Soil and Nitrogen Loss from Oregon Lands Occupied by Three Subspecies of Big Sagebrush

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Abstract

Measurements of runoff and soil loss from simulated high-intensity rainstorms are reported for shrub interspaces of 3 sites occupied by each of 3 subspecies of *Artemisia tridentata* (big sagebrush) in each of 4 locations in eastern Oregon. *A. tridentata* ssp. *wyomingensis* sites as a group had significantly higher soil loss than *A. tridentata* ssp. *vaseyana* sites. Comparisons of means within locations showed nonsignificant differences between land supporting big sagebrush subspecies except at Frenchglen. Soil loss was positively correlated with runoff, percent bare ground, and vesicular soil porosity; but it was negatively correlated with medium and coarse sand and coarse fragments in the surface soil and with organic ground cover. Aridisols lost more soil than Mollisols. Habitat types did not appear useful for indexing soil loss from these sites. Surface soil morphology, however, correlated with large significant differences in soil loss and may be a useful index. Organic and ammonium nitrogen loss was not correlated with a subspecies of *A. tridentata*, but did correlate with soil erosion and many of the soil features that affect soil erosion. Amounts of nitrogen lost do not appear to be critical.

Soil loss rates under natural conditions are among the highest for semiarid shrublands (Branson 1975). Osborn et al. (1978) found as much as 10 times greater sediment yields from brush-covered watersheds than from grass-covered watersheds. Buckhouse and Gaither (1982) measured potential soil losses of 431 kg per hectare for grassland ecosystems and 1,284 kg per hectare for sagebrush (*Artemisia* species) ecosystems in central Oregon.

Big sagebrush *(A. tridentatal)* is widespread, once occupying 145 million acres in western North America (Beetle 1960). Sagebrush ecosystems are also very diverse, suggesting a finer classification is needed, such as the habitat types of Daubenmire (1968) for improved management of western watersheds (Pfister 1981). In recent decades, improvement in sagebrush taxonomy has enabled identification of 3 subspecies of *A. tridentata*, each with distinct plant morphology and ecological requirements. Tisdale and Hironaka (1981) stressed the value of these subspecies in synecology and used them in classification by habitat type.

A. tridentata ssp. *wyomingensis* (Wyoming big sagebrush) dominates the most arid habitats of the 3 big sagebrush subspecies. It generally occurs below 1,800 m on moderately deep, well-drained soils which may be slightly calcareous near the surface. Because these sites are xeric and more easily degraded, a high percentage of them are in low ecological condition (Winward 1981). *A. tridentata* ssp. *tridentata* (basin big sagebrush) is a good indicator of potentially arable land because it occupies deep, well-drained soils. *A. tridentata* ssp. *vaseyana* (mountain big sagebrush) resides in the upper foothill to mountain areas. It occupies deep, well-drained soils with moisture available most of the summer (Winward 1980).

In Idaho, Hironaka and Fosberg (1979) found *A. tridentata* ssp. *wyomingensis* primarily on Aridisols (mostly Camborthids), *A. tridentata* ssp. *vaseyana* entirely on Mollisols (Cryborolls), and *A. tridentata* ssp. *tridentata* or a combination of these soil orders.

Plant growth is often stimulated by additions of nitrogen, especially when there is ample soil moisture (Sneva and Hyder 1965, Wallace et al. 1978) which allows the fertilized plants to use soil nitrogen more efficiently (James and Jurinak 1978). Most ecosystem nitrogen is tied up in soils (West and Klemmedson 1978). It is concentrated near the surface (Charley 1977) and is associated with clays and fine soil particles (Bremmer 1965, Chichester 1969, Swift and Posner 1972) and especially with organic matter (Nishita and Haug 1973, Swift and Posner 1972, and Nagi 1980). Being near the surface and associated with erodible material, it is susceptible to erosional loss (Fletcher et al. 1978). Although organic nitrogen is chemically unavailable for plant uptake, it does constitute the largest portion of the soil reserves, especially at and near the soil surface (West and Skujins 1978).

This research was undertaken to assess the capacity of big sagebrush subspecies to indicate differences in potential soil loss, organic and ammonium nitrogen loss, and runoff. These erosion parameters were related to other site factors, including soil classification, surface soil morphology, soil texture, organic matter, and ground cover of vegetation and litter.

Study Area and Methods

Four widely spaced study locations (Millican, Squaw Butte, Frenchglen, and Baker) were selected in 3 of the major geomorphic divisions of Oregon (High Lava Plains, Basin-Range, and Blue Mountains). At each location, 3 sites for each of 3 big sagebrush subspecies were studied, totaling 36 sites. Each site was located in a relatively homogeneous stand, representative of a common habitat type.

Rainfall simulation to initiate soil loss was done with a Rocky Mountain infiltrometer (Dortignac 1951). Sites were selected to be on slightly sloping terrain near a road and free enough of large surface soil stones that plot selection would not be unduly constrained. All but one of the *A. tridentata* ssp. *wyomingensis* sites were on Aridisols and all the *A. tridentata* ssp. *vaseyana* sites were on Mollisols. The lone *A. tridentata* ssp. *wyomingensis* site on a Mollisol was located very close to an *A. tridentata* ssp. *vaseyana* site;, neither site represented a large homogeneous area. *A. tridentata* ssp. *tridentata* sites were about evenly divided between Mollisol and Aridisol soil orders.

Before mid-July in 1980, herbaceous vegetation data were collected from 3 frequency transects of 10 30 × 61-cm plots each. Shrub density was determined with 3 1 × 30-m strip plots; canopy cover was estimated with 3 30-m line-intercepts (Pieper 1978). Following vegetation analysis, soils were described and classified (Soil Conservation Service 1975). Samples were analyzed in the laboratory for bulk density (Blake 1965), particle size distribution, and organic matter (Walkley and Black 1934).

In the summer of 1981 a set of 3 "F" type rainfall simulators were used to produce a high intensity (12.6 cm hr^{-1}), short duration (28 minutes) rainfall. This simulation should be considered as an index of potential rainfall because storms of this magnitude have a return

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Research was supported through funding provided by USDA Agricultural Research Service and the Eastern Oregon Agricultural Research Center. This article was submitted as Technical Paper No. 6752, Oregon Agricultural Experiment Station, Corvallis.

Manuscript received April 11, 1983.

period well in excess of 100 years in this region (Miller et al. 1973). A high intensity was needed to produce runoff on some sites, and using a Rocky Mountain infiltrometer with these rainfall rates makes results comparable to research done in Utah, Idaho, Colorado, and Oregon.

Infiltrometer sampling was conducted in shrub interspaces because Blackburn (1975) found that these areas produced greater amounts of runoff and sediment and because including shrub canopy zones would have greatly increased on-site variability. Six plots on each site were comprised of 3 30 × 76-cm steel frames driven into the ground side by side in such a way that runoff water would drain out the lower end.

Plots were pre-wetted at least 30 minutes prior to initiation of the runs in order to negate the effects of variable antecedent soil moisture. Water was applied with a gentle spray watering can until ponding began.[1] Sediment concentration was sampled with a 0.95-liter aliquot representative of a 28-minute run. Total soil loss was derived by multiplying sediment concentration by total runoff. An additional sample aliquot for nitrogen loss of approximately 175 ml was composited from the runoff water of the three subplots. This aliquot was immediately treated with 2 to 3 ml of 2 normal sulfuric acid and kept on ice until it could be frozen. Later, combined organic and ammonium nitrogen was determined with a macro-Kjeldahl apparatus (Jackson 1958).

Prior to each infiltrometer run, percent cover of canopy, bunchgrass base, litter, cryptogams, coarse fragments, bare ground, and surface soil morphology type were visually estimated in each plot. For analysis, bunchgrass base, litter, and cryptogams were combined and classified as organic ground cover. Field training for visual cover estimation was done wth a 100-point frame.

Laboratory analysis of clod bulk density (Blake 1965), particle size distribution (Day 1965), percent coarse fragments, and organic matter (Walkley and Black 1934) were determined from 2 samples of approximately the top 8 cm of surface soil morphology type collected at each site. All surface soil morphology types that would not form a reliable clod, and most other types as well, were field tested for bulk density using a modification of the excavation method (Blake 1965).

The 3 sites of each subspecies at each location served as replicates for a randomized complete block experimental design with location as the blocking factor and subspecies as the treatment. Simple and stepwise multiple correlation and one-way analysis of variance used sites or, where appropriate, plots or subplots, as replications. Tukey's procedure was used for multiple comparisons of equal sample size and Scheffe's test was used with unequal sample size. Significance tests were made at the 0.1 probability level (Steel and Torrie 1980).

Results and Discussion

There was a linear relationship ($r = .78$) between total runoff and sediment concentration in the runoff water which provides a closer relationship ($r = .97$) between total soil loss and sediment concentration. Discussion will focus on total soil loss since nearly all statistical tests with sediment concentration were nearly identical.

Soil loss was great enough on *A. tridentata* ssp. *wyomingensis* sites and low enough on some *A. tridentata* ssp. *vaseyana* sites to mask the interaction and indicate an overall significant difference between these 2 subspecies.

Subspecies of big sagebrush sort themselves primarily on the basis of climate and rooting zone soil moisture characteristics. Winward (1970) found different soil depths but not different surface-soil textures for the 3 subspecies in Idaho. Frenchglen sites have an elevational range greater than other locations, so the largely indirect hydrologic effects of big sagebrush subspecies distribtuion there had ample expression. However, the other 3 locations exhibited no significant differences in soil erosion among subspecies (Fig. 1).

[1]Ponding was impossible on one tephra-dominated site which produced no runoff.

Only 3 habitat types were represented by more than 3 sites. *Festuca idahoensis* (Idaho fescue) was the climax dominant in the understory of all *A. tridentata* ssp. *vaseyana* and half of the *A. tridentata* ssp. *wyomingensis* sites. These 2 habitat types (Hironaka and Fosberg 1979, Doescher 1982) had similar soil loss rates (Table 1). The *A. tridentata* ssp. *tridentata/Elymus cinereus* (basin wildrye) habitat type (Hironaka 1979) had a soil loss rate signifiantly higher than the *A. tridentata* ssp. *vaseyana/Festuca idahoensis* habitat type. This difference could be due to the generally poor condition of *A. tridentata* ssp. *tridentata/Elymus cinereus* sites. *Stipa thurberiana* (Thurber's needlegrass) was the climax dominant understory on a total of 6 sites of *A. tridentata* ssp. *tridentata* and *A. tridentata* ssp. *wyomingensis*. Analysis of sites grouped only by climax dominant understory showed no significant differences, even though *Stipa thurberiana* sites appeared to have higher soil loss rates than *Elymus cinereus* sites.

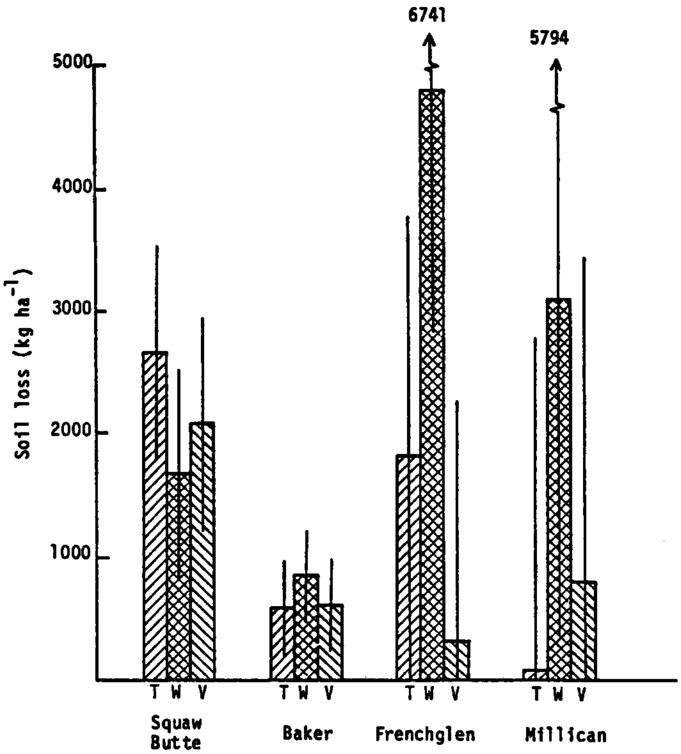

Fig. 1. *Soil loss by location and subspecies. T* = A. tridentata *spp.* tridentata, *W* = A. tridentata *ssp.* wyomingensis, *V* = A. tridentata *spp.* vaseyana. *At a location, subspecies with nonoverlapping confidence intervals are significantly different at the 0.1 level of probability.*

Table 1. Total soil loss on big sagebrush habitat types in central and eastern Oregon.

Habitat type	Number of sites	Total soil loss (kg ha^{-1})
A. tridentata ssp. *vaseyana/Festuca*[1]	12[4]	912 a[4,5]
A. tridentata ssp. *wyomingensis/Festuca*[2]	6	1066 ab
A. tridentata ssp. *tridentata/Elymus*[3]	6	2226 b

[1]Hironaka and Fosberg (1979).
[2]Doescher (1982).
[3]Hironaka (1979).
[4]Habitat types represented by 2 or fewer sites were omitted.
[5]The same letter indicates nonsignificant differences at the 0.1 level of probability.

When soil classification was used to group sites, differences among suborders were not significant, but Mollisols lost significantly less (1,103 kg ha^{-1}) soil than Aridisols (2,342 kg ha^{-1}). The higher organic matter in the epipedon of Mollisols is influential in promoting distinct soil structure which aids infiltration, and in forming soil aggregates which are less easily eroded. In addition, higher organic matter may indicate greater plant growth which also protects the soil. Organic ground cover averaged 62% on Mollisols and significantly less, 35%, on Aridisols.

Characteristics of the site which appear related to soil erosion can be grouped into 3 categories: soil morphology, soil cover, and soil texture. Soil morphology is not suitable for correlation analysis and is discussed below. Of the soil-surface and surface-soil variables, percent bare ground was most highly correlated with soil loss (r = .49); however, percent organic ground cover was highly inversely related (r = -.94) to percent bare ground and it was selective as the principal variable in multiple correlation analysis. The amount of medium and coarse sand in surface soil was the variable next most highly correlated with soil loss (r = -.41). However, 2 other particle size classes—clay and silt—and the amount of coarse fragments in surface soil were selected next in stepwise multiple linear correlation analysis (Table 2). Surface soil

Table 2. Correlation analysis of soil surface and surface-soil factors in 633 subplots with total soil loss in central and eastern Oregon.

Site Factor	Stepwise multiple R^2	Simple r
Organic ground cover	.20**	-.45**
Clay	.39**	.30**
Coarse fragments	.42**	-.19**
Silt	.47**	.23**
Bare ground		.49**
Medium and coarse sand (.25-2. mm)		-.41**
Bulk density		.22**
Organic matter		-.19**
Fine sand (.05-.25 mm)		.05

**Indicates significance at the .01 level of probability.

bulk density and organic matter were also significantly correlated with soil loss, but less so (r = .22 and -.19, respectively).

Numerous studies have shown organic ground cover is critical in erosion control (Branson et al. 1981) because it breaks the impact of falling raindrops and forms sediment traps on the soil surface. Coarse fragments on the soil surface can have a similar effect (Eckert et al. 1978).

Yariv's model (1976) predicts loss of medium and coarse sand-size particles on the basis of the high hydration energies of the minerals in smaller particles and the larger mass of larger particles The correlation of clay and silt with soil loss is in relation to the particle size distribution of the soil, not of the sediment. The correlation may reflect the rapid infiltration on sandy soils. Rapid infiltration decreases erosion both by decreasing water available for runoff and by decreasing the probability of detachment of soil particles since the surface tension and viscosity of the soil water mixture at the soil surface is greater (Yariv 1976).

Five of the Millican sites had a surficial deposit of tephra, a lithologic discontinuity that is different from other sites. Therefore, stepwise multiple linear correlation was repeated with these sites omitted. In that analysis, bare ground accounted for 32% of the variability in soil loss, again emphasizing the importance of ground cover. Coarse fragments in the surface soil increased the multiple coefficient of determination only slightly.

Morphology of the surface soil was perhaps the dominant influence on soil loss (Fig. 2). Both vesicular porosity and platey structure were associated with increased soil loss. Eckert et al. (1978) described 4 types of surface soil morphology and their microtopographic position. Three of the 4 types occurred in plots of this study. Type II is found on slope and coppice bench positions, has a very irregular surface, and deep, well-developed cracks separating polygons that are 5 to 8 cm in diameter. Type III is found on

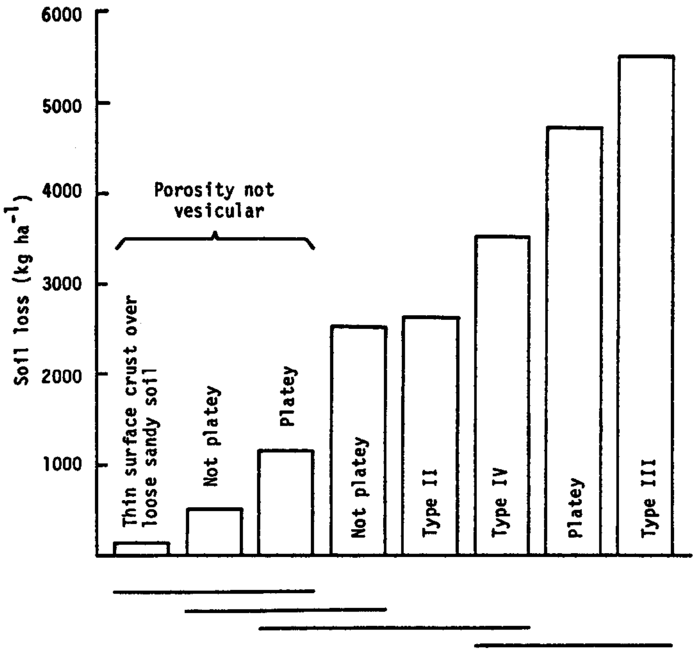

Fig. 2. *Surface soil morphology and soil loss. There is no significant difference (probability = 0.1) between bars over any one line. Types II, III and IV were described by Eckert et al. (1978).*

intercoppice microplains and has larger polygons with a flat top. Type IV has an almost unbroken flat surface with thin irregular cracks. All 3 types have platey structure, but vesicular pores are larger and well developed in Type III and especially in Type IV.

Vesicular porosity is indicative of unstable soil structure that is easily deformed by trapped air. Vesicular soil horizons are generally high in silt content, low in organic matter, and poorly aggregated (Miller 1971 and Blackburn 1975). Instability leads to easy displacement by falling raindrops, which may lead to clogging of surface pores and reduced infiltration as observed in this study and in the work of Blackburn (1975) and Eckert et al. (1978).

The correlation of soil loss to bulk density and organic matter also relates indirectly to the correlation of soil loss to soil morphology. Soil organic matter promotes soil aggregation and reduced bulk density (Wooldridge 1964) typical of soils with crumb structure. Low soil organic matter was probably not more strongly related to soil loss in this study because it is characteristic of both arid sites which may have erosive silty soils and of sandy soils which may be nonerosive due to a high infiltration rate. Bulk density is probably not more strongly correlated with soil loss in this study because low bulk density is characteristic of both erosive soils with vesicular porosity and nonerosive soils with well aggregated crumb structure.

Organic and ammonium nitrogen loss shows a similar pattern to soil loss (Fig. 3). However, no differences among subspecies in percentage nitrogen in the runoff water apply across all locations. At Frenchglan, *A. tridentata* ssp. *wyomingensis* sites lost more nitrogen than *A. tridentata* ssp. *vaseyana* sites. Similarity to soil loss data is illustrated by the significant correlation (r^2 = .55) between sediment concentration and nitrogen concentration in runoff water.

A stepwise multiple correlation of soil-surface and surface-soil factors with organic and ammonium nitrogen concentration in runoff water indicated the importance of medium and coarse sand as well as organic ground cover, coarse fragments, and clay—all factors primarily influencing soil loss (Table 3). Results in the 2 multiple correlations, soil loss and nitrogen loss, are very similar except that the simple coefficient of correlation for organic ground

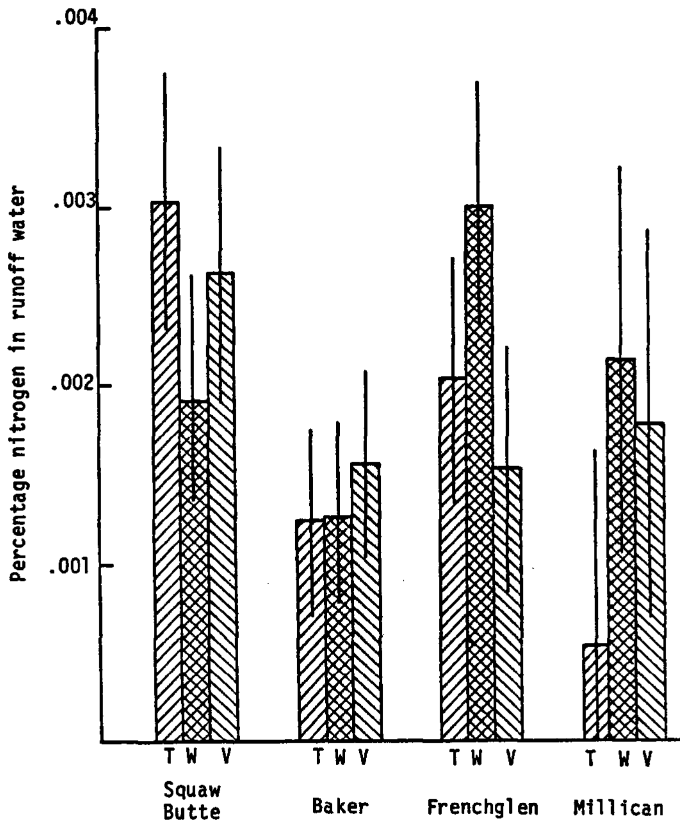

Fig. 3. *Percentage nitrogen in the runoff water by location and subspecies.* T = A. tridentata *ssp.* tridentata, W = A. tridentata *ssp.* wyomingensis, *and V.* = A. tridentatá *ssp.* vaseyana. *Bars at a location with nonoverlapping confidence intervals are significantly different at the 0.1 level of probability.*

cover is lower for predicting nitrogen concentration. Presumably more organic ground cover indirectly decreases nitrogen concentration by decreasing soil erosion, but also contributes a small amount of nitrogen to the runoff water.

The overall mean loss of organic and ammonium nitrogen from all sites was 4.34 kg ha^{-1}, with a highest observed loss of 19.96 kg ha^{-1}. Although this is greater than the average nitrogen loss rates measured in natural runoff water (about 1.5 kg ha^{-1} yr^{-1}, found by Sorensen and Porcella [1974]; and 1.6 kg ha^{-1} yr^{-1}, found by Dogan [1975]), a large loss might be expected due to the high intensity of the simulated storm. However, for comparison, it is much less than rates of fertilizer application (33.6 kg ha^{-1}) reported by Sneva and Hyder (1965). The loss is less than the average rates measured for cryptogamic crust fixation (7 kg ha^{-1} yr^{-1}) reported by Porcella et al. (1973), or (10 to 100 kg ha^{-1} yr^{-1}) by Rychert and Skujins 1974), and about equal to net input from precipitation (4 to 6 kg ha^{-1} yr^{-1}) recorded by West (1978). West (1972) reported nitrogen in the standing crop biomass of vegetation on an Idaho desert sagebrush site was 251 kg ha^{-1}, and soil nitrogen was 5,200 kg ha^{-1}.

Conclusions

Land occupied by big sagebrush is highly variable in soil and vegetation characteristics and in its response to high intensity simulated rainfall. This simulated rainfall caused more soil loss on *A. tridentata* ssp. *wyomingensis* than on *A. tridentata* ssp. *vaseyana* sites, and more soil loss on Aridisols than on Mollisols. Reduced runoff and soil loss found on some sites is partially explained by abundant ground cover, a sandy surface texture, coarse fragments in the surface soil, and/or a surface soil morphology that is neither platey nor vesicular.

Table 3. Correlation analysis of soil surface and surface-soil factors in 213 plots with nitrogen concentration in runoff water in central and eastern Oregon.

Site Factor	Stepwise multiple R^2	Simple r
Medium and coarse sand (.25–2. mm)	.17**	-.41**
Organic ground cover	.29**	-.35**
Coarse fragments	.31**	-.17**
Clay	.34**	.30**

**Indicates significance at the .01 level of probability.

Differences between soil orders and among surface soil morphology types point to the need for an even more refined classification than the habitat type promoted by Pfister (1981) and suggest soils must be included directly, as Bailey (1978) does for the landtype phase level of his hierarchical ecosystem classification system.

Organic and ammonium nitrogen loss is highly correlated with soil loss, it appears to be influenced by many of the same factors, and it is not well correlated with subspecies of big sagebrush. Loss of organic and ammonium nitrogen from raindrop impact and splash erosion on these sites does not appear to be critical.

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