0038-075X/08/17308-503–510
Soil Science

August 2008
Vol. 173, No. 8
Printed in U.S.A.

TECHNICAL ARTICLES

IMPACT OF SHEEP BEDDING ON SOIL NUTRIENT DYNAMICS IN THE CENTENNIAL MOUNTAINS OF MONTANA AND IDAHO

April B. Leytem[1] and Steven S. Seefeldt[2]

Sheep and lamb production is an important industry in Idaho, with summer sheep grazing in the mountains a common practice. Sheep are concentrated in bedding areas at night leading to concentrated grazing and manure and urine accumulation in these areas. To address the effects of bedding on soil nutrient status, we monitored 16 bedding areas in the Centennial Mountains, with a general survey performed in 2004 followed by more intense monitoring of six sites from 2005 to 2006. In 2004, soils were analyzed for total carbon (C) and nitrogen (N), organic C, total P, Olsen P, water-soluble phosphorus (WSP), soluble nitrate, and soluble ammonium. Over the period 2005–2006, soils were analyzed for soluble nutrients including Olsen P, WSP, soluble nitrate, and soluble ammonium. The 16 sites evaluated in 2004 had significantly greater total N, C, and organic C concentrations in the nonbedded areas, whereas Olsen P, WSP, and ammonium concentrations were greater in the bedding areas. When six sites were monitored over time, there was no significant effect of bedding on soluble P concentrations over time or between bedding and control areas, whereas there was a significant effect of time on soluble N concentrations but no significant differences between bedding and control areas. Although these results are preliminary, it seems as if sheep bedding can alter the nutrient content of soils increasing some measures of soil nutrients, while decreasing others, which ultimately can affect the productivity and plant species diversity in these areas. (Soil Science 2008;173:503–510)

Key words: Grazing impacts, soil nutrients, bed down areas.

SHEEP and lamb production is an important industry in the state of Idaho, as well as in other states and provinces in North America. During summer months in western North America, many bands of sheep are grazed in the mountains. Sheep bands generally have 1000 ewes with more than 1000 lambs, and they are accompanied by a shepherd with a horse and dogs to move and protect them. At night, the sheep are concentrated in an area typically less than 0.5 ha to guard them from theft and predation. These sheep bedding areas are typically on sites that are in open areas with few, if any, trees or shrubs and shallower soils and have reduced snow packs (Knight, 1994). Many of these sites are considered historic, in that they have been bedded on for up to a century. Consequently, large quantities of urine and manure may have been deposited on the sites, and heavy utilization and trampling of the vegetation, with mixing and possible compaction of the soil, may have occurred.

There have been no published data in the United States determining the impact of bedding areas on vegetation diversity, biomass production, and soil nutrient cycling. In East Africa, the

[1]USDA, Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory, Kimberly, ID. Dr. Leytem is corresponding author. E-mail: April.Leytem@ars.usda.gov

[2]USDA, Agricultural Research Service, U.S. Sheep Experiment Station, Dubois, ID.

Received March 7, 2008; accepted April 21, 2008.

DOI: 10.1097/SS.0b013e31817d9d2f

study of "bomas" (enclosures for cattle protection), which are the equivalent of bedding areas, has shown that, following abandonment, bomas often support a unique plant community and potentially alter the spatial pattern of nutrient cycling within the ecosystem (Augustine, 2003). In Northern Kenya, old bomas contained sixfold to ninefold more soil nitrogen (N) and phosphorus (P) than surrounding habitats and supported thickets of regenerating *Acacia tortilis* (Reid and Ellis, 1995). In southern Kenya, abandoned bomas were dominated by a lawn of *Cynodon nlemfuensis*, with enriched concentrations of nutrients both in soils and grasses (Stelfox, 1986). In these African environments, abandoned bomas are areas of concentrated nutrients supporting vegetation that is beneficial to grazing animals, as the majority of the surrounding areas are nutrient poor and do not support as much biomass production as the abandoned bomas.

In the semiarid, northwestern United States, the impact of bedding areas on soil nutrient cycling may or may not be similar to the bomas of Eastern Africa, but likely have the potential to affect the rangeland ecosystem. The objectives of this study were to determine the effects of sheep bedding areas on soil nutrient status and on how the soil nutrient status changes over time. Understanding these impacts will assist sheep producers and land use managers in making informed decisions concerning sheep-grazing practices and the use of bedding areas on rangelands.

MATERIALS AND METHODS

Two studies were conducted throughout the period 2004–2006 on the summer range of the U.S. Sheep Experiment Station and a U.S. Forest Service grazing allotment, which are located in the Centennial Mountains of Montana and Idaho (Fig. 1). Experiment one was a survey of 16 bedding areas located within the grazing allotment which characterized the soil nutrient status within and outside the bedding areas (Table 1). Experiment two monitored six of the sites (1–4 and 8–9) from the first experiment over time (before bedding in 2005, immediately after bedding in 2005, and before bedding in 2006) to determine the effect of bedding on soil nutrient status immediately after bedding and following winter.

The slope of these sites ranged from 0 to 20% and sizes ranged from 0.07 to 0.43 ha. Sites 1 and 12 were near the base of the mountains, were at approximately 2000-m elevation. All of the other sites were on mountain ridges from 2367- to 2547-m elevation. All but three sites were historic (rotationally grazed for >50 years), with the new bed grounds bedded for the first time in 2004 (Table 1). Precipitation at the higher elevation sites averages 80 cm per year, with more than 50% falling as snow. At the lower elevation sites, precipitation averages 50 cm per year with less than 50% falling as snow. Summer temperatures range from approximately 12 to 35 °C at the lower elevations, with the higher elevations typically at least 2 to 4 °C cooler.

In the upper elevation sites, the predominant tree is lodgepole pine (*Pinus contorta* var. *latifolia*) with scattered Douglas fir (*Pseudotsuga menziesii* var. *glauca*) and Engelmann spruce (*Picea engelmanni*). The ridge areas are a mixed forb and short grass meadow community. Common grasses included slender wheatgrass (*Elymus trachycaulus*), oniongrass (*Melica bulbosa*), and mountain brome (*Bromus marginatus*). Common forbs include sticky geranium (*Geranium viscosissimum*), mountain knotweed (*Polygonum douglasii*), narrowleaf collomia (*Collomia linearis*), and short-beaked agoseris (*Agoseris glauca*). The bedding sites were located on open ridges as sheep tend to prefer elevated, open areas and will not bed under trees.

The lower elevation site 12 is a typical sagebrush-steppe community where mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*), antelope bitterbrush (*Purshia tridentata*), thick-spike wheatgrass (*Elymus lanceolatus* ssp. *lanceolatus*), bluebunch wheatgrass (*Pseudoroegneria spicata* ssp. *spicata*), and plains reedgrass (*Calamogrostis montanensis*) dominate the vegetation. Site 1 is a foothill meadow community, and the vegetation was dominated with wyethia (*Wyethia helianthoides*), thick-stem aster (*Eurybia integrifolia*), and textile onion (*Allium textile*).

The summer rangeland is divided into three summer grazing allotments, and there are only two bands of sheep grazed on these allotments in any one season. The sheep-grazing management follows a rest-rotation cycle, with two consecutive summers of sheep grazing on each allotment followed with a year of rest. Flock size during the three years of the study averaged 850 ewes with 1300 lambs, with sheep grazing occurring during July and August.

The perimeter of each site was mapped using a Trimble GeoXT GPS unit (Trimble

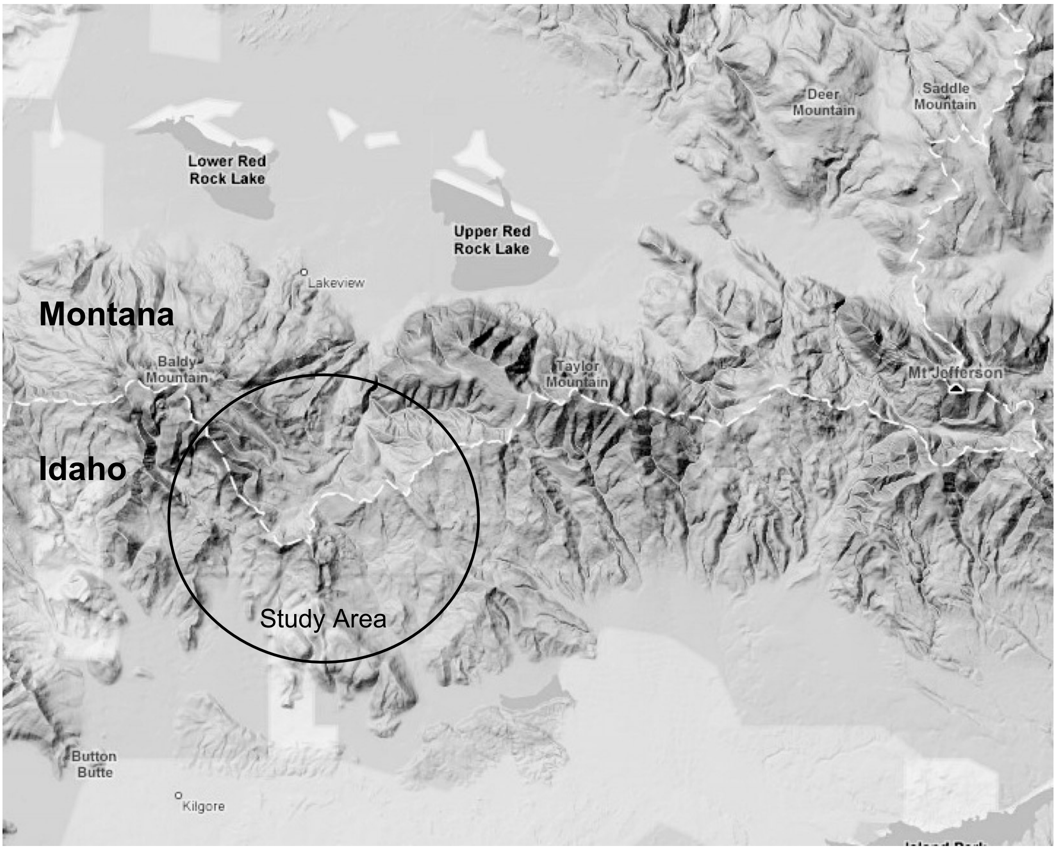

Fig. 1. Area of study in Centennial Mountains of Montana and Idaho.

TABLE 1

Select site properties for sheep bedding areas studied in the U.S. Sheep Experiment Station summer range in the Centennial Mountains of Idaho and Montana

	Historic	Slope	Aspect	Elevation	Size
Site		%		m	ha
1	No	0	n/a	2028	0.43
2	Yes	6–20	South and Southeast	2399	0.09
3	Yes	0–18	Northwest and Southwest	2389	0.32
4	Yes	6–15	East	2547	0.32
5	Yes	6–15	Northwest	2565	0.12
6	Yes	5–15	North	2416	0.14
7	Yes	6–15	South	2384	0.28
8	Yes	6–15	Southeast	2394	0.31
9	Yes	5–15	North	2412	0.26
10*	Yes	0–10	Northeast	2440	0.08
11*	No	0–20	Northeast	2367	0.11
12*	Yes	0–15	East	2370	0.13
13*	Yes	4–15	Northwest	2471	0.21
14*	Yes	0–15	Southeast	2467	0.10
15*	No	0	n/a	1997	0.28
16*	Yes	4–15	Northeast	2463	0.07

*Denotes sites that were grazed before sampling.

Navigation Ltd., Sunnyvale, CA). At each site, three plots (30 × 60 cm) were randomly located inside the bedding area. Three additional plots (30 × 60 cm) were placed outside the bedding area in locations that were at least 10 m away from the perimeter but were as similar as possible in elevation, aspect, and soil type. The soils in this area are not well mapped, but consist mainly of forested Agric Cryoborolls, forested Typic Cryoborolls, and Typic Cryorthents (oral communication with the National Forest Service June 2004).

Six soil cores, 10 cm deep and 10 cm in diameter, were collected in each plot, air dried, and sieved to pass a 2-mm screen before analysis. Total soil N and carbon (C) content was determined by combustion of a 50-mg sample in a Flash EA 1112 CN analyzer (CE Elantech, Lakewood, NJ). Soil organic C (OC) was determined using the method of Walkley and Black (1934). Soil pH was measured in a saturated paste using a combination electrode (Robbins and Wiegand, 1990). Sodium bicarbonate extractable P (Olsen P) was determined using the method of Olsen et al. (1954). Water-soluble P (WSP) was determined by shaking 1 g soil with 100 mL deionized water for 1 h followed by filtration with a 0.45-μm Whatman filter. Both Olsen P and WSP were quantified by the colorimetric method of Murphy and Riley (1962). Soil nitrate (NO_3^-) and ammonium (NH_4^+) were determined by shaking 12.5 g soil with 50 mL of 2 *M* KCl for 30 min followed by filtration with Whatman no. 42 filter paper, with N determined colorimetrically by flow injection analysis. Total P was determined by microwave-assisted digestion of a 0.25-g dried sample with 9 mL of concentrated HNO_3 and 3 mL of concentrated HCl, with P determined by inductively coupled plasma optical emission spectroscopy.

All statistical analyses were performed using the Statistical Analysis System (SAS, 1996). All dependent variables were tested for normal distribution using the univariate procedure with the Kolmogorov-Smirnov goodness-of-fit test. Soil total N, total C, NO_3^-, and NH_4^+ were logarithmically transformed to achieve normal distribution before analysis but are reported in untransformed units in the text. In experiment one, analysis was conducted with the MIXED procedures of SAS using location (control or bedding area) as the fixed variable and site as a random variable. In experiment two, the six sites that were analyzed over time (before bedding, just after bedding, and the following summer before bedding) were longitudinally analyzed using the MIXED procedure in SAS to test for effects of time and location (in or out of bedding area) on soil WSP, Olsen P, NO_3-N, NH_4-N, and total soluble N (TSN; sum of NO_3-N and NH_4-N). Bedding site was specified as the subject with treatment as the subplot, whereas time was the repeated measure. Differences in treatments are reported at the $\alpha = 0.05$ level of significance in the text unless otherwise stated.

RESULTS AND DISCUSSION

Select chemical properties from the 16 sites sampled in 2004 are presented in Table 2. Total soil N, soil C, and soil OC concentrations ranged from 1.5 to 6.7 mg N g^{-1}, 19.3 to 75.2 mg C g^{-1}, and 19.4 to 79.9 mg OC g^{-1}, respectively. The total soil N, C, and OC concentrations were significantly higher in the control areas compared with the bedding areas. The majority of soil C at all sites evaluated was in the form of OC. The total soil N was significantly correlated with soil OC (correlation coefficient = 0.87, $P > 0.0001$), suggesting that the majority of soil N is associated with organic matter on the sites. This is similar to findings of Bell et al. (2006) who reported that total N and C were greater in nongrazed versus grazed rangeland in Texas. Xiao-gang et al. (2007) also found that total N and total OC in the surface soil decreased by 10 to 18% in perennial pasture compared with native pasture in an alpine site in western China. Zou et al. (2007) reported that soil OC decreased by 82% in heavily grazed steppe areas compared with protected areas in the north of China.

One explanation for the decreased total C and N in bedding areas is that the removal of vegetation in these bedding areas resulting from sheep grazing (Seefeldt and Leytem, 2008) leads to a reduction of soil C and N over time as the vegetation is not left on site to decompose. This is further supported by the fact that the majority of soil C on these sites is OC and therefore most likely a result of plant biomass turnover and root growth, and the soil N is highly correlated with soil OC. In general, the rate of organic matter accumulation or loss in soils is dependent on the amount of biomass added to the soil minus the biological oxidation, which removes organic matter from the soil and is dependent on the amount of soil disturbance (Reicosky et al., 1995). Sharrow and Ismail (2004) reported that

TABLE 2

Select chemical properties of soils from control and bedding locations sampled in the summer of 2004 including the mean of all sites for each location, the standard error, the range, and statistical significance

Soil property	Location	Mean (S.E.)†	Range	$P > F$
Total N, mg g^{-1}	Control	3.5 (0.2)	1.8–6.7	0.01
	Bedding	3.1 (0.2)	1.5–6.5	
Total C, mg g^{-1}	Control	38.6 (1.8)	21.4–75.2	0.02
	Bedding	35.2 (1.7)	19.3–74.0	
OC, mg g^{-1}	Control	43.6 (2.1)	23.7–79.9	0.02
	Bedding	38.2 (1.8)	19.4–81.6	
Total P, mg g^{-1}	Control	1.29 (0.03)	0.88–1.62	0.86
	Bedding	1.29 (0.05)	0.68–2.25	
Olsen P, mg kg^{-1}	Control	45.42 (2.49)	7.68–78.42	0.007
	Bedding	55.07 (3.14)	8.10–100.78	
WSP, mg kg^{-1}	Control	35.11 (1.96)	8.98–70.65	0.001
	Bedding	42.69 (3.09)	9.60–96.64	
NO_3-N, mg kg^{-1}	Control	3.43 (0.37)	0.57–12.40	0.08
	Bedding	5.68 (1.00)	0.46–35.34	
NH_4-N, mg kg^{-1}	Control	5.64 (0.63)	1.25–17.18	0.04
	Bedding	15.99 (3.80)	0.92–95.71	

†Values are the means of 16 sites (control areas or bedding areas) with the standard error in parenthesis.
NO_3-N = nitrate nitrogen; NH_4-N = ammonium nitrogen.

pastures in western Oregon stored almost all of their C and N in soil organic matter. They also estimated that the percent of biomass returned to pastures in the form of manure is only approximately 30% of that consumed. Therefore, although the sheep are depositing C and N in the form of manure and urine in the bedding areas, it is likely that the total amount deposited is less than what is being removed.

The decrease in total C and N in bedding areas in the present study is contradictory to results from abandoned bomas in East Africa. Stelfox (1986) reported that soils within bomas contained twice as much organic matter as soils from control areas. Augustine (2003) found that bomas that had recently been abandoned (1–5 years) had higher total soil N than the areas which had been abandoned for longer periods and therefore attributed the increased N to be from manure and urine inputs during the time the areas were actively used as bomas. Reid and Ellis (1995) reported that soils from abandoned bomas contained ninefold more total C and threefold more total N than adjacent control soils and that these elevated concentrations of C and N in bomas remained for up to 20 years following abandonment. This difference in total C and N accumulation in bomas is due to the fact that the majority of the areas surrounding bomas are nutrient poor and do not support much biomass production. Therefore, the accumulation of manure in the bomas leads to higher soil C and N concentrations, whereas in the rangeland of the present study, the control sites have large amounts of biomass production compared with the bedding areas and therefore have greater soil C and N accumulation.

The total P concentration ranged from 0.68 to 2.25 mg P g^{-1}, with no significant effect of bedding. These findings contradict those of boma studies in Eastern Africa. Stelfox (1986) reported that total soil P in samples collected from within bomas was approximately 50% higher than in control areas. Augustine (2003) reported that total soil P in recently abandoned bomas was approximately sevenfold greater than in bushland soils and that elevated levels of soil P persisted for longer periods than soil N. Reid and Ellis (1995) reported that bomas had sixfold as much total soil P as control areas, with these enhanced P levels persisting for long periods. As much of the P in soils in the present study is likely a result of weathering of parent material in this region, there may be little overriding influence of the movement of P on or off the bedding areas because of vegetation removal and manure additions.

The Olsen P and WSP ranged from 7.7 to 100.8 and 9.0 to 96.6 mg P kg^{-1}, respectively, with both measures of soluble P being significantly higher in the bedding areas. The soluble NO_3-N and NH_4-N ranged from 0.46 to 35.3 and 0.92 to 95.7 mg N kg^{-1}, respectively, with the NH_4-N being significantly higher in the bedding areas, whereas NO_3-N was not significant at the $\alpha = 0.05$ level ($P > F = 0.08$). The soluble P and N measured at the 16 sites evaluated in 2004 indicated that there is an accumulation of soluble nutrients in the bedding areas compared with the control areas, although NO_3-N was only significantly different at the $\alpha = 0.10$ level. This increase in soluble nutrients in the bedding areas is likely a result of both urine and manure nutrient deposition. Bell et al. (2006) reported that manure additions to rangeland soils increased soil NO_3-N, NH_4-N and Mehlich 3 extractable P in the top 25 mm of soil. Sharpley et al. (1984) reported that addition of cattle manure to soils increased soluble P up to 25%, which was dependent on the rate of manure applied. Iyamuremye et al. (1996) also reported that manure additions significantly increased Olsen P concentrations on several soils.

To determine the effect of time and impact of snowmelt on soil nutrient status, we selected six sites to monitor more closely to determine if nutrients deposited in the bedding areas in the summer were still present the following year. The six sites were sampled before grazing in 2005, then immediately after the sheep had been bedded on the sites in 2005 to determine the changes in nutrient status due to sheep activity. Because these areas are covered with snow during the majority of the year and are likely to have significant runoff events with runoff melt in the early summer as well as leaching of nutrients through the soil profile, we went back to these same sites following snowmelt before the sheep

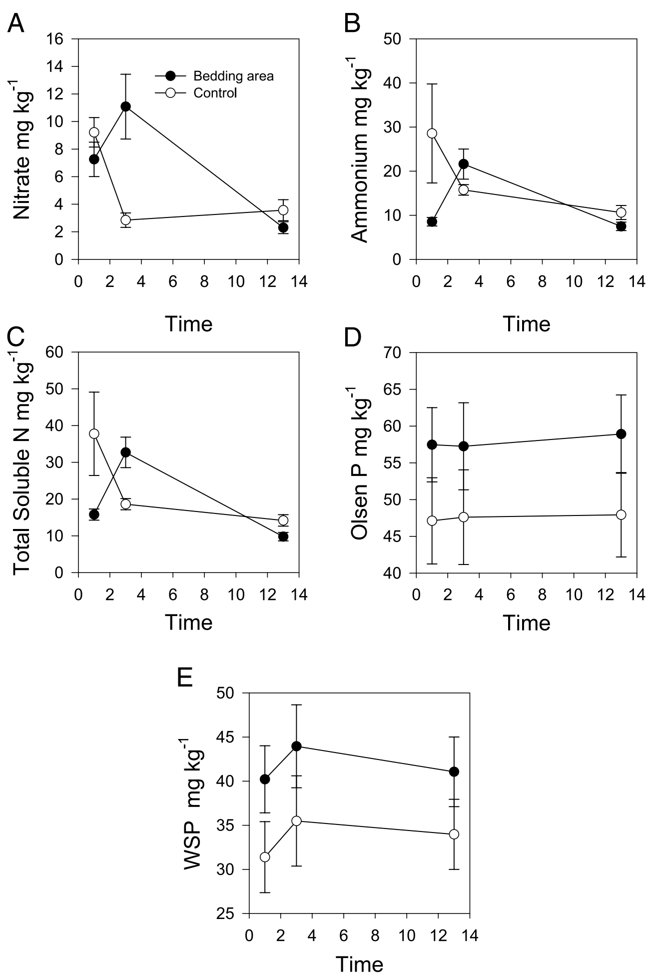

Fig. 2. Average nutrient concentrations and standard errors in control and bedding areas over time (months) for the six sites monitored during 2005–2006.

were brought up for grazing (summer 2006) to determine if the nutrients were still present.

The soil N and P data from the six sites monitored over 2005–2006 are shown in Fig. 2. Inside the bedding area, the WSP and Olsen P ranged from 21.3 to 64.4 mg P kg^{-1} and 33.4 to 101.7 mg P kg^{-1}, respectively, over the three sampling dates. Outside the bedding area, the WSP and Olsen P ranged from 7.3 to 72.6 mg P kg^{-1} and 5.4 to 87.3 mg P kg^{-1}, respectively, over the three sampling dates. Inside the bedding area, the NO_3-N and NH_4-N ranged from 0.8 to 24.2 mg N kg^{-1} and 4.1 to 38.9 mg N kg^{-1}, respectively, over the three sampling dates. Outside the bedding area, the NO_3-N and NH_4-N ranged from 0.5 to 17.0 mg N kg^{-1} and 5.8 to 104.0 mg N kg^{-1}, respectively, over the three sampling dates. As the N content in soils receiving manure will be nitrified over time, a better representation of soluble N over time can be captured by adding the two concentrations together and evaluating the TSN. The TSN on all sites located within bedding areas increased by an average of 110% after bedding and then decreased by an average of 69% the following year. The TSN on all sites located outside the bedding area decreased over time by an average of 47%.

As illustrated in Figs. 2a–c, the NO_3-N, NH_4-N, and TSN within bedding areas increased after bedding and then decreased again following winter, whereas NH_4-N and TSN decreased over the three sampling times in control areas. The parameters WSP, Olsen P, NO_3-N, NH_4-N, and TSN were evaluated for the effects of time and location (in or out of bedding areas) and the interaction of time and location (Table 3). For both WSP and Olsen P, there was no significant effect or interaction of time and location. As can be seen in Fig. 2, the soluble P measured on these sites changed little over time, and there were no significant differences in soluble P, although in general bedding sites seemed to have greater soluble P concentrations. Unlike soluble P, all measures of soluble N were significantly impacted by time and had a significant interaction between time and location, although location itself was not significant (Table 3). All measures of soluble N increased after sheep bedding and then decreased again following winter in the bedding areas (Fig. 2). The combined soluble N (NO_3-N + NH_4-N) increased by an average of 110% after sheep bedding on the sites. In contrast, the soluble N in the control areas decreased steadily over time, with the combined soluble N decreasing by 47% over this time period.

TABLE 3

Effects of time and location (inside or outside the bedding area) on soluble nutrients measured at sheep bedding sites over the period 2005–2006

	Source (P > F)		
	Time	Location	Time × location
WSP	0.22	0.43	0.92
Olsen P	0.87	0.47	0.96
Nitrate	<0.0001	0.45	0.0007
Ammonium	<0.0001	0.30	0.0012
TSN	<0.0001	0.48	<0.0001

As manure and urine are deposited in bedding areas, the N nitrifies over time changing from NH_4-N to NO_3-N; therefore, TSN captures the impact of sheep bedding on changes in N status better than using either one or the other measure individually. Eventually, the majority of soluble N on site will be converted to NO_3-N, which is highly mobile in soils and would be susceptible to loss through leaching and runoff during snowmelt. Therefore, it is not surprising that soluble N concentrations reduced significantly following winter on all sites. Augustine (2003) reported that TSN (NO_3-N + NH_4-N) was 16-fold greater in soils from newly abandoned bomas compared with bushland soils. In this study, Augustine (2003) also measured TSN in the soil profile to 65-cm depths and found that recently abandoned bomas had elevated TSN to depths of 65 cm, indicating that soluble N leached down through the soil profile on these sites. As the bomas aged, the TSN decreased over time at all soil depths.

As nutrient deposition through manure and urine is concentrated in small patches, the variation in soluble nutrients can be quite large, particularly in bedding areas, and is dependent on whether a particular sample contains recently deposited manure or urine. Therefore, due to the high variability of within-area nutrient concentrations, in some cases it may be difficult to detect differences between bedding and control areas. The impact of bedding was most clearly seen in the soluble N data; the input of NH_4-N and conversion to NO_3-N from urine deposition by sheep were more easily detected immediately after bedding. However, the impact of bedding on soil soluble N is short lived and disappeared on sites following one winter.

In summary, of the 16 sites evaluated in 2004, there was a decrease in total C, N, and OC and an increase in soluble P and N in the bedding areas compared with the control areas. When selected sites were evaluated before grazing and immediately following grazing, there were increases in soil soluble N in the bedding areas, presumably due to the activity of sheep in these areas. Although there were increases in soil soluble N after bedding, these values decreased following winter and were not significantly different than control areas, suggesting that nutrients are lost through leaching or runoff with snowmelt waters. As this was the first comprehensive study examining the impact of sheep bedding on soil nutrient dynamics, one cannot draw absolute conclusions from the data, but it seems as if sheep bedding can alter the nutrient content of soils, increasing some measures of soil nutrients while decreasing others.

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