

This is a repository copy of *Are calcareous soil ecosystems and associated drainage waters less susceptible to damage from winter road salting than acidic soil ecosystems?*.

White Rose Research Online URL for this paper:  
<http://eprints.whiterose.ac.uk/3738/>

---

**Article:**

Cresser, M.S. and Green, S.M. (2008) *Are calcareous soil ecosystems and associated drainage waters less susceptible to damage from winter road salting than acidic soil ecosystems?* *Chemistry and Ecology*. pp. 1-13. ISSN 0275-7540

<https://doi.org/10.1080/02757540701814614>

---

**Reuse**

Items deposited in White Rose Research Online are protected by copyright, with all rights reserved unless indicated otherwise. They may be downloaded and/or printed for private study, or other acts as permitted by national copyright laws. The publisher or other rights holders may allow further reproduction and re-use of the full text version. This is indicated by the licence information on the White Rose Research Online record for the item.

**Takedown**

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing [eprints@whiterose.ac.uk](mailto:eprints@whiterose.ac.uk) including the URL of the record and the reason for the withdrawal request.

*promoting access to White Rose research papers*



**Universities of Leeds, Sheffield and York**  
**<http://eprints.whiterose.ac.uk/>**

---

This is an author produced version of a paper published in Chemistry and Ecology.

White Rose Research Online URL for this paper:  
<http://eprints.whiterose.ac.uk/3738>

---

**Published paper**

Green, S.M., and Cresser, M.S. (2008) *Are calcareous soil ecosystems and associated drainage waters less susceptible to damage from winter road salting than acidic soil ecosystems?* Chemistry and Ecology, Volume 24, Issue 1, pp.1-13.

---

1 **Are calcareous soils in uplands less prone to damage from road salting than**  
2 **acidic soils?**

3  
4 SOPHIE M. GREEN\* and MALCOLM S. CRESSER

5 University of York, Environment Department, Heslington, York YO10 5DD, UK  
6

7 Previous studies of upland roadside soils in Cumbria, that would normally be naturally  
8 acidic, have highlighted that (a) runoff from roads subjected to long-term road salting can  
9 dramatically raise soil pH down slope in upland areas; (b) the soil pH increase dramatically  
10 changes N cycling in soils down slope, increasing mineralization of organic matter,  
11 ammonification, ammonium leaching down slope and nitrification and nitrate leaching; (c)  
12 the increase in nitrification substantially increases nitrate leaching to down-slope rivers, and  
13 this is readily detectable in field studies; and (d) loss of soil organic matter over decades of  
14 salting is so great that organic matter is no longer substantially solubilized by high salt  
15 concentrations found in soil solution below road drains. This paper tests and supports the  
16 hypothesis that such effects are minimal for more calcareous soil ecosystems. It examines  
17 the soil and soil solution chemistry on another Cumbrian upland highway, the A686 near  
18 Leadgate, Alston. Sodium % of soil CEC values for soil transects affected by spray  
19 containing road salt are similar at both the A6 and A686 sites. However, spatial trends in  
20 calcium, magnesium, ammonium, and nitrate concentrations as well as pH differ, as a direct  
21 result of the higher weathering rate of parent material and possibly also the presence of  
22 limestone walls above both spray-affected and control transects at the A686 site.  
23

24 *Keywords:* Road salt; sodium; chloride; base cations; weathering rate; N cycling

25 **1. Introduction**

26 De-icing agents are widely applied to roads around the world under sub-zero temperature or  
27 snowy conditions to prevent the formation (or reformation) of ice and thus maintain safe  
28 driving conditions. Materials used include rock salt (sodium chloride), calcium chloride,

---

\* Corresponding author: Tel: +441904 434790; Fax: +434 1904 432998  
Email: [sg507@york.ac.uk](mailto:sg507@york.ac.uk) (S.M. Green)

29 calcium magnesium acetate (CMA), magnesium chloride, potassium chloride, sodium formate  
30 and urea [1-4]. Sodium chloride tends to be the preferred agent in the UK, applied in solution  
31 or as a solid, depending upon the conditions. It may be mixed with grit, and sometimes  
32 contains an anti-caking agent [5,6]. Much of the applied material ends up being transferred to  
33 roadside soils, especially down-slope of the highway.

34 Road salt is used on 64.5% of roads in the County of Cumbria in North West England.  
35 Thus for 2262 km of road in the county, episodically the roadside soils are exposed to  
36 incoming road salt (i.e. impure NaCl) via spray, runoff and drainage. Green and Cresser [7,8]  
37 and Green *et al.* [9-11] assessed the impacts of road salt on a soil that would naturally be very  
38 acidic adjacent to a highway, on its soil solution, and on water in an adjacent, down-slope  
39 river. The study site at the A6, Selside, Cumbria experiences directly piped runoff onto the soil  
40 surface and/or spray. They reported the following main findings:

- 41 1. Runoff from an upland road subjected to long-term road salting dramatically  
42 raised soil pH down slope [7].
- 43 2. The pH increase markedly changed N cycling in soils down slope, increasing  
44 mineralization of organic matter, ammonification and nitrification and nitrate  
45 leaching [8, 10]. Further modification was caused by displacement of  
46 ammonium by sodium ions and mobile anion effects on soil H and cation  
47 mobility's.
- 48 3. The increase in nitrification substantially increased nitrate leaching to a down-  
49 slope river, and this was readily detectable in field studies [10].
- 50 4. Loss of soil organic matter over decades of salting was so great that  
51 immediately beside the road organic matter was no longer substantially  
52 solubilized by the high salt concentrations found in soil solution below road  
53 drains [9, 11].

54 It might be expected, however, that such impacts would be much less in roadside soils with  
55 higher biogeochemical mineral weathering rates (thus a naturally higher pH). The relative  
56 contribution of calcium to the total cation pool would naturally be much higher, making the  
57 impact of seasonal high sodium inputs less dominant. Incoming sodium ions are energetically  
58 unfavorable to displace divalent calcium ions compared to those of hydrogen on the CEC.

59 Therefore, the effects observed on acidic upland soils are likely to be dampened on calcareous  
60 soils. This hypothesis has been tested for spray-affected roadside soils at a second sampling  
61 site, using a similar protocol and methodology.

62

## 63 **2. Materials and methods**

### 64 **2.1 Field site**

65 The study site was an upland area along the A686 at Leadgate, Alston, Cumbria, UK (NY 688  
66 430 GB Grid; Lat: 54.780929N Long: 2.486611W), with altitudes up to 609 m above sea level  
67 (Fig. 1). The road section used runs parallel to the Black Burn; however, the river could not be  
68 sampled at this site due to health and safety implications (especially in winter). The A686 is a  
69 priority two route and has a speed limit of 60 mph. In terms of traffic density, the A686 has  
70 927 vehicles eastbound and 996 westbound per day (John Robinson, Cumbria County Council,  
71 pers. comm.). During the sampling period (October 2005-July 2006), 114 salting outings were  
72 completed at a rate of 10-40 g m<sup>-2</sup>, depending on the predicted conditions and previous salting  
73 regime applied (John Robinson, pers. comm.).

74 The soils are brown earths (Cambisols), with a minimal litter layer but varying degrees  
75 of gleying in places. The bedrock is primarily limestone and sandstone. The vegetation is  
76 predominately grasses, *Juncus* and bryophytes and the land is grazed by sheep. Two possible  
77 transect scenarios were studied; (a) spray-affected soils (A1 and A2 – south of the A686  
78 between the milestone and Blackburn Bank) and (b) control soils (A3 and A4) directly above  
79 the road; the two scenarios differ in altitude by only 15 m. Both contaminated and control  
80 sampling areas are minimally managed, and have evolved from the same parent material. A  
81 wall ca. 1 m high separates the road from the salt-affected sampling sites and an identical wall  
82 is above the control transects.

83

### 84 **2.2 Soil sample collection**

85 Soils for the two salting impact scenarios were sampled in duplicate, with a horizontal spacing  
86 of at least 10 m. Transects were laid perpendicular to the road; two were immediately down  
87 slope of the highway (A1 & A2). The control (un-impacted) transects, referred to as A3 & A4,  
88 were above the road, at ~ 100 m from the highway. Soil samples were collected to 10 cm

89 depth with a stainless steel trowel at 2, 4, 8, 16, 32 and 64 m from the wall (1 m away from the  
90 road) on the 20<sup>th</sup> April 2006, soon after a full period of winter salting. Initial soil sampling was  
91 completed on the 5<sup>th</sup> October 2005 for an inter-seasonal comparison of samples prior to the  
92 winter maintenance period commencing. This was done to quantify probable maximum and  
93 minimum effects throughout a single salting year.

94 The samples, in polyethylene bags, were stored at 2-4 °C prior to chemical analysis.  
95 Stones, identifiable vegetation fragments and roots were removed as quickly as possible by  
96 careful hand sorting immediately prior to use.

97

### 98 ***2.3 Soil solution sampling***

99 To ensure sufficient sample was obtained for analyses, soil solutions for each transect were  
100 sampled using sets of three MOM Eijkelkamp rhizon soil solution samplers, 10 cm long and  
101 2.5 mm in diameter, evacuated with 60-ml syringes. Soil solutions were sampled at 2, 4, 8, 16,  
102 32 and 64 m from the walls, over a depth interval of 5-10 cm.

103 Soil solutions were sampled most intensively throughout the winter period. Sampling  
104 was conducted from 12/10/2005-08/07/2006. The air was purged from the syringes, and  
105 thereafter, they were stored at 2-4 °C prior to chemical analysis of the samples.

106

### 107 ***2.4 Soil and soil solution analyses***

108 Soil samples were chemically analyzed for exchangeable base cations, pH, KCl-extractable  
109 ammonium-N and nitrate-N, loss on ignition (LOI) and cation exchange capacity (CEC). Soil  
110 solution was analyzed for major base cations ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ), ammonium-N, nitrate-  
111 N, chloride, sulphate, DOC and pH. Identical techniques to those outlined in Green *et al.* [10]  
112 were used. Performance of all instrumental methods was checked using synthetic reference  
113 standards.

114

### 115 ***2.5 Statistical analysis***

116 Data from paired soil transects were combined to enhance the representation of each transect  
117 scenario (a) indirect and (b) control by increasing the sample size, and non-parametric tests  
118 applied. The Kruskal-Wallis test was used to determine whether means were significantly  
119 different between control and spray-affected transects, and with distance for each scenario.

120 Significance of correlations was tested using Spearman's rank. For all statistical tests,  
121 significance was accepted at  $\alpha \leq 0.05$ . Analyses were performed using SPSS version 11.0.1  
122 (2001).

123

### 124 **3. Results**

#### 125 **3.1 Soil data**

126 Figure 2 shows ammonium acetate-extractable base cations, exchange acidity and KCl-  
127 extractable ammonium as a percentage occupation of CEC at 2, 4, 8, 16, 32 and 64 m, plotted  
128 on a log scale, disaggregated by transect type (i.e. spray vs. control). The Na % occupancy of  
129 CEC for spray-affected and control transects differs significantly at the 1% level (indirect >  
130 control). Percentage occupation of the CEC by sodium does not exceed 0.32% for control  
131 soils, compared to maximum value of 1.68% for spray-affected transects at 4 m. The  
132 percentage contribution for the impacted transects of sodium to the CEC steadily declines from  
133 4 to 64 m, but remained well above the levels observed for the control transects.

134 Calcium % occupation of CEC for salt-affected transects is not significantly below that  
135 for the control (Fig. 2). The Ca % of CEC for control transects declines slightly with distance  
136 along the control transect from 4 to 64 m. In both control and spray-affected soils Ca %  
137 occupation remains relatively high, as hypothesized for the more calcareous soil, and is never  
138 at values that would cause concern.

139 At 2 to 4 m the Mg % occupation of CEC for the spray-affected soils exceeds that of  
140 the controls. Values for transect types tend to converge at 8 m.

141 The K % of CEC for the salt-impacted soils exceeds that in the control soils at all  
142 distances from the highway (1 % level). The control generally appears to fluctuate between  
143 0.04 - 0.2%, with no significant difference observed with distance. For the spray-affected  
144 transects K % declines from 3% at 4 m to 0.44% at 32 m (5 % level).

145 For  $H^+$  % of CEC the two scenarios show no significant difference. At 2 m the  $H^+$  % of  
146 CEC for the both impacted and control soils was 65% (Fig. 2). Soil pH for the control soils  
147 showed a significant increase in acidity with distance (at the 5% level).

148 It is immediately obvious (Fig. 2) that CEC for the salt-impacted transects contains  
149 consistently (and significantly) higher ammonium % than the control transects (1% level);  
150 neither scenario shows a significant change in ammonium % of CEC with distance.

151 Figure 3 shows the percentage occupation of CEC by base cations, hydrogen and  
152 ammonium at 2, 8 and 32 m on the 15<sup>th</sup> October 2005; it may be used to assess seasonal  
153 differences from the data from April in Fig. 2. There is a slight reduction in Na % of CEC  
154 close to the road, ~ 0.2%, on the salt-affected transects compared with the April data, whilst the  
155 control maintains a steady and consistent Na % occupation of the CEC.

156 Between 2 and 32 m, Mg % occupation of CEC increases from 2 or 3.7% to just over 5  
157 % for control and spray-affected scenarios respectively in October (Fig. 3). Over the same  
158 distance Ca % of CEC on the salt-impacted transects increases from 25.2% to 40.5%, whilst Ca  
159 % occupation of the control declines from 40 to 27.1%, similar to the decline seen for the  
160 control transects in April.

161 The K % of CEC increased in October for the control transect from the April value of <  
162 0.5% to 1.5 – 2%. For the salt-impacted transect, K % of CEC showed a lower degree of  
163 variability, and was almost consistent at 2 and 8 m between the two time periods. At 32 m the  
164 % occupation of K increased from 0.44 to 2.66% however for spray-affected soils.

165 The H<sup>+</sup> % of CEC generally shows relatively very little overall change in the degree of  
166 acidity between April and October (Fig. 3). For the salt-impacted soils there appears to be a  
167 decline in acidity with distance from 2 - 32 m (68-52% of CEC); in contrast the H<sup>+</sup> % for the  
168 control appears to increase from 2 - 32 m (56 to 66% of CEC); however, neither trend is  
169 significant at the 5% level.

170 Ammonium as a % of CEC was similar in April and October for the control soils over  
171 the spatial range studied, but was apparently higher for the salt-affected soils from 2 – 8 m in  
172 April. Though consistent, the effect was not however significant. In these soils, similar spatial  
173 trends are apparent for both time periods, with sharp increases in % occupation of CEC by  
174 ammonium between 32 - 64 m.

175 The spray-affected transects have, on average, a pH at 2 m approximately 0.5 units  
176 lower in April 2005 than the control transects (Fig. 4a; 1% level). This corresponds to the  
177 higher calcium dominance of the CEC for the control (Fig. 2). Soil pH of the control transects  
178 apparently declines from 5.84 to 5.35 over 64 m, whilst the spray-affected soil pH apparently  
179 increases from 5.32 to 5.64, but neither trend is significant. In October (Fig. 4b) the spray-  
180 affected soils are still the most acidic, with the difference between the scenarios now being  
181 significant at the 1% level.



182 Figure 5 shows the concentrations of KCl-extractable nitrate-N for spray-affected and  
183 control transect soils in April 2006 and October 2005. There is no significant difference  
184 between the spray-affected and control soils with regard to nitrate-N content for either time  
185 period. The spatial variation generally exceeded variation between transects.

186 Figure 6 shows the spatial variation in soil LOI (%) for April 2006 and October 2005  
187 for the two transect scenarios. Organic matter loss apparently has occurred from salt-impacted  
188 soils compared with control soils. Control soils have a significantly higher LOI (1% level) in  
189 both April and October, at a generally consistent level. Salt-impacted soils at 64 m possess a  
190 significantly higher LOI (1% level) than those at every other distance; LOI% is highly  
191 correlated to the soil water content (70.2%) in April 2006, reflecting greater water retention in  
192 more organic soils.

193

### 194 **3.2 Soil solution data**

195 Sodium concentrations as high as  $156 \text{ mg l}^{-1}$  were observed 2 m from the road at spray-affected  
196 transects beside the A686, but values varied with the prevailing weather conditions. The  
197 sodium concentrations for the spray-impacted transects declined to  $5\text{-}15 \text{ mg l}^{-1}$  at 64 m down  
198 slope; the controls gave a background level of  $4.4 \text{ mg l}^{-1}$  across all distances. The observed  
199 trends in sodium ion concentrations were also apparent in chloride data (significantly  
200 correlated to  $\text{Na}^+$  at the 1% level). However, whereas at the A6 site  $\text{Na}^+$  was largely  
201 displacing  $\text{H}^+$ , so soil pH increased substantially, at the A686 site there is also strong  
202 competition from  $\text{Ca}^{2+}$  from biogeochemical weathering. Therefore the more strongly retained  
203 divalent  $\text{Ca}^{2+}$  ions have a bigger effect on the composition of the cations occupying the CEC,  
204 and the  $\text{Ca}^{2+}:\text{Na}^+$  ratio in soil solution is much higher for spray-affected soils at the A686 than  
205 it was at the same time of year (April) at the A6 site. This can be very clearly seen in Fig. 7  
206 (note the change in scales between sites).

207 Calcium concentrations as high as  $86 \text{ mg l}^{-1}$  were observed in soil solutions at (data not  
208 shown) 4 m from the spray-affected transects. They ranged between  $5\text{-}12 \text{ mg l}^{-1}$  for spray-  
209 affected transects between 8-16 m. The controls on average had an elevated concentration at 2  
210 - 4 m (from  $13\text{-}25 \text{ mg l}^{-1}$ ), thereafter declining and stabilizing from 8-64 m at  $10\text{-}12 \text{ mg l}^{-1}$ ,  
211 suggesting a significant  $\text{Ca}^{2+}$  input from the walls by weathering.

212 Magnesium concentrations were less than  $2.5 \text{ mg l}^{-1}$  for control transects. Spray-

213 affected transects had the highest  $Mg^{2+}$  concentration at 4 m,  $\sim 35 \text{ mg l}^{-1}$ , and thereafter  $Mg^{2+}$   
214 concentration generally declined.

215 Soil solution pH ranged from 6 - 7.5 for spray-affected and 6 - 6.6 for the control  
216 transects. As the distance from the highway increased the pH for A1 and A2 tended to decline,  
217 whilst A3 and A4 also showed a tendency towards pH decline as distance from the wall  
218 increased (Fig. 8). However these trends were nothing like as marked as those seen at the A6  
219 site, where the increase in pH attributable to salting was much more consistently around 1 to  
220 1.5 pH units. These trends at the A686 site probably reflect the impact of the limestone walls.

221 In the earlier study at the A6 site, the soil solutions from the spray-affected transects  
222 consistently contained much higher (more than an order of magnitude) nitrate concentrations  
223 than the control soil solutions. This resulted in substantially increases in the nitrate  
224 concentration in a local, adjacent river [8]. The control soil solutions in the A686 study also  
225 contained minimal amounts of nitrate-N (generally  $< 1 \text{ mg l}^{-1}$ ), whilst the salt-affected transects  
226 had spatially and temporally variable concentrations (Fig. 9; note change in scale). Nitrate-N  
227 concentrations on spray-affected transects showed no consistent trend attributable to a road  
228 salting effect, although 9 out of 96 samples contained a concentration  $> 5 \text{ mg nitrate-N l}^{-1}$ .

229 At 2 - 4 m, and (more consistently) at 64 m, ammonium-N concentrations apparently  
230 tended to be higher for the salt-affected transect soil solutions (Fig. 10). This might have been  
231 anticipated from the apparent increase in ammonium % of CEC for the salt-affected transects,  
232 but that effect was not significant, as discussed earlier. Ammonium-N concentrations in control  
233 soil solutions were very low, mostly below  $0.2 \text{ mg l}^{-1}$ . For salt-affected transect A1 (but not  
234 for transect A2), ammonium-N concentration was consistently high from 2 to 16 m on  
235 08/07/2006, but for no obvious reason.

236

#### 237 **4. Discussion**

238 Some sodium ion effects are clear from the differences between the spray-affected and control  
239 transects. Figure 2 demonstrates the percentage occupation of cation exchange sites for  
240 sodium, magnesium, calcium, potassium, ammonium-N and hydrogen ions in April 2005.  
241 There is clear sodium elevation for the spray-affected transects as compared to the control over  
242 2 - 64 m. However the contribution of  $Na^+$  to exchangeable base cations is lower than at the  
243 A6 site [7]. The higher Na % occupation of CEC does not directly correspond to a lower  $H^+$  %

244 of CEC for the control transects, and thus a lower  $H^+$  % of CEC for spray-contaminated  
245 transects at the A686 site, in marked contrast to observations for the A6 site [7]. The  $H^+$  % of  
246 CEC is inversely correlated with the % Ca and Mg of CEC (1% level) at the A686 site. Thus,  
247 it is more likely that the exchangeable hydrogen ions are competitively displaced by incoming  
248 calcium and magnesium ions than by sodium. Evidence presented earlier suggests this is  
249 partly from the limestone walls above all transects at the site.

250 Green and Cresser [7] hypothesized that close to the highway a reduction would be  
251 observed in the calcium and magnesium % occupation of the CEC in the acid soils of the A6  
252 site, but the opposite was observed in practice. It was thought that the higher levels of calcium  
253 were a result of the calcium content in the rock salt [7, 10]. Hence, it would not be surprising  
254 to observe the same trend at the A686 as a result of the same road salt product being used.  
255 However, Ca and Mg % of CEC values are elevated above those observed at the A6 for the  
256 spray-affected and control sites, suggesting additional source(s) of calcium and magnesium.  
257 This is also reflected in the raised calcium concentrations in soil solutions for the controls.

258 It is clear that the calcium input via limestone dissolution (parent material or wall  
259 components) is having an affect on pH and Ca % on the CEC. The Ca % of CEC is greater for  
260 the A686 at 2 m (26.6%) than for the A6 (17.7%) in April. This is also apparent in October for  
261 the spray-affected transects. It is thought that the additional calcium from the limestone wall  
262 constructed above both the control and spray-affected transects is very significant because pH  
263 declines with distance for the control transect. Mobile anion effects contribute to the lower soil  
264 solution pH for the spray-affected transects. The sodium input effects on pH are effectively  
265 negligible at the A686 sites.

266 Initially there appeared to be some evidence to suggest that the N-cycle is being  
267 disrupted by the use of road salts at the A686 site. However, spatial and temporal shifts in pH  
268 will not be modifying mineralization and nitrification rates significantly, so none of the  
269 apparent effects on the N cycle were significant statistically. Green and Cresser [7, 8] showed,  
270 in contrast, that displacement of ammonium ions from the exchange sites occurred in reaction  
271 to increased sodium concentrations during salting of the A6. It is interesting to note that the  
272 percentage CEC occupation by ammonium observed at the A686 is consistent with that of the  
273 spray-affected soils at the A6.

274 Spray from road salting had a very strong and significant effect on soil solution nitrate

275 concentration in the naturally acidic soils alongside the A6 [8]. Figure 9 showed that no such  
276 strongly consistent significant effect occurred at the A686 site. This is almost certainly  
277 because of the lack of consistent significant pH change at the A686 site.

278 LOI is, as for the A6 soils [8], greater for the control soils than for the spray-affected  
279 soils (Fig. 6 - 1% level). In comparison to the A6, however, there does not appear to be a build  
280 up of organic matter down slope from organic matter dispersal by high  $\text{Na}^+$  concentrations.  
281 This may be is a product of topography (lesser degree of slope angle for the A686). It seems  
282 most likely that at the A686 site the dominant cause is roadside pollution of diverse types  
283 lowering the annual input of organic litter to the roadside soils.

284 The A686 shows signs of reversibility of salt effects there after road salt application  
285 had ceased for the season, *via* reduction in sodium ion % of CEC between April and October.

286 The acidic upland site of the A6 possesses a host of ecological implications through the  
287 introduction of elevated concentrations of road salt (cation exchange reactions) and the  
288 significant temporal/spatial pH shift. Changes in pH lead to changes in microbial activity  
289 which is highlighted by the enhanced nitrification observed at the A6, which have a  
290 reverberation on the N cycle. Displacement of ammonium ions from the CEC may lead to N  
291 deficiencies in roadside soils. In addition toxicity effects of high salinity on microbes may be  
292 masked by the signal observed. Vegetation may be affected by road salt in several ways: by  
293 accumulating  $\text{Na}^+$  in toxic concentration within plant tissues (Townsend, 1980); by increasing  
294 osmotic pressure differences causing desiccation (drying) (Bryson & Barker, 2002; Larcher,  
295 1995; Townsend, 1980); by altering mineral nutrition balances (reduced levels of available  
296 ammonium, and  $\text{K}^+$  within the soil) (Bayuelo-Jiménez *et al.*, 2003; Serrano & Rodriguez-  
297 Navarro, 2001); and by altering soil structure. However, damage usually results from a  
298 specific ion effect rather than from an increase in osmotic potential (Townsend, 1980). The  
299 specific ion effect involves movement of the ions such as sodium and chloride into plant cells,  
300 where they adversely affect cell membrane stability, metabolism and growth, and at high  
301 concentrations is toxic, possibly leading to fatality (Larcher, 1995; Townsend, 1980). In  
302 addition ammonium and nitrate leaching may also suppress vegetal growth.

303 Furthermore, elevated chloride concentrations are known to interfere with  
304 photosynthesis in algae in surface waters (Williams *et al.*, 1999), with shifts in population  
305 occurring with 12–235  $\text{mg l}^{-1}$  due to the varying degree of sensitivity between algae species

306 (DOE & DOH, 2001). In higher organisms they can result in potentially fatal metabolic  
307 acidosis and osmotic stress, as well as behavioural changes (Williams *et al.*, 1999). It is  
308 possible that changes in population, community structure and/or biodiversity may occur due to  
309 acute and chronic toxicity of road salts, in combination with other physical and chemical  
310 impacts generated directly or indirectly from the application of road salt.

311         Raised levels of sodium ions in water can cause high blood pressure and hypertension,  
312 so individuals whom already suffer from this condition and on salt-restricted diets should not  
313 ingest greater than 20 mg l<sup>-1</sup>. Several states in the northeast US and Canada have measured  
314 sodium from road salt in well waters at concentrations that are 2-140 times the recommended  
315 limit for individuals on salt-restricted diets (Amrhein *et al.*, 1992). Hence, increases in sodium  
316 and chloride ions can also cause problems with water balance in the human body. This is a  
317 particular concern when considering upland soils and associated freshwater bodies as these  
318 tend to be used as potable sources in the UK (Smart *et al.*, 2001).

319         In addition enhanced loadings of nitrate and ammonium may occur as product of cation  
320 displacement and enhanced nitrification as a result of the effect of pH on the soil microbe  
321 community, both of which have an eutrophication risk.

322         In the case of the A686 such implications are unlikely to be realized due to the presence  
323 of the higher rate of weathering of parent material. The occupation of the CEC with Ca<sup>2+</sup> and  
324 Mg<sup>2+</sup> in the first instance protects the soil ecosystem for a shift in pH due to the displacement  
325 of H<sup>+</sup> ions. This effectively protects the roadside environment to the long-term episodic  
326 influxes of road salt. Furthermore, such ecological implications outlined above may only occur  
327 in extreme cases.

328

## 329 **5. Conclusion**

330 The data from the A6 and A686 spray-affected transects, compared with the relevant control  
331 transects, conform well only in terms of Na<sup>+</sup> % occupation of the CEC. The high weathering  
332 rate of the calcareous parent material within the wall and in the soil itself, rather than high salt  
333 input, regulates the soil pH down-slope at the A686 site. As a consequence at the A686 site the  
334 disruption of the N cycle is negligible compared with that reported earlier for the A6 sites. It  
335 may be concluded that major N cycle disruption that occurs as a consequence of road salting  
336 when roads run through naturally very acidic soil ecosystems is much less of an issue when the

337 roadside soil ecosystems are calcareous. That said, the lower organic matter content in salt  
338 impacted soils of both types (indicated by significantly lower LOI values) warrants further  
339 investigation.

340

#### 341 **Acknowledgements**

342 The authors are indebted to NERC, DEFRA and the University of York for financial support  
343 for this research, and to Mr. B.W. Knowles for permission to work on his farm.

344

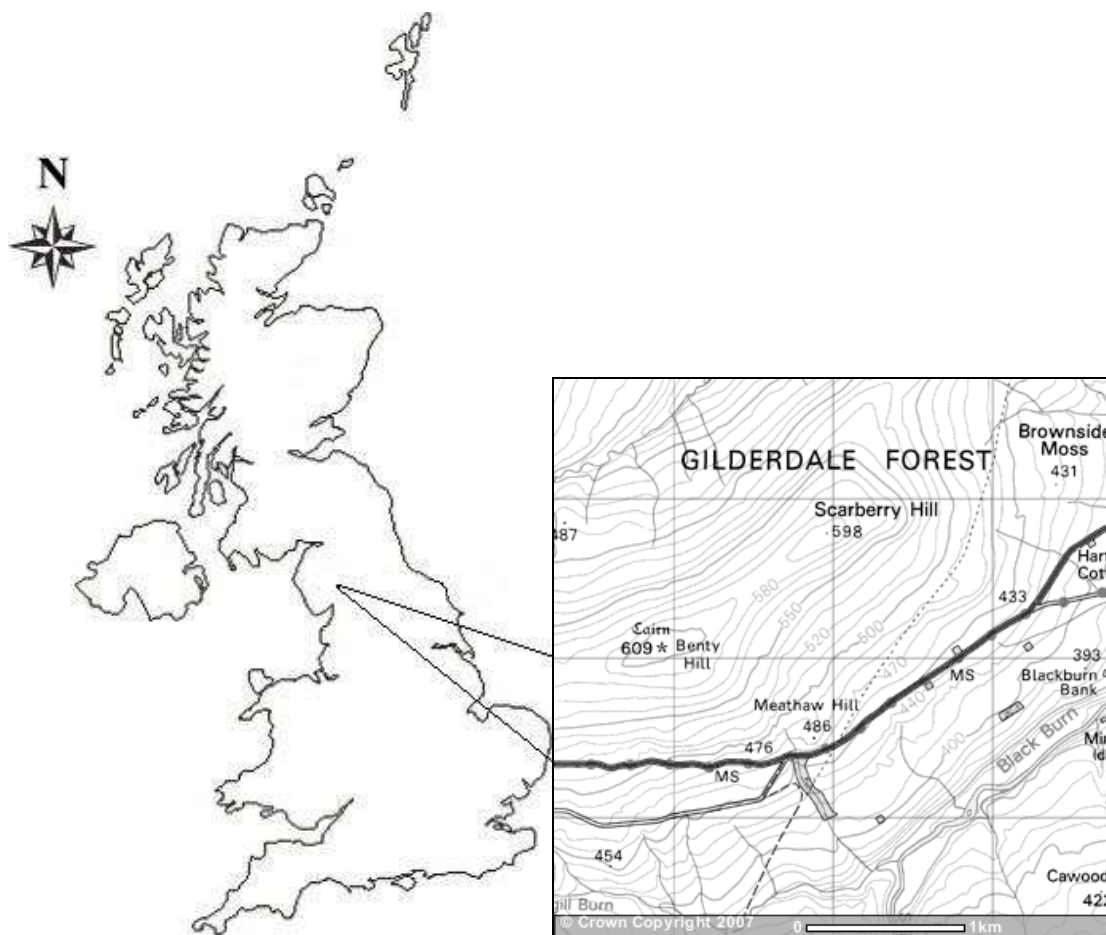
#### 345 **References**

- 346 [1] C. Amrhein, J.E. Strong, P.A. Mosher. Effect of deicing salts on metal and organic-  
347 matter mobilization in roadside soils. *Environ. Sci. Technol.*, **26**, 703 (1992).
- 348 [2] B. Bauske, D. Goetz. Effects of de-icing-salts on heavy-metal mobility. *Acta*  
349 *Hydrochim. Hydrobiol.*, **21**, 38 (1993).
- 350 [3] D.A. Turnbull, J.R. Bevan. The impact of airport de-icing on a river: The case of the  
351 Ouseburn, Newcastle upon Tyne. *Environ. Pollut.*, **88**, 321 (1995).
- 352 [4] P.Y. Robidoux, C.E. Delisle. Ecotoxicological evaluation of three de-icers (NaCl,  
353 NaFo, CMA) – Effect on terrestrial organisms. *Ecotoxicol. Environ. Safety*, **48**, 128  
354 (1999).
- 355 [5] G. Blomqvist, E.L. Johansson. Airborne spreading and deposition of de-icing salt - a  
356 case study. *Sci. Total Environ.*, **235**, 161 (1999).
- 357 [6] A.C. Norrstrom, E. Bergstedt. The impact of road de-icing salts (NaCl) on colloid  
358 dispersion and base cation pools in roadside soils. *Water Air Soil Pollut.*, **127**, 281  
359 (2001).
- 360 [7] S.M. Green, M.S. Cresser. Spatial and temporal variations in the effects of road salting  
361 on the properties of upland soil and soil solutions down slope of a highway. *Sci. Total*  
362 *Environ.*, submitted for publication, February (2007).

363

- 364 [8] S.M. Green, M.S. Cresser. Nitrogen cycle disruption through the application of de-icing  
365 salts on upland highways, *Water Air Soil Pollut.*, in press (2007).
- 366 [9] S.M. Green, R. Machin, M.S. Cresser. Long-term road salting effects on dispersion of  
367 organic matter from roadside soils into drainage water. *Soil Use Manage.*, submitted  
368 for publication, September (2007).
- 369 [10] S.M. Green, R. Machin, M.S. Cresser. Effect of long-term changes in soil chemistry  
370 induced by road salt applications on N-transformations in roadside soils. *Environ.*  
371 *Pollut.*, in press (2007).  
372
- 373 [11] S.M. Green, R. Machin, M.S. Cresser. Does road salting induce or ameliorate DOC  
374 mobilization from roadside soils to surface waters in the long term? *Environ. Monitor.*  
375 *Assess.*, submitted for publication, July (2007).

376  
377



378

379 Figure 1. Map showing the location of the A686 field site, Leadgate, Alston, UK. (C)  
380 Crown Copyright Ordnance Survey. All rights reserved.



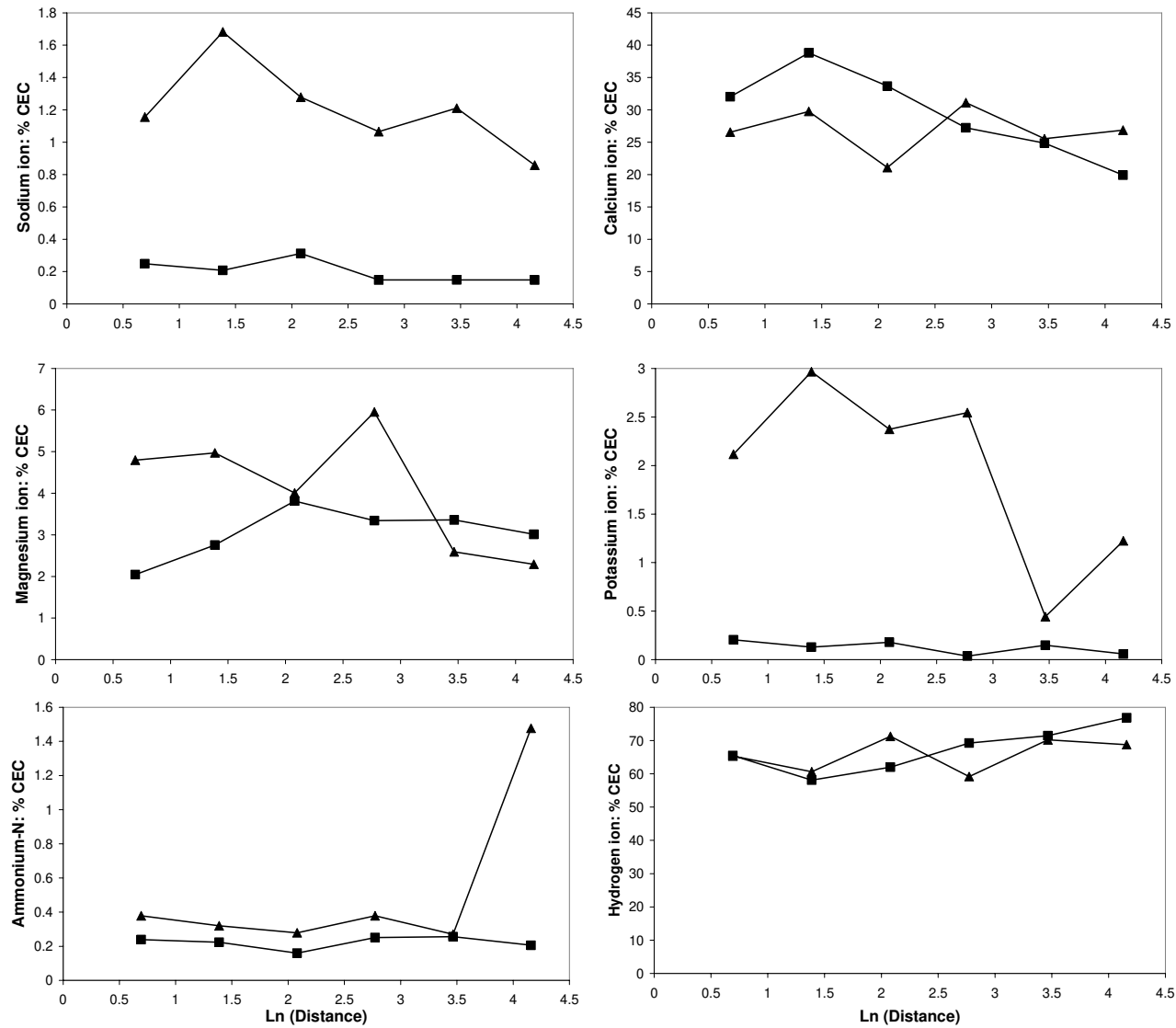


Figure 2. Proportion of base cations, ammonium-N and hydrogen of CEC (%), April 2006 at 2, 4, 8, 16, 32 and 64 m away from the wall for spray-affected (triangles) and control transects (squares).

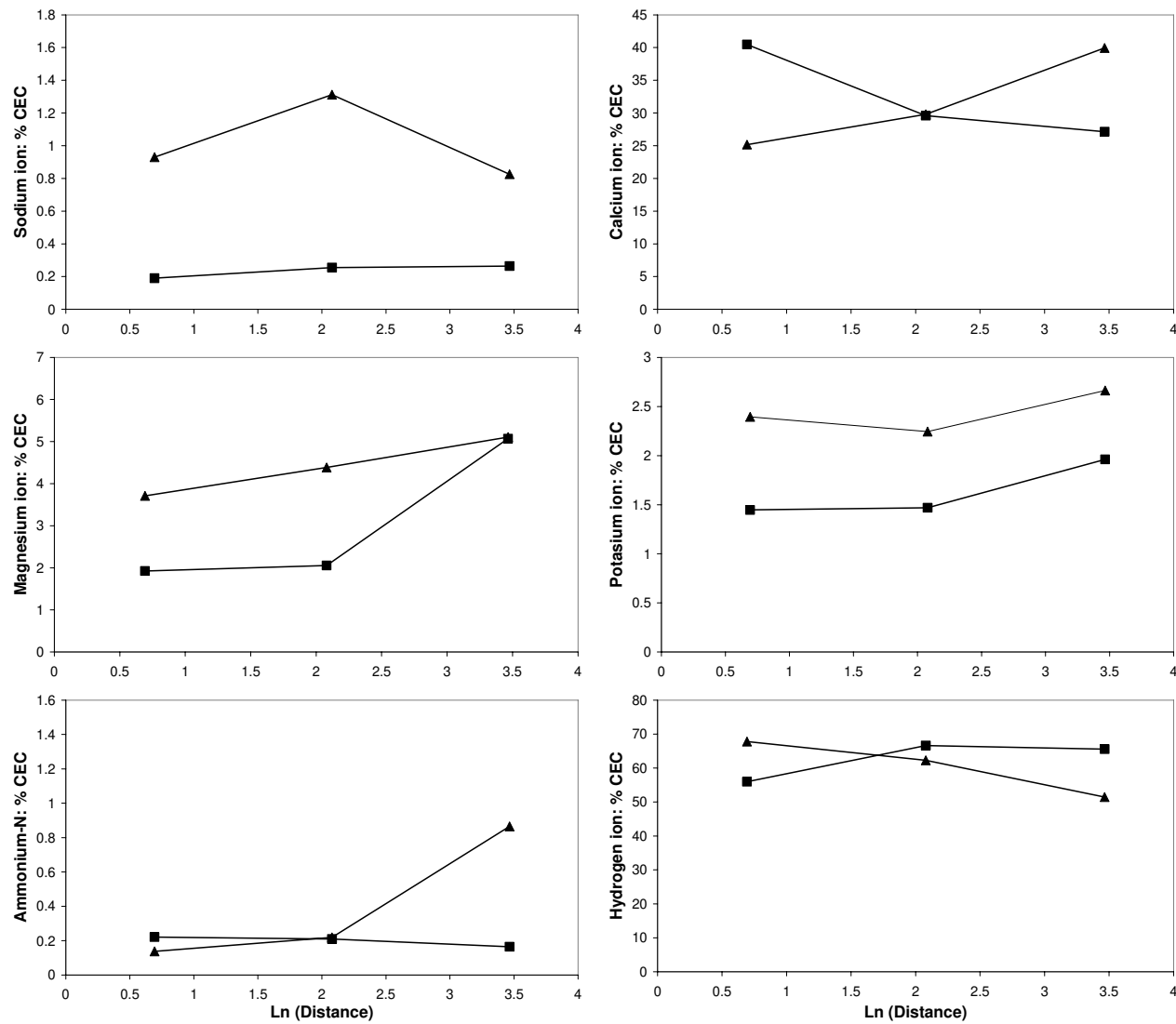


Figure 3. Proportion of base cations, ammonium-N and hydrogen on the CEC, October 2005 (%) at 2, 8 and 32 m from the wall, for spray-affected (triangles) and control transects (squares).

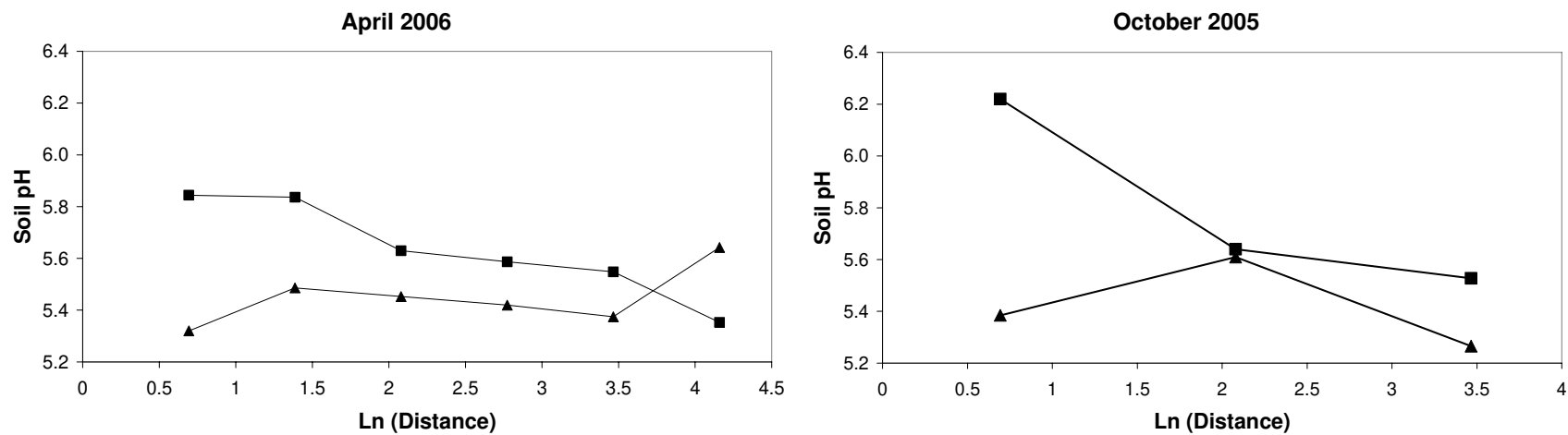


Figure 4. Soil pH (H<sub>2</sub>O) for April 2006 and October 2005 for soil samples at 2, 4, 8, 16, 32 and 64 m from the wall in April and 2, 8 and 32 m in October, for spray-affected (triangles), and control (squares) soils.

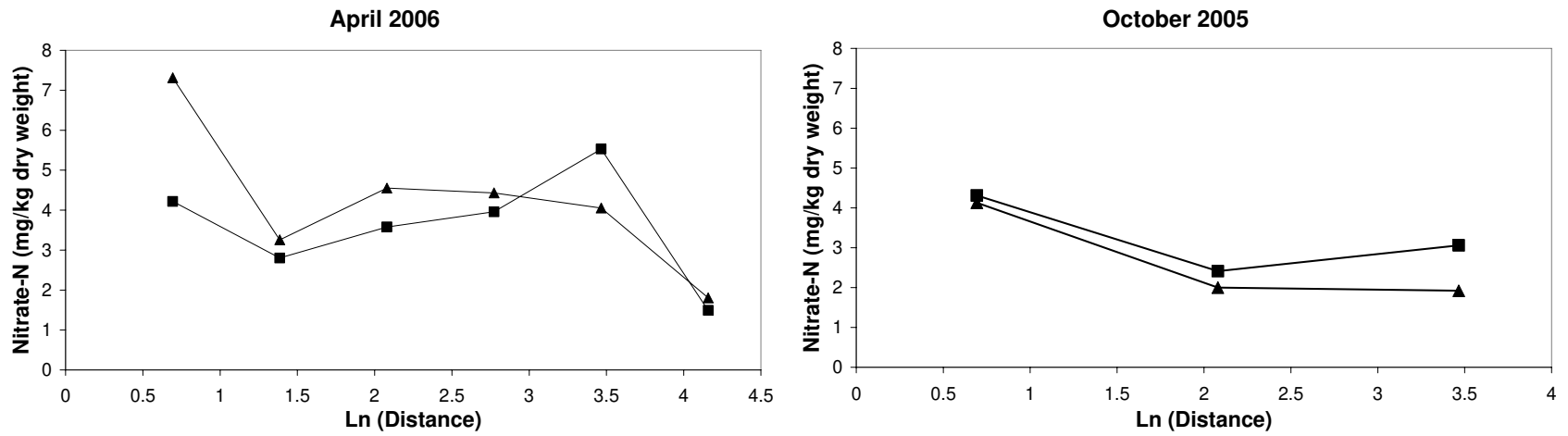


Figure 5. KCl-extractable nitrate-N concentration (mg/kg) for April 2006 and October 2005 for soils sampled at 2, 4, 8, 16, 32 and 64 m from the wall in April and 2, 8 and 32 m in October, for spray-affected (triangles) and control (squares) soils.

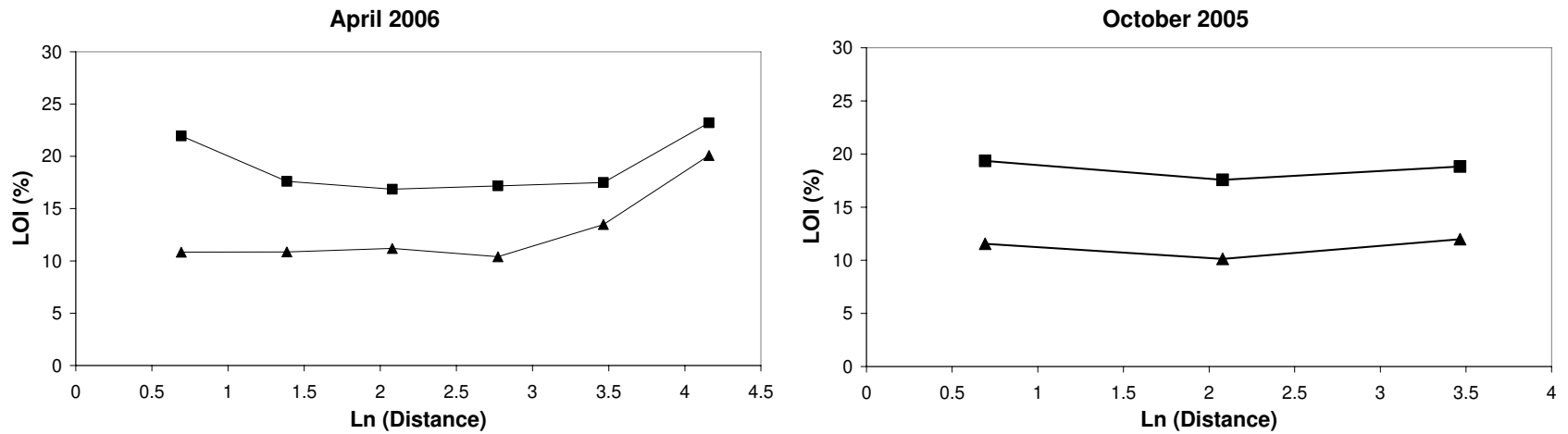


Figure 6. Loss-on-ignition (%) for April 2006 for soils sampled at 2, 4, 8, 16, 32 and 64 m from the wall (April) or 2, 8 and 32 m (October) for salt-affected (triangles) or control (squares) soils.

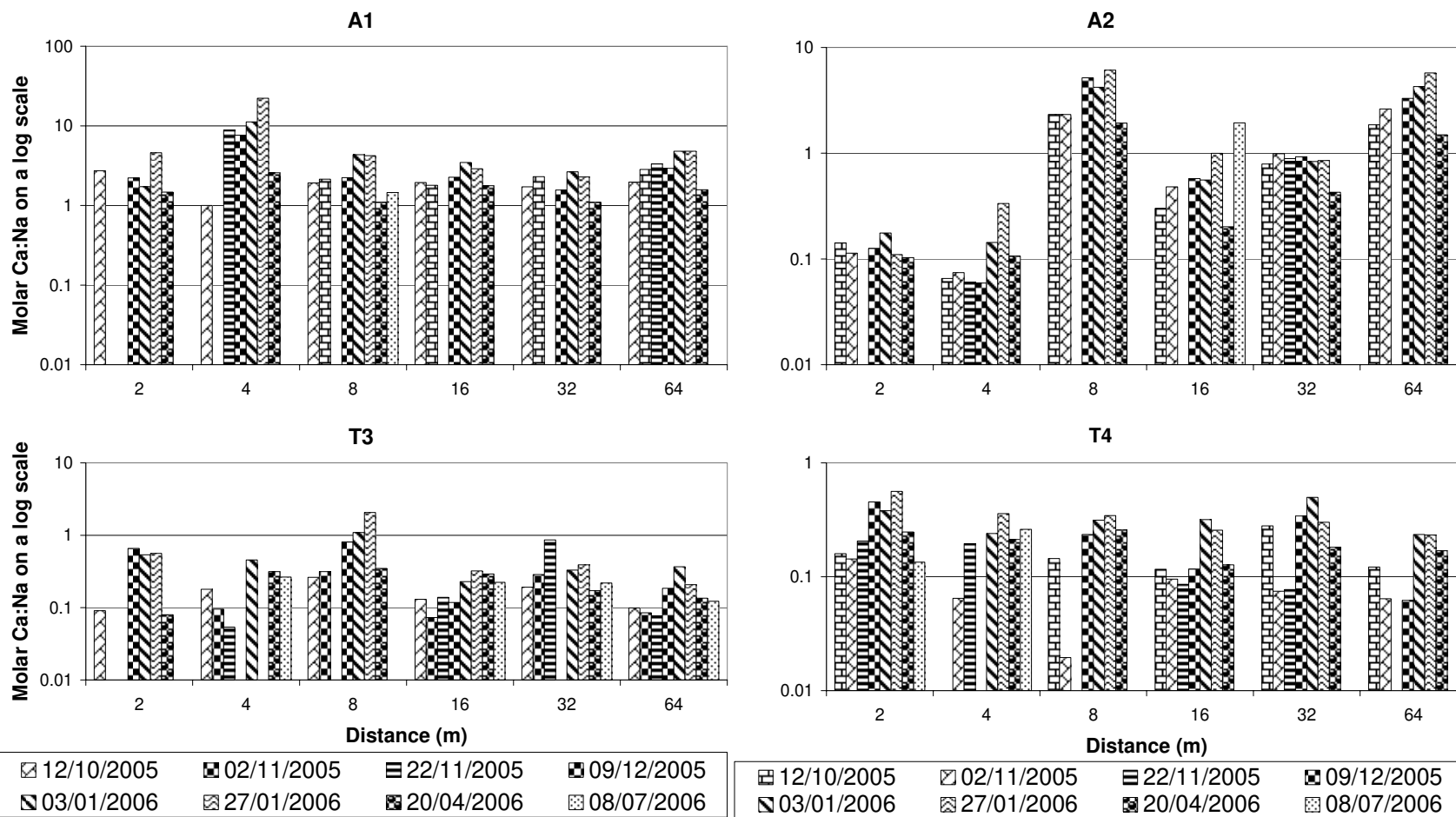


Figure 7. Comparison of the ratio of calcium to sodium concentrations, expressed on a mol<sub>c</sub> basis on a log scale, in soil solutions along the lengths of the spray effect transects in this study (A1 and A2, top) and in the earlier A6 study (T3 and T4, bottom). Note changes in scale.

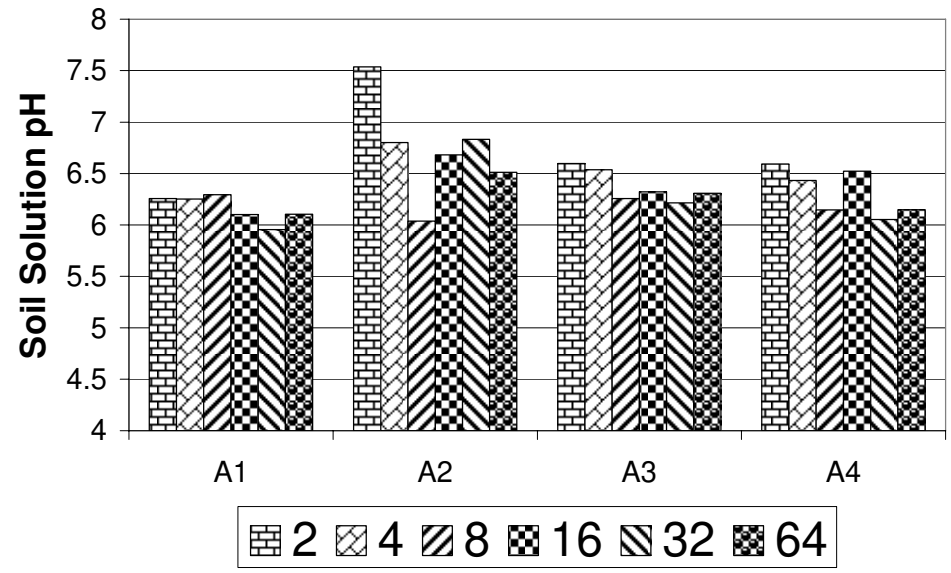


Figure 8. Soil solution pH at 2, 4, 8, 16, 32 and 64 m for spray-affected soils (A1 & A2), and control soils (A3 & A4).

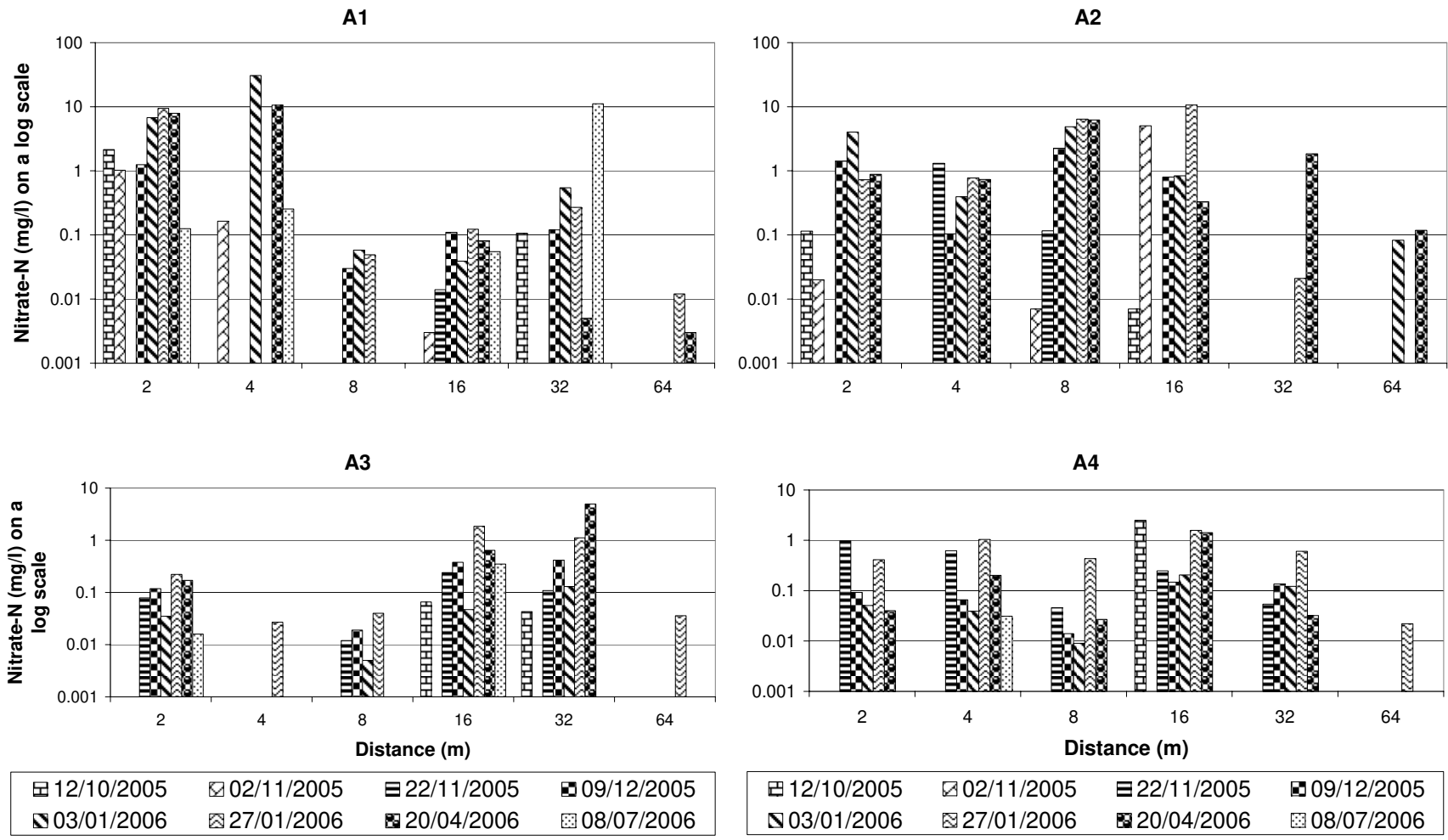


Figure 9. Nitrate-N concentration on a log scale for soil solutions at 2, 4, 8, 16, 32 and 64 m for spray-affected soils (A1 & A2) and control soils (A3 & A4). Note changes in scale.



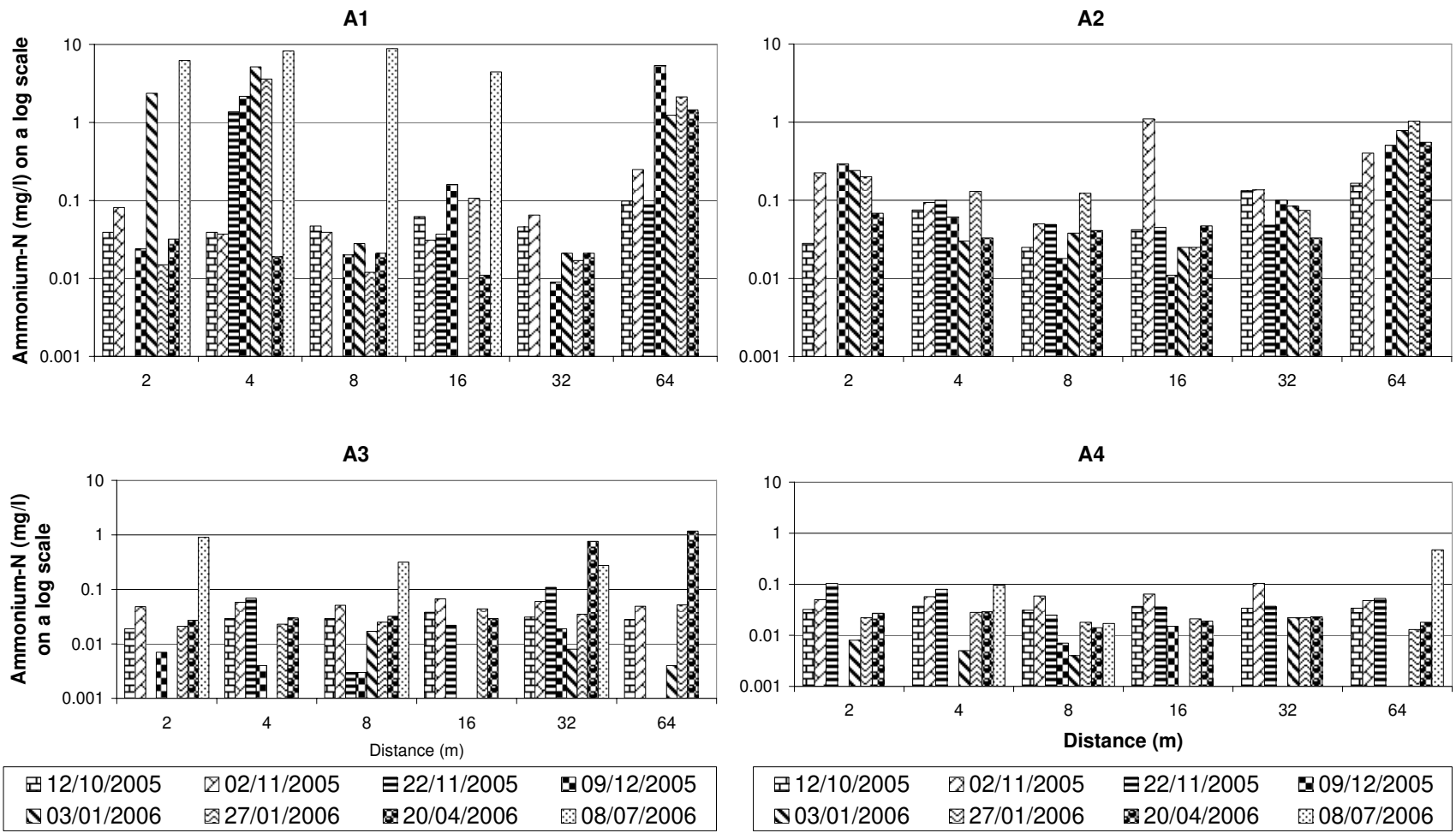


Figure 10. Ammonium-N concentration on a log scale for soil solutions at 2, 4, 8, 16, 32 and 64 m for spray-affected soils (A1 & A2), and control soils (A3 & A4).