found are believed to result from sampling timing.

Strong relationships were found only on the ranch with the highest grazing intensity and only when sampling coincided with grazing. Strong relationships were not found on the other ranches regardless of sampling timing. No strong relationships were found early in the growing season (May) regardless of sampling timing, or grazing intensity. These results highlight the importance of recovery time from grazing pressure, and the freezing and thawing processes during winter months that ameliorate the effects of animal impact.

Intensive time-controlled grazing may be affecting physical and chemical soil relationships at higher stocking rates. The benefits and drawbacks of high stocking rates remain unclear.

Recommendation for Further Study

- Sample on a regular basis (every 1-2 weeks) throughout growing/grazing season
- Take multiple samples at each sampling site
- Include a ranch operating with high grazing intensity and or stocking rates
- Compare high grazing intensity ranch(es) with low intensity ranch(es)
- Include a control by constructing a grazing enclosure on both high and low intensity ranches

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APPENDIX

Table 5. Shaule data, July 1996.

Distance from Water (m)	Respiration (CO ² /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	2.22142857	3	0.8031	0.0113	76.7
70	2.20619469	15	0.7899	0.0406	-
105	2.23482143	11	0.5778	0.0097	92.5
140	2.20350877	20	0.8995	0.0098	78.7
240	2.33796296	18	0.9592	0.0184	92.3
340	2.26339286	30	1.1195	0.0193	92
35	2.12393162	3	0.9675	0.0285	-
70	2.12649573	21	0.8486	0.0161	76
105	2.20619469	34	0.9208	0.0186	89.4
140	2.11694915	29	1.0305	0.0185	88.4
240	2.25495496	30	1.0277	0.0151	95.1
340	2.18086957	16	1.2192	0.0119	95.4
35	-	9	0.9451	0.0117	85.4
70	2.24818182	54	1.0090	0.0216	81.9
105	2.13793103	22	1.1906	0.0106	93.2
140	2.1626087	18	1.1622	0.0104	93.1
240	2.225	10	0.9625	0.0194	95.6
340	2.21061947	15	1.0103	0.0127	97.3

Table 6. Morton data August 1996.

Distance from Water (m)	Respiration (CO ² /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)
35	10.8	2	1.0330	0.0731
70	11.3	7	1.1077	0.0369
105	10.9	4	0.9859	0.0381
140	11.1	5	1.2536	0.0505
240	10.8	5	0.8600	0.0498
340	-	1	0.9687	0.0569
35	9.9	1	0.9156	0.1434
70	10.8	1	0.9347	0.0876
105	10.6	1	0.8937	0.1267
140	10.5	1	0.7954	0.0978
240	11.5	3	1.2055	0.0366
340	11.1	17	1.0372	0.0470
35	11.1	17	1.2842	0.0515
70	11.5	7	1.1212	0.0495
105	11.4	26	0.9872	0.0614
140	11.4	12	1.0620	0.0448
240	11.3	2	0.8283	0.0617
340	10.6	2	1.0592	0.0893

Table 7. Milton data, June 1996.

Distance from Water (m)	Respiration (CO ² /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	22	2.25	97.7	0.0433	1.1945
70	20	2.3184466	94	0.0519	1.1713
105	15	2.12212389	91.9	0.0451	1.1003
140	17	2.20458716	93.8	0.0294	1.2242
240	11	2.12105263	90	0.0343	1.2161
340	14	-	93.5	0.0379	1.2308
35	22	1.93269231	94.6	0.0380	1.2909
70	15	2.1688172	86.9	0.0697	1.1772
105	13	2.08453608	77.7	0.1134	1.2853
140	7	1.96796117	76.8	0.0640	1.0463
240	17	1.99345794	89.1	0.0511	1.2548
340	9	2.11683168	95	0.0497	1.3271
35	30	2.17553191	84.3	0.0473	1.2583
70	7	2.00980392	94.1	0.0364	1.4203
105	16	2.07373737	91.6	0.0328	1.3909
140	13	2.058	95.7	0.0405	-
240	12	1.96666667	91.4	0.0350	1.3779
340	8	1.95283019	95	-	1.3246
35	29	1.81565217	84.9	0.0128	1.1322
70	27	1.82	84.1	0.0147	1.2082
105	30	-	85.9	0.0125	1.4314
140	30	1.98396226	92.8	0.0194	1.1222
240	20	1.81724138	87.6	0.0124	1.0963
340	19	1.94220183	92.2	0.0178	1.2371
35	31	1.64705882	94.7	0.0070	1.5574
70	16	1.72105263	93.5	0.0083	1.4854
140	-	1.77657658	94.4	0.0083	1.2506
240	20	1.84722222	84.6	0.0132	0.9267
340	20	-	89.2	0.0174	1.0317

Table 8. Lane data, June 1996.

Distance from Water (m)	Respiration (CO ² /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	1.9144	33	1.1211	0.0245	90.8
35	1.7557971	9	0.8284	0.0097	84
35	1.95	23	0.9259	0.0290	69.5
70	1.94878049	39	1.0489	0.0278	90.3
70	1.96511628	25	1.1827	0.0224	90.6
70	1.88307692	29	1.0357	0.0169	77.8
105	1.8380597	14	0.9329	0.0064	76.3
105	1.90079365	23	0.9690	0.0306	90
105	1.9351145	25	1.0826	0.1886	92.8
140	1.92045455	22	1.2075	0.0213	85.2
140	1.83333333	13	1.0002	0.0215	73.6
140	1.9224	24	0.9471	0.0232	87.6
240	1.85777778	12	1.0320	0.0095	82.9
240	1.89133858	17	1.2166	0.0277	83.3
240	1.9984252	15	1.2135	0.0193	90.6
340	1.94384615	10	1.1869	0.0183	85.4
340	1.88432836	9	1.0423	0.0245	81.3
340	1.875	22	1.0628	0.0299	81.4

Table 9. Heynemann data, June 1996.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minute/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.9485	62	0.0662	78.7	-
70	1.1633	17	0.0611	64.8	-
105	1.1678	23	0.0663	59.8	-
140	1.0309	30	0.0553	92.3	-
240	0.9465	19	0.1236	90.1	-
340	1.2612	13	0.0750	-	-
35	1.7918	27	0.0871	92.2	2.469697
70	1.1292	27	0.0686	80.4	2.4969388
105	1.0239	10	0.0963	90	2.741573
140	1.2815	26	0.0297	91.1	2.2757009
240	1.1550	37	0.0480	73	2.0931034
340	0.8856	14	0.0738	91	2.4203884
35	1.3774	22	0.0394	95.3	2.2480392
70	1.1911	11	0.0416	94.1	2.1637255
105	1.3439	11	0.0376	92.4	2.2794118
140	0.6545	12	0.0272	92.7	2.2171429
240	1.3129	14	0.0379	94.1	2.1181818
340	1.1123	4	0.0385	94.7	2.3897959

Table 10. Shaule data, September 1996.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.560177	-	0.834166	0.2215	69.3
35	0.507273	-	0.826439	0.2352	47.1
35	0.545045	-	1.318766	-0.0850	47.5
70	0.563717	-	0.653697	0.3061	54.4
70	0.581818	-	0.601111	0.5115	72.7
70	0.597297	-	1.131579	0.2004	71.7
105	0.612613	-	1.031905	0.1935	65.1
105	0.571429	-	1.145234	0.1769	70.6
105	0.582143	-	1.036981	0.1815	74.4
140	0.583784	-	0.973059	0.2051	71
140	0.520536	-	1.198651	0.1718	72.4
140	0.574107	-	1.344103	0.1416	86
240	0.526786	-	1.066734	0.1865	80.1
240	0.578571	-	0.925626	0.1872	36.2
240	0.584821	-	1.132848	0.1840	33.3
340	0.533929	-	0.93452	0.1655	79.3
340	0.584071	-	1.283299	0.1971	57.7
340	0.584821	-	1.269936	0.1948	79.4

Table 11. Milton data, September 1996.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	-	-	1.067109	0.1099	95.5
70	0.6756756757	-	0.991501	0.0994	96.4
105	0.6785714286	-	1.07233	0.0980	91.7
140	0.704587156	-	1.099259	0.1135	83.7
240	0.6954954955	-	1.009893	0.1263	93
340	0.7072072072	-	1.031915	0.1000	96.3
35	0.2765765766	-	1.070854	0.0997	91.2
70	0.2765765766	-	1.051692	0.0939	90.4
105	0.2747747748	-	0.888655	0.1040	92.2
140	0.2699115044	-	0.945783	0.1030	93.5
240	0.2705357143	-	0.998343	0.1414	84
340	0.2696428571	-	0.936157	0.1198	86.9
35	0.2831858407	-	1.06455	0.1156	83.6
70	0.275862069	-	1.270313	0.1390	95.7
105	-	-	1.059011	0.1074	94.1
140	0.2850877193	-	1.028678	0.1439	85.1
240	0.2886956522	-	1.07126	0.0875	95.5
340	0.2886956522	-	1.138814	0.1465	86.5
35	0.4642857143	-	1.08893	0.0657	89.5
70	0.4543859649	-	1.127327	0.0839	63.6
105	0.452173913	-	1.233333	0.0700	90.6
140	0.4504347826	-	1.061097	0.0824	90.6
240	0.4543859649	-	1.352	0.0878	90.9
340	0.4543859649	-	1.098827	0.0758	42
35	0.4305084746	-	1.357368	0.0620	96
70	0.4379310345	-	1.170886	0.0666	95.3
105	-	-	-	-	-
140	0.4408695652	-	1.246176	0.0838	96.3
240	0.4408695652	-	1.029243	0.0720	89.2
340	0.4495575221	-	1.009714	0.1013	99.4

Table 12. Morton data, September 1996.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minute/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	2.37333333	-	2.373333	0.2541	93
70	2.37142857	-	2.371429	0.2109	90.5
105	2.28256881	-	2.282569	0.1879	88.2
140	2.39230769	-	2.392308	0.1969	90.7
240	2.28256881	-	2.282569	0.2782	96
340	2.36857143	-	2.368571	0.2732	94.5
35	2.63541667	-	0.489033	0.3666	77
70	2.537	-	0.331168	0.3317	61.4
105	2.47058824	-	0.599225	0.3309	58.6
140	2.4375	-	0.657982	0.3099	83.9
240	2.33333333	-	1.120682	0.2439	77.3
340	2.36915888	-	0.853973	0.2531	71.4
35	2.37431193	-	1.044328	0.2011	86.6
70	-	-	0.766667	0.2613	74.6
105	2.43207547	-	0.840193	0.2459	60.8
140	2.43113208	-	0.650524	0.2911	71.3
240	2.4212963	-	0.628522	0.3059	87.9
340	2.47358491	-	0.453414	0.3487	85.4

Table 13. Shaule data May 1997.

Distance from Water (m)	Respiration (CO ² /m ² /day)	Infiltration (minute/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.37827	10	0.61113	0.0728	95.3
70	0.390342	6	0.514709	0.0591	101.1
105	0.377965	31	0.786114	0.0371	100
140	1.761978	19	0.707151	0.0789	101.6
240	0.402414	20	0.626737	0.0577	102
340	0.39791	36	0.77202	0.0561	102.5
35	0.378913	8	0.540661	0.0718	96.8
70	0.329489	8	0.585941	0.0817	99.4
105	0.403292	47	0.711351	0.0419	99.7
140	0.444444	47	0.700082	0.0584	101.9
240	0.407072	60	0.766528	0.0520	102.1
340	0.398849	23	0.678927	0.0497	103.2
35	-	17	0.712631	0.0679	97.5
70	-	29	0.592257	0.0353	101.3
105	-	23	0.708676	0.0424	103.4
140	-	21	0.603299	0.0567	102.6
240	-	11	0.650536	0.0465	93.1
340	-	11	6.32574	0.0418	97.4

Table 14. Morton data, May 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	-	3	0.869843	0.3162	92.4
70	-	24	1.063169	0.2294	95
105	-	31	1.190697	0.2355	94.7
140	-	7	1.073645	0.2707	93.8
240	-	2	0.641048	0.3208	97.3
340	-	14	1.024344	0.2808	97.6
35	0.372414	60	0.440676	1.2861	65.5
70	0.321839	9	0.878333	0.5346	56.7
105	0.308046	2	0.76501	0.5170	85.2
140	0.220893	10	1.154747	0.4287	94
240	0.437385	19	1.196254	0.2171	95
340	0.367816	16	0.812764	0.3203	95.4
35	0.328698	7	1.01628	0.3053	94.1
70	0.344973	23	1.214889	0.2361	93
105	0.361345	55	0.830638	0.3600	87.3
140	0.348008	32	0.819778	0.3366	81.8
240	0.267559	4	0.646488	0.2630	88.4
340	0.258333	2	0.786467	0.3567	94.2

Table 15. Milton data, May 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minute/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.470733	24	0.782401	0.0556	102.9
70	0.474438	23	0.515968	0.0599	101.8
105	0.482618	25	0.712822	0.0556	103.3
140	0.49857	15	0.748527	0.0450	101.3
240	0.437092	19	0.761012	0.0725	103
340	0.510621	25	0.630048	0.0614	100.6
35	0.529915	15	0.54579	0.0592	104.7
70	0.500428	10	0.658639	0.0618	103.8
105	0.531505	13	0.619379	0.0450	105
140	0.532646	9	0.600145	0.0522	103
240	0.532875	11	0.67841	0.0374	102.1
340	0.519983	7	0.609177	0.0424	95.4
35	0.515856	25	0.767034	0.0277	99.5
70	0.466497	46	0.56666	0.02618	101.8
105	0.501062	24	0.585488	0.02489	102.9
140	-	26	0.620203	0.0302	101.3
240	0.512164	12	0.645688	0.04263	102.2
340	0.526316	9	0.611052	0.04975	103.9
35	0.483333	42	0.637307	0.0249	99.5
70	0.492207	32	0.625262	0.04236	101.2
105	0.490798	37	0.638889	0.03035	101.8
140	0.495868	27	0.679218	0.03078	103.2
240	0.473896	17	0.721489	0.0375	102.3
340	0.496596	15	0.637913	0.04437	98.8
35	0.523605	54	-	-	103
70	0.511628	14	-	-	103.7
105	-	0	-	-	105.3
140	0.525869	16	-	-	103.2
240	0.511291	44	-	-	103.1
340	0.484071	26	-	-	103.4

Table 16. Lane data, May 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.371417	35	0.645649	0.2194	82.7
70	0.448123	37	0.720773	0.1916	94.7
105	0.443906	60	0.773972	0.2047	95.8
140	0.431974	35	0.681957	0.1749	94.6
240	0.447942	47	0.721206	0.1926	94.5
35	0.461603	43	0.690268	0.2189	95.8
70	0.461603	53	0.597383	0.2189	89.3
105	0.491184	26	0.672669	0.2323	93.7
140	0.470193	44	0.698111	0.1719	95.5
240	-	53	0.775103	0.2006	92.8
340	0.461797	46	0.669821	0.2411	95.5
35	0.325421	51	0.50675195	0.325619448	66.7
70	0.325421	17	0.80718746	0.188348595	68.4
105	0.348392	11	0.61794658	0.283398622	99.7
140	0.383142	3	0.57573853	0.23389738	93.2
240	0.382702	28	0.80356894	0.188237335	99.7
340	-	60	0.51887272	0.261568627	98.3

Table 17. Heynemann data, May 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.363559	50	-	0.2806	83.1
70	0.329341	24	-	0.3175	79.2
105	0.31651	42	-	0.3150	86.4
140	0.371477	19	-	0.3692	87.8
240	0.427716	22	-	0.2292	92.3
340	0.349382	44	-	0.3480	90.1
35	0.331675	60	0.901308	0.2971	89.2
70	-	60	0.897701	0.3103	87.1
105	0.414938	38	0.889078	0.2170	89.8
140	-	36	0.925621	0.3060	92.6
240	0.356551	20	0.670099	0.3422	86.2
340	0.290216	29	0.670813	0.4497	87.2
35	0.312891	29	0.788715	0.3547	89.1
70	0.259197	33	0.931889	0.2766	89.3
105	0.226131	23	0.934881	0.2169	78.7
140	0.378851	28	0.96044	0.2463	87.4
240	0.340673	51	0.943916	0.2832	77.5
340	0.369295	60	0.888338	0.2581	96.8

Table 18. Shaule data, July 1997

Distance from Water (m)	Respiration (CO ² /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.433953	23	0.411696	0.0705	86.1
70	0.395804	18	0.586038	0.07012	91.4
105	0.429185	26	0.612977	0.052	91.7
140	0.462566	54	0.566379	0.04717	86.4
240	0.453028	23	0.660853	0.05446	93.4
340	0.433746	34	0.598225	0.06977	93.9
35	0.42524	13	0.544781	0.0346	64.6
70	0.452675	23	0.588024	0.03642	74.3
105	0.402194	55	0.616195	0.048	88.7
140	0.365631	46	0.582883	0.0812	83
240	0.419708	60	0.690404	0.0472	91.8
340	0.452055	12	0.783238	0.04322	89.8
35	-	37	0.55869	0.0288	64.8
70	0.412277	60	0.49322	0.0756	91
105	0.361887	20	0.475585	0.126582	62.6
140	0.453504	38	0.615267	0.04856	85.5
240	0.443936	19	0.555187	0.04143	80.1
340	0.452675	23	0.490163	0.03279	95.2

Table 19. Morton data, July 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.224517	3	0.332077	0.1695	63.70
70	0.331393	12	0.828645	0.07507	93.20
105	0.286353	3	0.5068	0.111747	96.10
140	0.317248	17	0.677963	0.124334	92.70
240	0.267857	1	0.378975	0.202863	91.40
340	0.272288	1	0.541011	0.215975	94.80
35	0.133809	60	0.498502	0.7153	63.3
70	0.196604	9	0.693438	0.38719	55.4
105	0.178811	3	0.551215	0.213483	88.2
140	0.206001	10	0.502738	0.216133	98.4
240	0.278652	14	0.807906	0.134547	85
340	0.229523	44	0.74028	0.190702	93.2
35	0.272356	2	0.654762	0.1476	90.7
70	0.30839	42	0.72195	0.09837	91.7
105	0.349682	60	0.778486	0.07267	87.8
140	0.277273	60	0.692193	0.07841	75.6
240	0.281818	1	0.483519	0.161963	79.4
340	0.177515	2	0.601432	0.262897	70.7

Table 20. Milton data, July 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.438517	24	-	0.0419	95.9
70	0.416855	5	-	0.0499	89.5
105	0.43123	25	-	0.0481	94
140	0.427273	17	-	0.0366	92.4
240	0.418562	32	-	0.0446	95.1
340	0.405467	17	-	0.0787	91.9
35	-	13	0.748892	0.0330	94.2
70	0.328621	19	0.579192	0.0532	97.3
105	0.347594	7	0.696639	0.0428	97.8
140	0.376426	13	0.803438	0.0353	96.5
240	0.371494	20	0.958172	0.0204	96.6
340	0.362949	13	0.89211	0.0329	95.3
35	0.393762	17	0.684926	0.0420	70.4
70	0.397661	28	0.937825	0.0305	93.9
105	0.385965	17	1.122682	0.0263	94.9
140	0.389864	29	0.855211	0.0272	96.8
240	0.381769	8	1.054952	0.0630	96.1
340	0.386266	12	-	0.0884	96.4
35	0.386719	36	0.864931	0.0164	90.5
70	0.390625	34	0.872957	0.0210	87.7
105	0.386719	24	0.872932	0.0202	94.3
140	0.37861	20	0.914313	0.0595	93.8
240	0.394223	31	0.911698	0.0276	96.1
340	0.398126	15	1.146433	0.0135	95.5
35	0.390533	6	0.925265	0.0132	98.4
70	0.367299	45	0.946345	0.0195	98.3
105	-	-	-	-	99.4
140	0.363349	20	0.988622	0.0210	95.9
240	0.371983	8	0.857928	0.0365	90.8
340	0.384463	60	0.885088	0.0405	94.7

Table 21. Lane data, July 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.2391	60	0.672827	0.0742	83.8
70	0.328176	34	0.75212	0.06863	87.4
105	0.302045	54	0.677599	0.0801	86.5
140	0.255576	60	0.724933	0.06977	86.9
240	0.361949	60	0.774389	0.07538	92.8
35	0.282075	31	0.758126	0.0820	88.6
70	0.304823	46	0.658449	0.08767	81.2
105	0.340909	60	0.596308	0.0865	87.9
140	0.309091	53	0.591952	0.0836	83.5
240	0.326975	50	0.787029	0.06702	83.6
340	0.290645	50	0.673151	0.0924	80.8
35	0.440953	14	0.76635514	0.03741685	54.5
70	0.460759	17	0.51575656	0.06623134	86.4
105	0.501266	24	0.55032084	0.01534213	81.5
140	0.463476	29	0.71714006	0.03769462	95.6
240	0.448363	33	0.61733817	0.0482524	96.2
340	0.457746	24	0.67096555	0.04097117	96.5

Table 22. Heynemann data, July 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.239686	59	0.53612	0.1655	74.1
70	-	55	0.672979	0.2053	86
105	0.282021	45	0.731783	0.1645	86.9
140	0.262026	29	0.60911	0.1658	87.2
240	0.296643	8	0.552198	0.1414	81.4
340	0.289855	23	0.431592	0.6121	85.1
35	0.201207	42	0.503495	0.2152	86
70	0.30961	42	0.614947	0.1641	86
105	0.321543	17	0.82354	0.1199	75
140	0.325563	29	0.555471	0.1384	81.9
240	0.329582	40	0.643276	0.2126	54.2
340	0.297547	44	0.680292	0.0994	16.2
35	0.635514	60	0.572027	0.2817	58.5
70	1.233645	40	0.436824	0.426448	9.3
105	0.968343	27	0.543451	0.2423	58.3
140	1.301115	60	0.535128	0.214778	53.3
240	1.115242	25	0.444282	0.41287	9.8
340	1.107011	42	0.462813	0.329169	43.3

Table 23. Shaule data September 1997.

Distance from Water (m)	Respiration (CO ² /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.445462	35	0.379431	0.0257	43.7
70	0.445462	52	0.477699	0.0220	84.4
105	0.441299	29	0.50375	0.0111	69.3
140	0.445277	60	0.590055	0.0181	54.9
240	0.445833	60	0.683117	0.0274	77
340	0.458333	50	0.6012	0.0168	82.1
35	0.454167	30	0.577234	0.0154	58.6
70	0.429167	21	0.388064	0.0239	71.6
105	0.45	20	0.504283	0.0112	91
140	0.445833	20	0.516216	0.0148	90
240	0.458333	20	0.691169	0.0210	85.9
340	0.466667	30	0.71573	0.0271	91
35	0.435511	16	0.559623	0.0181	66.4
70	0.431323	39	0.478204	0.0184	93.6
105	0.448261	35	0.591801	0.0198	89.2
140	0.452451	60	0.706912	0.0182	42.4
240	0.460829	43	0.573993	0.0262	69.4
340	0.448261	29	0.615469	0.0139	93.1

Table 24. Morton data, September 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.320833	4	0.66501	0.2398	65.5
70	0.420833	11	0.570082	0.1988	82.6
105	0.395833	8	0.57961	0.2074	95.5
140	0.4125	47	0.687297	0.1962	77.4
240	0.376301	8	0.436001	0.2910	71
340	0.320256	5	0.427524	0.3000	61.6
35	0.358333	4	0.32871	0.7802	13.7
70	0.3625	6	0.541798	0.4461	26.3
105	0.345833	7	0.438976	0.4613	30.2
140	0.375	4	0.54581	0.2932	18.5
240	0.383333	6	0.708767	0.2411	61.4
340	0.4125	10	0.623096	0.2240	66
35	0.408333	12	0.75967	0.2757	49.8
70	0.416667	60	0.627146	0.2376	59.2
105	0.4125	60	0.537595	0.2827	48.2
140	0.391667	60	0.516688	0.2923	48.5
240	0.416667	3	0.423439	0.3236	19.1
340	0.358333	7	0.590524	0.3363	25.1

Table 25. Milton data, September 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	-	42	0.516301	0.0519	85
70	-	33	0.685857	0.0215	88.3
105	-	33	0.558652	0.0546	87.4
140	-	35	0.639	0.0247	88.1
240	-	28	0.747773	0.0477	86.4
340	-	38	0.591808	0.0557	87.2
35	0.491667	23	0.577909	0.0614	83.6
70	0.441667	47	0.580683	0.0666	88.4
105	0.470833	36	0.541869	0.0435	85.7
140	0.479167	20	0.481539	0.0480	85.4
240	0.475	21	0.531447	0.0380	84.8
340	0.470833	23	0.566816	0.0476	90
35	-	28	0.592041	0.0752	75.4
70	-	42	0.61917	0.0265	93.1
105	-	31	0.500646	0.0372	92.1
140	-	36	0.600539	0.0383	93.2
240	-	8	0.627507	0.0479	90.3
340	-	16	0.552504	0.0423	89.5
35	0.42237	37	0.610413	0.0408	81.6
70	0.42237	36	0.659821	0.0477	79.7
105	0.434102	35	0.603732	0.0316	88
140	0.437842	33	0.621326	0.0272	89.3
240	0.449219	24	0.569615	0.0439	89.4
340	0.4375	33	0.596495	0.0279	93.5
35	0.45509	37	0.698484	0.0307	95
70	0.459449	32	0.651707	0.0303	96.5
140	0.462704	19	0.512683	0.0278	94.9
240	0.462704	31	0.549235	0.0340	91.2
340	0.466507	33	0.589325	0.0475	90.5

Table 26. Lane data, September, 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.34528	60	0.524957	0.2075	24.1
70	0.349803	60	0.794883	0.1210	55.7
105	0.420131	10	0.581168	0.1558	29.3
140	0.411379	29	0.62457	0.1502	36.2
240	0.375546	43	0.666722	0.1218	46.9
35	0.538293	60	0.616286	0.1835	34.1
70	0.349803	60	0.641129	0.1551	36.7
105	0.393529	60	0.624117	0.1231	42
140	0.380411	60	0.48909	0.1307	39.6
240	0.371666	60	0.571482	0.1405	50.2
340	0.686489	46	0.673732	0.1727	34.2
35	0.332075	35	0.55879615	0.1105	2
70	0.339623	34	0.58606061	0.1007	7.3
105	0.320513	33	0.48628571	0.1387	47.5
140	0.324161	37	0.68927079	0.1146	64.6
240	0.346777	27	0.58377933	0.1298	60.2
340	0.309084	54	0.47241152	0.1275	71.9

Table 27. Heynemann data, September 1997.

Distance from Water (m)	Respiration (CO ₂ /m ² /day)	Infiltration (minutes/l)	BD (g/cm ³)	Soil Water (g H ₂ O/g soil)	NO ₃ (ppm)
35	0.489372	60	0.616086	0.1595	76.2
70	0.509145	32	0.595769	0.2418	85.4
105	0.529179	59	0.440009	0.3339	73.8
140	8.707483	60	0.582681	0.1419	57.1
240	0.543747	60	0.624804	0.1609	76.2
340	0.582141	60	0.649568	0.2276	38.4
35	0.511811	39	0.577095	0.2295	61.4
70	0.496803	29	0.566718	0.2055	65.2
105	0.536153	17	0.630638	0.1265	71.3
140	0.472209	27	0.560571	0.1549	48.2
240		60	0.58851	0.1010	69.7
340	0.4914	28	0.431969	0.1974	75.3
35	0.461611	23	0.413069	0.2282	83.6
70	0.469925	17	0.464465	0.2010	81.5
105	0.454972	37	0.470337	0.1835	81.1
140	0.501171	27	0.537867	0.1594	65.5
240	0.471963	60	0.51703	0.1793	80.5
340	0.465549	33	0.467816	0.1855	80

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