Effects of proximity to roads on tissue surface pH, conductivity and heavy metal contents of a grazing grass species

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Abstract
Globally, road networks are expanding in the countryside. Though beneficial to society, the roads potentially have detrimental effects on grazing quality. The effects are seldom quantified. In this study *Eragrostis lehmanniana*, a common native grazing grass in parts of the world, was examined for indicative data on the impacts of roads on grasses. Aboveground tissue samples were collected monthly on three occasions during the growing season, at the same respective locations near three high traffic highways. Non-senescent specimens were sampled along transects of up to 400 m perpendicular to the highways, starting from the road edge and then at intervals of at least 10 m. Concurrent control samples were collected at a site more than 3 km from a road. In the laboratory, a whole stem of each specimen was washed in 40 ml of distilled water, whose pH and electrical conductivity were then measured. Heavy metal concentrations (HMC) in dry grass tissue were determined using ICP-MS analysis. Consistently, tissue surface pH was lower, and electrical conductivity higher, close to the road edge than farther away. Heavy metal concentrations were high close to the road edge, some (Fe, Ni) beyond the tolerable limits of cattle and gazelle-like grazers. Using the respective control site means as thresholds, linear regression of pH and conductivity against distance showed that the effects were pronounced for 70 m – 600 m from the road edge. The low pH was due to acidity caused by motor vehicle-emmited nitrogen and sulpher oxides (NOx, SOx) reacting with atmospheric water vapour. High conductivity and HMC were judged to be due to motor vehicle-sourced metal elements and particulate matter. Spacing roads at least 1.2 km apart in grazing areas is recommended to reduce the detrimental effects.

Introduction
Roads have been documented to have negative ecological effects (Forman and Alexander 1998). However, the effects on grazing grass and the grazers are seldom quantified. Quantifying the effects would be useful to rangeland managers, for the purpose of planning mitigation measures.

The quality of grazing grass (i.e., grazing quality) is one of the factors that influence the productivity of rangelands (Fynn 2012). Any factor that can reduce grazing quality is, therefore, of concern. Motor vehicle emissions can potentially deteriorate the quality of grass in the vicinity of roads. Motor vehicles emit oxides of sulpher (SOx) and nitrogen (NOx). These interact with atmospheric water vapour to form acids (sulphuric acid, nitric acid, respectively). The resulting 'acid rain' can be deposited on grass surfaces (leaves, flowers). Motor vehicle emissions also contain metal elements (De Silva et al. 2021), including heavy metals like cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn). Since the motor vehicle emissions can be transported in the air, their effects on grazing quality can potentially manifest far from the road edge, depending on prevailing winds. The objective of this study was to determine numeric indicators of the effect of proximity to highways on the tissue properties of grazing grass.

Methods
Study Area and Experimental Design
The study was conducted in the savanna rangelands of northern South Africa. The area experiences seasonal (summer) rainfall, from about October in one year to April/May the following year. A prevalent grazing grass in the study area, *Eragrostis lehmanniana* nees, was selected for the study. It is a tufted, perennial C4 grass (Mantlana et al. 2009). Though only of average grazing value, *E. lehmanniana* is consumed by both livestock and wild grazers (Grunow 1980). It is native to southern Africa, although considered an invasive weed in some parts of the world (Buerdsell et al. 2022).

Three high speed highways were selected for the study, on the basis of differences in traffic volumes. At sections of the respective highways where there were no land use (property right) access restrictions, one transect perpendicular to the highway was set out, starting at the road edge. The transects were set out irrespective of the prevailing wind direction. Along the transects, sampling of *E. lehmanniana* aboveground tissue was conducted on three occasions at the same transect locations, in order to establish consistency in trends. For comparison, sampling was also conducted at a control site more than 3 kilometres from a road on each sampling occasion. The goal was to collect tissue samples at different growth stages of the grass tissue. Sampling could not be conducted in the early growth stages of *E. lehmanniana* specimens (soon after the onset of the rains), due to the difficulty of distinguishing *E. lehmanniana* from other *Eragrostis* species. Therefore, sampling only commenced after the flowering stage. Only non-senescent grass was sampled.

Grass Tissue Sampling

Three sampling periods during the 2021/2022 rainy season were used: 25-27 January 2022 (sampling period 1, SP1), 15-17 February 2022 (sampling period 2, SP2), and 15-17 March 2022 (sampling period 3, SP3). The sampling dates were designed to be approximately one month apart. Weeks during which extensive wet weather was forecast were avoided. SP1 was preceded by a one week dry spell, SP2 by intermittent rain in the previous week, and SP3 by a one week dry spell. However, there was sporadic rain during SP3.

On each sampling occasion, the first set of roadside *E. lehmanniana* tissue samples were collected at the road edge (distance (d) = 0 m). Aboveground tissue samples were collected from three different plants, by cutting five whole stems (with leaves and flowers) just above the soil level. Then, samples were collected from a subsequent sampling site more than 10 m away from the previous site. This continued up to d = 400 m from the road edge where possible. Away from the road edge, the sampling was dictated by the availability of *E. lehmanniana* specimens. Therefore, regular spacing of sampling distances from the road edge could not be used. Similarly, the lengths of the transects varied at the different highways, depending on land use and property right access restrictions. By SP2 and SP3, grazing far from the road edge had reduced the availability of grass for sampling. This resulted in shorter transects during SP2 and SP3. During each sampling period, aboveground tissue samples were collected from three different plants at the same control site. All tissue samples were stored in labelled bags and later transported to the laboratory for analysis.

Laboratory Analysis of Grass Tissue Samples

In the laboratory, one randomly selected whole stem (with its leaves and flowers) from a sampling bag was immersed in 40 ml of distilled water in a brand new 210 mm × 295 mm plastic bag. The bag containing the stem tissue and distilled water was shaken for 10 seconds. Then the distilled water with the washed-off grass tissue surface material was transferred to a clean (distilled water rinsed) beaker, where the pH and electrical conductivity, respectively, were measured using a Lasec PC 80 + DHS ® benchtop multimeter. The process was repeated for every sample, using clean plastic containers and beakers each time. To determine the concentrations of heavy metal elements, dry respective stem tissue samples (stems, leaves, flowers) were microwave acid-digested using using the EPA Method 3051A. Heavy metal concentrations (HMC) were then determined using an Agilent Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Due to the high costs of sample analysis, only the February (SP2) samples from the highway with the highest traffic volumes were analysed. Trends in pH, electrical conductivity and HMC away from the road edge were modelled using linear regression.

Results and Discussion

Trends in Grass Tissue Surface pH and Conductivity away from the Road Edge

Grass tissue surface pH at the road edge was lower that at the control site, and it increased with distance away from the road edge (Figure 1). The trend was consistent at all three highways, on all three sampling occasions. The lowest pH, 6.9 at d = 0 m, was determined from SP1 when there was no rainfall in the preceding week (Figure 1(a)). This suggests that roadside grazing grass can be acidic in dry conditions. The pH values were generally higher during SP2 and SP3 due to dilution by rainfall. Flückiger-Keller et al. (1979) determined roadside tree leaf surface pH as low as 4.6. According to van Ryssen (2006), acidity can affect mineral metabolism. Physical damage of the leaf surfaces through acid deposition on grass leaves (Evans 1984) can reduce grazing grass quantities. For the three studied highways, linear regression showed that the control site pH value was attained at various distances (136 m – 623 m) from the road edge (Table 1), due to local factors like wind direction. Highway 1, whose transect was aligned in the prevailing wind direction, yielded the strongest linear trend (R^2 range: 0.756 – 0.969).

Grass tissue surface conductivity was higher at the road edge than at the control site, and it reduced with distance away from the road edge. The trend was consistent at all studied highways, on all three sampling occasions. The highest conductivity value was 46.6 μS/cm, when the control site mean was 19.1 μS/cm. It was obtained from the same SP1 highway and road edge (d = 0 m) sampling site that yielded the lowest pH value of 6.9. Like the pH trends, the control site conductivity value was attained at various distances (70 m – 632 m) from the road edges (Table 1). The Highway 1 transect had the strongest linear trend (R^2 range: 0.805 – 0.975). The conductivity values were generally lower during SP2 and SP3, due to dilution by rainfall.

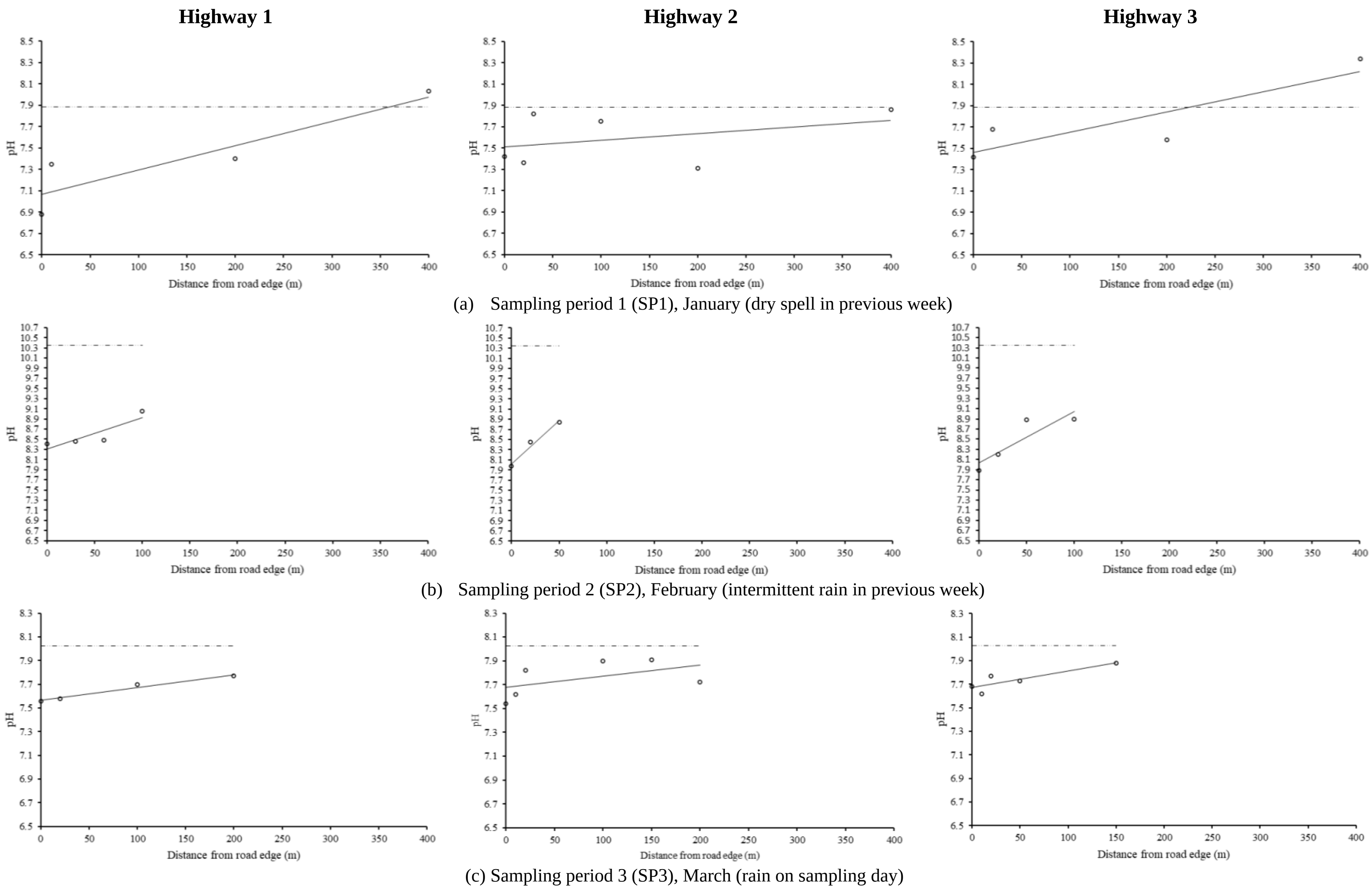

Figure 1. Trends in *Eragorstis lehmanniana* grass tissue surface pH with distance from the road edge (solid lines) in comparison with the control site mean (dashed lines).

Table 1. Regression model-predicted distances from the road edge at which *E. lehmanniana* grass tissue surface properties (pH, electrical conductivity) would equal the control site mean.

Sampling period (SP)	Highway	Regression model (where d is distance from road edge)	R^2	Model-predicted distance (d) to attain control site mean
SP1 (25-27 January)	1	pH = 0.0023d + 7.0698	0.820	354 m
		Conductivity = -0.072d + 43.797	0.890	343 m
	2	pH = 0.0006d + 7.5093	0.145	623 m
		Conductivity = -0.0218d + 25.469	0.113	294 m
	3	pH = 0.0019d + 7.4615	0.762	220 m
		Conductivity = -0.0588d + 58.245	0.068	632 m
SP2 (15-17 February)	1	pH = 0.0061d + 8.3085	0.756	335m
		Conductivity = -0.0651d + 8.8906	0.975	127 m
	2	pH = 0.0171d + 8.0221	0.970	136 m
		Conductivity = -0.1003d + 6.241	0.975	128 m
	3	pH = 0.0102d + 8.031	0.785	227 m
		Conductivity = -0.0139d + 8.2621	0.485	551 m
SP3 (15-17 March)	1	pH = 0.0011d + 7.566	0.969	419 m
		Conductivity = -0.0299d + 17.338	0.805	131 m
	2	pH = 0.0009d + 7.677	0.263	389 m
		Conductivity = -0.0146d + 15.879	0.364	164 m
	3	pH = 0.0014d + 7.6718	0.754	253 m
		Conductivity = -0.024d + 14.963	0.857	70 m

Change in Grass Tissue Heavy Metal Concentrations (HMC) away from the Road Edge

Heavy metal concentrations in road edge grass tissue samples were generally higher than at the control site. They reduced with distance from the road edge. Some road edge samples had Fe and Ni concentrations that were beyond the maximum tolerable limits of goats and gazelle-like grazers (Fe: 500 mg/kg; NRC 2007), and cattle (Ni: 50 mg/kg; NRC 1996), indicating potential heavy metal toxicity to grazers. Therefore, high HMC can potentially reduce grazer numbers in rangelands through metal toxicity-induced mortality.

Conclusions

Proximity to highways can result in poorer quality grazing grass. The poorer quality manifests in terms of low grass tissue surface pH (acidity) and high electrical conductivity due to metallic elements, as well as HMC in tissue. The results in this study suggest that the effects are pronounced for up to 600 m from the road edge. This implies that countryside roads should be spaced more than 1,200 m apart, in order to reduce the effects.

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